POOR LEGIBILITY

ONE OR MORE PAGES IN THIS DOCUMENT ARE DIFFICULT TO READ DUE TO THE QUALITY OF THE ORIGINAL

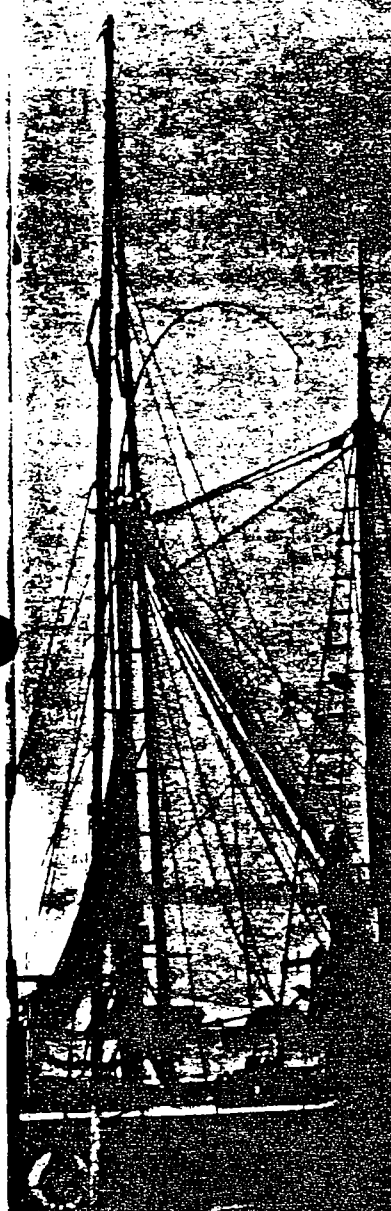
SFUND RECORDS CTR
88045524

SFUND RECORDS CTR
0639-06867

LIBRARY COPY

CALIFORNIA'S LIVING MARINE RESOURCES AND THEIR UTILIZATION

R0873



[illegible]
[illegible] S. Leet
[illegible] M. Dewees
[illegible] Haugen

SMB-26729

For information about ordering this publication, contact Sea Grant Extension Program, Department of Wildlife and Fisheries Biology, University of California, Davis, CA 95616-8751.

Support was provided primarily by the National Marine Fisheries Service Saltonstall-Kennedy Program, grant number NA90AA-H-SK124. Additional support was supplied by the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, under grant number NA89AA-D-SG138, project number A/AE-1 through the California Sea Grant College, and in part by the California Resources Agency.

In accordance with applicable State and Federal laws and University policy, the University of California does not discriminate in any of its policies, procedures or practices on the basis of race, religion, color, national origin, sex, marital status, sexual orientation, age, veteran status, medical condition, or handicap. Address inquires regarding this policy to the Affirmative Action Director, University of California, Agriculture and Natural Resources, 300 Lakeside Drive, 6th Floor, Oakland, CA 94612-3560. (415) 987-0097.
University of California, the United States Department of Agriculture, and the United States Department of Commerce Cooperating.

SMB-26730

CALIFORNIA'S LIVING MARINE RESOURCES AND THEIR UTILIZATION

Editors

William S. Leet, Christopher M. Dewees, Charles W. Haugen

Sea Grant Extension Publication
UCSGEP-92-12

1992

SMB-26731

PHOTO CONTRIBUTORS

Dan Anderson
Christine Barsky
Tracy Borland
Kenneth Briggs
Calif. Dept. of Fish & Game
Harry Carter
Tony Chess
Fred Conte
Christopher Dewees
Dale Glantz
Paul Gregory
Jim Hardwick
Bob Hulbrock
Deborah Jacques
Susumu Kato
David Leighton
Milton Love
Ron McPeak
Bob Meek
Dave Ono
Diane Pleshner
Pat Reilly
John Richards
Susan Smith
John Stephens
John Sunada

Marine Mammal Illustrations by Phil Schuyler

TABLE OF CONTENTS

INTRODUCTION 1

MARINE PLANT RESOURCES
- Giant Kelp 2
- Agarophytes and Carrageenophytes 5
- Marine Plants: Discussion 6

CRUSTACEAN RESOURCES
- Ocean Shrimp 8
- Spot Prawn 10
- Ridgeback Prawn 11
- Bay Shrimp 12
- Sand Crab 14
- Dungeness Crab 15
- Rock Crabs 18
- Sheep Crab 20
- California Spiny Lobster 22
- Crustacean Resources: Discussion 24

MOLLUSK RESOURCES
- Littleneck Clams 26
- Pismo Clam 27
- Pacific Razor Clam 29
- Gaper Clams 31
- Washington Clams 32
- Abalones 33
- California Market Squid 36
- Mollusk Resources: Discussion 39

OTHER INVERTEBRATES
- Sea Urchins 41
- Sea Cucumbers 44

FISH RESOURCES

Sharks, Skates and Rays
- Angel Shark 46
- Leopard Shark 48
- Thresher Shark 49
- Shortfin Mako 51
- Blue Shark 53
- Cow Sharks 54
- Other Mackerel Sharks 55
- Skates and Rays 56
- Sharks, Skates and Rays: Discussion 59

Anadromous Fishes
- Salmon 60
- Salmon: Discussion 65
- Steelhead 67
- White Sturgeon 70
- Striped Bass 72

Smelt
- True Smelts 75
- Silversides 78
- Grunion 80
- Smelt: Discussion 81

SMB-26733

Pelagic Wetfish
Northern Anchovy 81
Pacific Sardine 83
Pacific Herring 86
Jack Mackerel 89
Pacific Mackerel 91
Pelagic Wetfish: Discussion 94

Flatfishes
California Halibut 94
Dover Sole 97
English Sole 99
Petrale Sole 100
Rex Sole 102
Starry Flounder 103
Sanddabs 104
Other flatfishes 105
Flatfishes: Discussion 106

Roundfishes
Sablefish 107
Pacific Hake 109
Opah 112
Louvar 113

Rockfishes
Rockfishes: Overview 114
Black Rockfish 117
Blue Rockfish 118
Blackgill Rockfish 120
Bocaccio 120
Chilipepper 122
Olive Rockfish 123
Vermillion Rockfish 123
Widow Rockfish 125
Shortbelly Rockfish 126
Brown Rockfish 127
Copper Rockfish 128
Canary Rockfish 129
Bank Rockfish 129
Other Nearshore Rockfish 130
Thornyheads 132
California Scorpionfish 133
Roundfish: Discussion 135

Tunas
Albacore 136
Northern Bluefin Tuna 138
Yellowfin and Skipjack Tunas 140
Pacific Bonito 143
Tunas and Bonitos: Discussion 146

Billfishes
Striped Marlin 146
Swordfish 148

Nearshore Fishes
Kelp Bass 150

SMB-26734

Sand Basses 151
Giant Seabass 153
Yellowtail 155
California Barracuda 157
Cabezon 160
Lingcod 161
Kelp Greenling 164
White Seabass 165
California Corbina 168
Spotfin and Yellowfin Croakers 168
White Croaker 170
Surfperches 171
California Sheephead 175
Opaleye and Halfmoon 177
Nearshore Fishes: Discussion 178

AQUACULTURE
Abalone 180
Mussels 181
Oysters 183
Rock Scallop 187
Salmon 188
Aquaculture of Marine Species: Discussion 190

UNDERUTILIZED SPECIES
Box Crab 192
Kellet's whelk 193
Octopuses 194
Pelagic Red Crab 195
Pacific Hagfish 196
Spotted Ratfish 197
Pacific Grenadier 198
Pacific Saury 199
Ocean Whitefish 201
Ocean Sunfish 202

MARINE RECREATIONAL FISHING 204

MARINE MAMMAL RESOURCES
Pinnipeds 208
Whales, Dolphins, and Porpoises 211
Sea Otters 216
Marine Mammals: Discussion 219

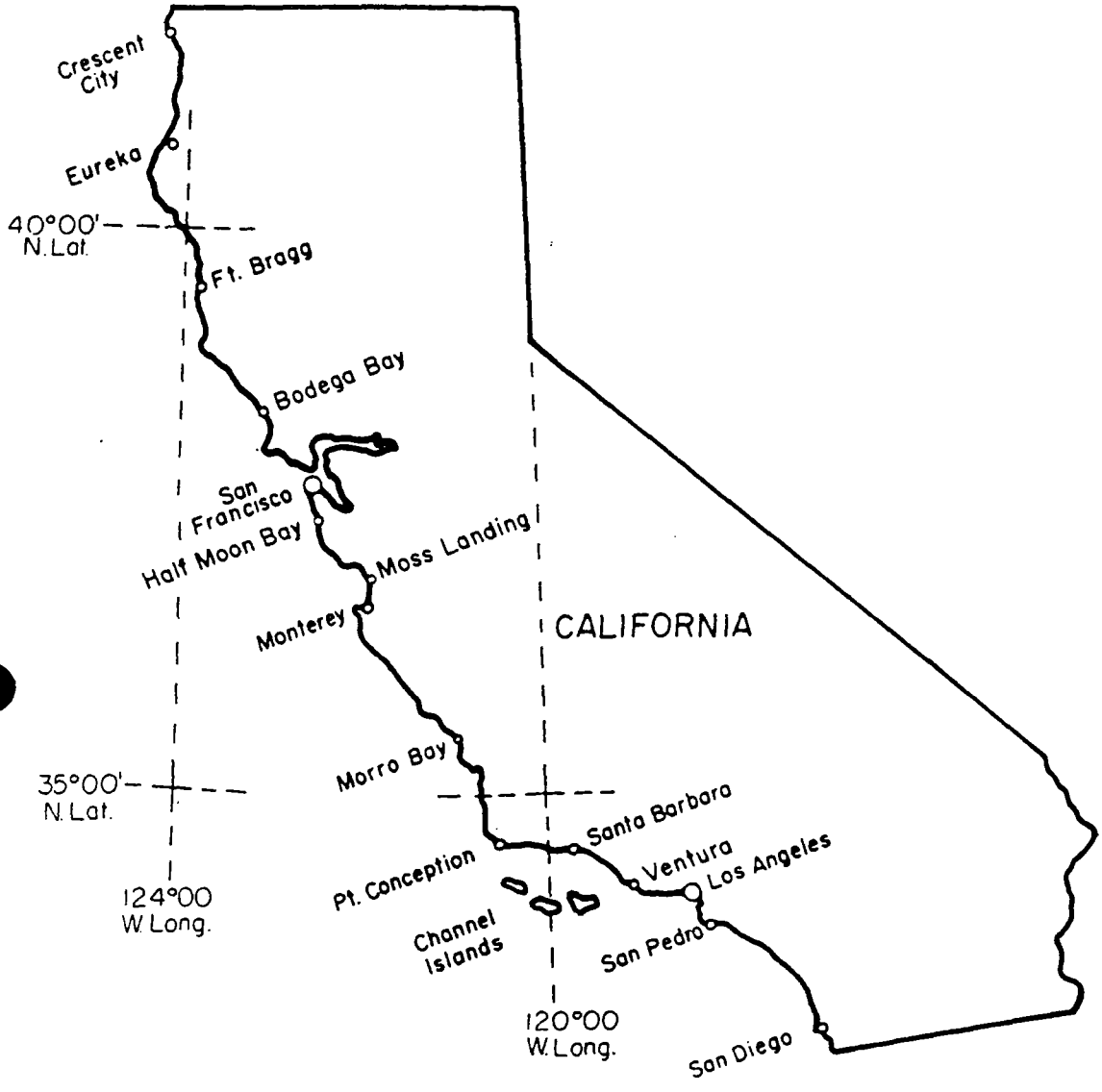
MARINE BIRD RESOURCES 221

ECONOMIC UTILIZATION OF OCEAN RESOURCES 228

APPENDIX 235

INDEX 256

SMB-26735



Major landing ports in California

SMB-26736

INTRODUCTION AND HISTORICAL OVERVIEW

Since the California Department of Fish and Game published *California Ocean Fisheries Resources to the Year 1960 (1961)* and *California's Living Marine Resources and Their Utilization* (1971), major changes have occurred in California's marine resources and their management. Fisheries landings peaked in 1976 at 900,967,215 pounds, but declined to 371,457,722 pounds by 1991. Tropical tunas, which dominated landings, are seldom landed for canning in California. A red sea urchin fishery started and now it is the state's leading value fishery. Significant fisheries developed for widow rockfish, hake and herring. Specialized new fisheries and aquaculture enterprises have begun.

Resource management changed significantly with Congress' establishment of Regional Fisheries Management Councils in 1976 having jurisdiction nationwide over fisheries resources beyond three miles from the coast. Public concern with the environmental effects of increased pressures on marine resources has grown tremendously. Legislation concerning marine mammals, coastal and offshore development, pollution, and endangered species strongly affects marine resource management today. These changes suggest that this revised book is needed and perhaps overdue.

In the two decades preceding 1971, California's tuna canning industry had recovered from a post-World War II slump brought on by competition from imports to become one of the largest, most profitable fisheries in the world. By 1971, a modern fishing fleet of purse seiners based in San Diego and San Pedro fished throughout the eastern Pacific Ocean and was beginning to expand onto new fishing grounds in the western Pacific and Atlantic Oceans. Tropical tunas landed at California's canneries comprised almost half of the state's marine fish landings. During the early 1980's, California's tuna industry faced rising domestic labor costs, ageing processing facilities, more stringent waste discharge regulation, and increased competition from abroad. By 1985 the industry left California in favor of facilities located in American Samoa and Puerto Rico, dropping California tuna landings to about 53 million pounds annually.

Japan's economic growth during the 1970's and 1980's fueled a growing demand for fishery products from throughout the world and opened a lucrative market for species which had been largely ignored until then by California fishermen. Starting with landings of less than 77,000 pounds in 1972, California's fishery for red sea urchins, whose gonads are carefully extracted in California plants for export to Japan, grew to become California's most valuable fishery, harvesting over 51 million pounds worth over $21 million to fishermen in 1989.

California's market fishermen ranged along the coast of Baja California to capture white seabass, yellowtail and other species for California's fresh fish markets as they had done since the close of World War II. In an attempt to develop its own fishing industry, Mexico began limiting California market fishermen's access to Mexican territorial waters in the early 1970's and by 1975 had totally excluded all American fishing vessels.

The number of participants in recreational fishing, which had grown substantially throughout the decades of the 1950's and 1960's, was relatively static in the 1970's and 1980's. The number of active commercial passenger fishing vessels (open partyboats) declined from 467 in 1970 to 308 in 1989, and the number of sportfishing licenses remained static despite a substantial increase in California's population.

Originally prepared for the California legislature, *California's Living Marine Resources and Their Utilization* proved to be one of the most valuable general reference works available on California's economically important marine species. Over the years it has been widely used by fisheries researchers and managers, policymakers, enforcement officers, the fishing industry, and educators. Increased concern about marine environmental issues suggests a broadening need for the information in this book. A primary purpose of the book is to provide a baseline of information for all concerned with living marine resource management in California.

We have retained the style and format of the 1971 edition. Many of the conventions of scientific writing are foregone because we feel this style better serves the broad interests of the readers of this book. Following each section, there is a short list of references. These are not necessarily the references which were consulted or cited in the preparation of each section, but are general references for further reading. We have updated the landings statistics with graphs in appropriate chapters. Detailed fish and shellfish landings statistics are found in appendices. Readers of the 1971 edition will quickly notice the increased knowledge available today about California's marine resources.

We were fortunate to be able to recruit the top experts from agencies, universities and private industry to write the sections on each species. Each chapter was peer reviewed. The author's name and affiliation appear at the end of the section they wrote. We want to thank the more than 200 authors and reviewers who enthusiastically volunteered their time and expertise. The strong support of California Department of Fish and Game Director Pete Bontadelli, National Marine Fisheries Service Southwest Region Director E.C. "Charlie" Fullerton, and NMFS Southwest Fisheries Center Director Izadore Barrett was vital to the project. Rob Collins provided commercial and recreational fisheries landing data. Jill Frommelt prepared the manuscript for publication and Leon Davies provided editorial assistance. Sus Kato provided enthusiastic support as the project monitor.

This project was supported primarily by the National Marine Fisheries Service Saltonstall-Kennedy Program, grant number NA90AA-H-SK124. Additional support was supplied by the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, under grant number NA89AA-D-SG138, project number A/EA-1 through the California Sea Grant College, and in part by the California State Resources Agency.

Christopher M. Dewees

William S. Leet

Robson A. Collins

SMB-26737

GIANT KELP

History of the Harvest

Various species of kelp have been used for hundreds of years in many parts of the world as food for humans and animals. Kelp has also been used for many years in Asia and Europe as a fertilizer and as a component of gunpowder.

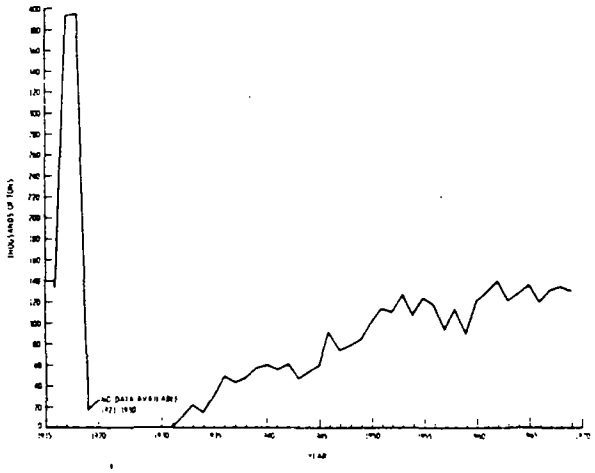
Giant kelp (*Macrocystis pyrifera*) was first harvested along the California coast during the early 1900's. Many harvesting companies operated from San Diego to Santa Barbara beginning in 1911; one large company, the Hercules Powder Company, operated from San Diego beginning in 1915. These companies primarily extracted potash and acetone from kelp for use in manufacturing explosives during World War I. In the early 1920's, kelp harvesting virtually stopped.

In the late 1920's, giant kelp was again harvested off California. Philip R. Park, Inc., of San Pedro began harvesting the kelp in 1928 to provide ingredients for livestock and poultry food. The Kelco Company of San Diego (now a Division of Merck & Co., Inc.) began harvesting and processing giant kelp in 1929 to extract algin. A unique natural compound, algin is found in the cell walls of kelp. It is valuable as an efficient thickening, stabilizing, suspending, and gelling agent. Algin is used in a wide range of food and industrial applications including desserts, gels, milk shake mixes, dairy products, and canned foods. It is also used in salad dressings to emulsify and stabilize them, in bakery products to improve texture and retain moisture, in frozen foods to assure smooth texture and uniform thawing, and in beer to stabilize the foam. In industrial applications, it is used for paper coating and sizing, textile printing, and welding-rod coatings. In pharmaceutical and cosmetic applications, it is used in tableting, dental impression compounds, antacid formulations, and facial creams and lotions.

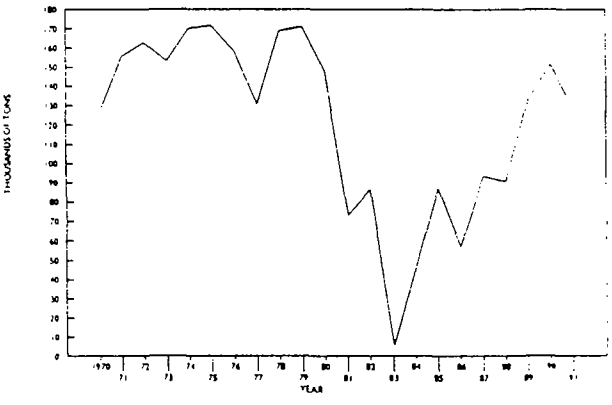
Giant kelp also has other commercial uses. It is harvested in California to supply food to several aquaculture companies for rearing abalones. It is also used for the herring-roe-on-kelp fishery in San Francisco Bay.

Today, giant kelp is harvested between Imperial Beach, near the U.S.-Mexico border, and Monterey Bay, California. It is one of California's most valuable living marine resources and in the mid-1980's supported an industry valued at more than $40 million a year. The annual harvest has varied from a high of 395,000 tons in 1918 to a low of less than 1,000 tons in the late 1920's. During the 10-year period 1970 to 1979, the harvest averaged nearly 157,000 tons, while during 1980 to 1989 the average harvest was only 80,400 tons. The harvest was low in the 1980's because the kelp forests were devastated by the 1982-1984 El Niño and the accompanying storms, and by the "200 year storm" that occurred in January, 1988. In most areas, the beds of giant kelp recovered quickly. Harvests increased to more than 130,000 tons in 1989 and to more than 150,000 tons in 1990.

The Kelco Company harvests giant kelp with specially designed vessels that range in length from 140 to 180 feet. The



California kelp harvest, 1916-1969.



California kelp harvest, 1970-1991.

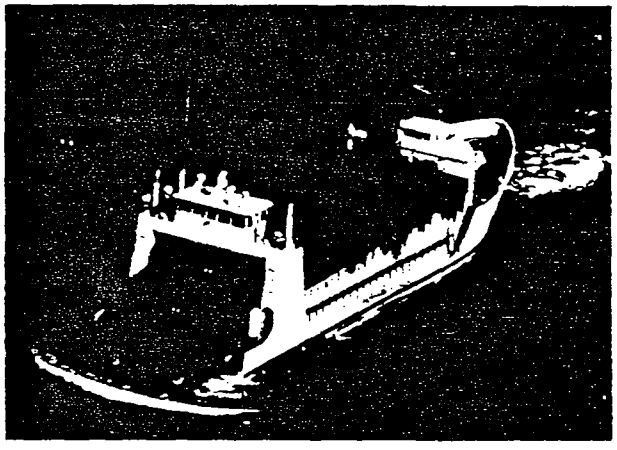
cutting mechanism and system to convey the kelp into the harvester bin are located on the stern. A propeller on the bow slowly pushes the harvester stern-first through the kelp bed, and the reciprocating blades mounted at the base of the conveyor are lowered to a depth of three feet into the kelp as harvesting begins. The cut kelp is gathered on the conveyor and deposited in the bin. These vessels can each collect up to 600 tons of kelp in one day.

Other methods of harvesting are used throughout the state to suit the harvesters' purposes and needs. For example, the Pacific Kelp Company harvests giant kelp off central California with a modified U.S. Navy landing craft, the cutting device and conveyor system being mounted on the bow. This vessel holds approximately 25 tons of kelp. In the herring-roe-on-kelp fishery, kelp is harvested by hand from small skiffs or other small boats and then transported by truck north to San Francisco Bay.

Since 1917, kelp harvesting has been managed by the California Department of Fish and Game (CDFG) under regulations of the Fish and Game Commission. Although the kelp surface canopy can be harvested several times each year without

SMB-26738

damage to the kelp bed, regulations state that kelp may be cut no deeper than four feet beneath the surface. There are 74 designated kelp beds and each is numbered; a kelp harvesting permit is required, and specific beds can be leased for 20 years. No more than 25 square miles or 50 percent of the total kelp bed area (whichever is greater) can be exclusively leased by a company holding a harvesting permit. In addition to leased beds, there are "open" beds that can be harvested by any company holding a permit. Permit holders also pay an additional $1.91 per wet-ton of kelp harvested. In 1990, 150,922 wet tons were landed throughout the state of California, creating more than $250,000 in revenues.



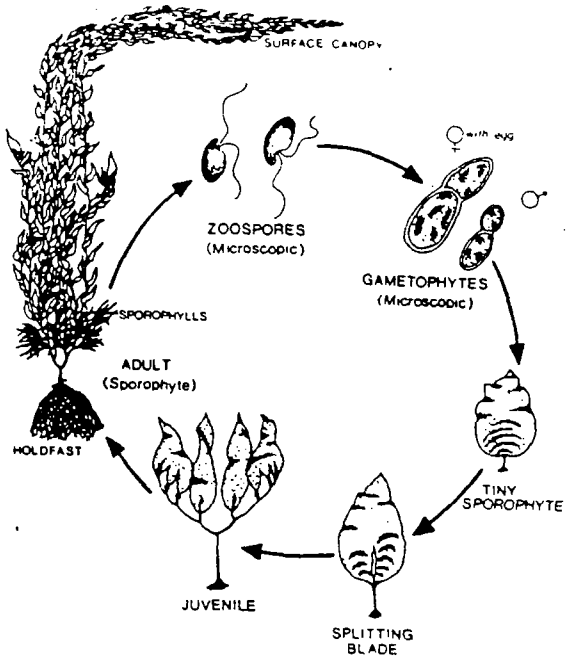
Kelp cutter operating near Santa Barbara.

To facilitate harvesting operations, Kelco conducts regular aerial surveys. The information is used to direct harvesting vessels to mature areas of kelp canopy. This optimizes the use of kelp because the surface canopy can be harvested before natural dieback occurs. Modern harvesting techniques do not adversely influence the rich fauna associated with kelp beds.

Status of Biological Knowledge

Forests of giant kelp occur in the temperate oceans of the Northern and Southern Hemispheres. These forests are especially well developed along the west coast of North America from southern Baja California, Mexico, to San Mateo County. They create a unique habitat that provides food, shelter, substrate and nursery areas for nearly 800 animal species. Many of the animals and some plants are of importance to sport and commercial fisheries.

Typically, giant kelp flourishes in wave-exposed areas of nutrient-rich, cool water that is 20 to 120 feet deep. By means of a root-like structure called a holdfast, the kelp attaches to rocky substrate. Along the protected shoreline of Santa Barbara County, however, giant kelp also grows on sand substrate. Here, it attaches to exposed worm tubes or the remains of old holdfasts. Kelp fronds originate from the holdfast, and eventually grow to the surface. A frond is composed of a stem-like stipe and numerous leaf-like blades. A gas-filled bladder (pneumatocyst) at the base of the each blade helps buoy the frond in the water column.



Giant kelp life cycle.

Giant kelp absorbs nutrients from the water through all its surfaces. Under optimal conditions of high nutrient levels and low ocean temperatures (50-60° F), fronds can elongate up to 24 inches a day. Fronds can reach a length of more than 150 feet, and large plants can have more than 100 fronds. The fronds eventually mature, die, and break away (slough) naturally, giving way to young fronds. Although giant kelp plants can live up to eight years, individual fronds survive for only about six to nine months, and individual blades about four months.

Giant kelp reproduction involves two very different growth forms, the large canopy-forming sporophyte and the microscopic gametophyte. Specialized reproductive blades (sporophylls), located just above the holdfast on an adult sporophyte, liberate trillions of microscopic zoospores each year. The zoospores then settle on the bottom and develop into microscopic male and female gametophyte plants. Fertilization of the female gametophyte produces an embryonic sporophyte. This tiny plant will develop into a canopy-forming adult within seven to 14 months if it survives competition with other plants and avoids being eaten by grazers or being destroyed by undesirable environmental factors.

The density and abundance of a kelp canopy varies by location, year, and season. In central California, sloughing and deterioration occurs in late summer and early fall. Canopies virtually disappear during the late fall and winter, when storms cause frond and plant loss. Canopies usually begin forming again in the spring, becoming dense in the summer. Off southern California, kelp canopies frequently grow throughout the year in the mild weather conditions. Dense canopies often develop during the winter, when there are virtually no canopies in central California.

The health and survival of the kelp forests are influenced by a variety of factors, including: grazing by fishes, sea urchins, and crustaceans; plant competition; storms; El Niño events; sedimentation; pollution; and disease. In southern California, fishes such as opaleye and halfmoon regularly graze upon kelp. Large numbers of these fishes can damage the kelp forests, especially when conditions are unfavorable for kelp growth. Purple, white and red sea urchins can create "urchin barrens," where kelp and other vegetation have been destroyed and young plants are prevented from becoming established. Crustaceans, such as amphipods, isopods and crabs, can also graze and damage kelp.

Excessive wave action from storms and surge can break kelp fronds and dislodge entire plants. Dislodged plants increase kelp loss by entangling nearby plants, pulling them from their attachment. The El Niño event of 1982-1984 was characterized by severe storms and the northward movement of warm, nutrient-poor water into California. These conditions devastated kelp forests along the entire coast.

Competition for substrate, light and nutrients also influences giant kelp growth and survival. Sedimentation of the rocky bottom can retard kelp growth and even bury young plants, preventing development and reproduction.

Pollution can affect kelp forests in a variety of ways. Industrial and domestic wastewater discharges carrying toxins, including pesticides and heavy metals, are released into coastal waters where they can accumulate in the sediments. Such chemicals alter the physical and chemical environment near the discharge and may decrease growth and survival of the kelp forests. Thermal outfalls from power plants also have localized effects on kelp forests. Wastewater and thermal discharges can increase turbidity and redistribute sediments into nearby kelp forests, affecting kelp growth and survival. A variety of pathogens are known to affect kelp but their broad impacts on kelp forests have not been studied. While tumors, galls and lesions have been observed on kelp, only occasionally have they caused severe damage.

Kelp Restoration

In the 1950's and 1960's, once-productive kelp forests off Point Loma and La Jolla, in San Diego County, and Palos Verdes Peninsula (PVP), in Los Angeles County, began to deteriorate. This was attributed to biological and physical factors related primarily to human activities. Pollution from domestic and industrial wastes contributed to the long-term losses of kelp forests by increasing turbidity, altering substrates and introducing toxic substances into the nearshore environment. Intensive fishing for sea urchin predators such as sheephead and spiny lobster, and for sea urchin competitors such as abalone, has altered the sea urchin populations in the forest. As a result, sea urchin populations increased in density and overgrazed the kelp.

In 1963, Scripps Institution of Oceanography and Kelco began a cooperative project to develop techniques to protect and restore kelp forests off San Diego. Work involved both sea urchin control and kelp transplanting. Kelco continues kelp restoration work in San Diego forests today.

Giant kelp forest.

Between 1967 and 1980, kelp restoration was conducted along the PVP by the Institute of Marine Resources and the CDFG. This work also combined sea urchin control and kelp transplanting. The objective was to establish several small stands of kelp which would provide "seed stock" for new and expanding forests. In 1974, the first naturally expanding kelp stand in 20 years was observed off PVP. By 1980, when restoration work was discontinued, nearly 600 acres of kelp had become established. By 1989, aerial surveys revealed over 1,100 acres of kelp off PVP.

Kelp restoration work has also been conducted in storm damaged areas off Santa Barbara and Orange Counties. Shortly after the 1982-1984 El Niño, Kelco began developing techniques for restoring the kelp beds in Santa Barbara County. In 1987, under contract with CDFG, Kelco implemented operations for anchoring giant kelp in the sandy habitat near Santa Barbara. Several kelp forest nuclei have been established; however, sea urchin grazing and deleterious water conditions have slowed progress. Loss of the Orange County kelp forests, from Newport Harbor to San Mateo Point, was caused by heavy rainfall and siltation in 1980, the 1982-1984 El Niño, and the effects of urchin grazing. Under contract with CDFG, MBC Applied Environmental Sciences company established kelp forest nuclei between Newport Harbor and Laguna Beach. This was done by transplanting adult and juvenile giant kelp and controlling sea urchins. Those kelp forests south of Laguna Beach recovered naturally after a few years.

During the last 25 years, restoration techniques have proven useful for rehabilitating and protecting kelp forests in southern California. Improvements in wastewater treatment, a continued sea urchin fishery and continued kelp restoration work should insure that forests of giant kelp prosper.

SMB-26740

Status of Population

During the 1980's, two major events affected kelp beds: the 1982-1984 El Niño and a devastating storm. The warm water and storms associated with the El Niño destroyed plants, resulted in poor growth, and yielded minimal canopies throughout southern and central California. Effects of the El Niño have lingered into the 1990's. The giant kelp forests on sand substrate near Santa Barbara have not yet returned. Though restoration work is presently being done in this area, recovery is slow. In 1967, there were approximately 18 square miles of kelp canopy near Santa Barbara, compared to only six square miles in 1989.

The storm that occurred on January 18, 1988, produced swells exceeding 20 feet in height and destroyed exposed kelp beds throughout southern California overnight. In most areas, significant canopies did not return until 1989. At San Clemente Island, however, plants that had settled following the storm produced harvestable canopy by the end of July, 1988.

During the last 20 years, the size, distribution and location of the kelp canopy throughout California has fluctuated considerably. Decreases in canopy area were due to natural and man-induced disturbances and increases were due to natural growth and restoration efforts. During the most recent statewide kelp forest survey, conducted in 1989, a total of 68 square miles of giant kelp was charted along the California coast, 40 square miles from Point Arguello to the Mexican border and 28 square miles from Point Arguello to Año Nuevo.

In summary, forests of giant kelp in California must continue to be managed and restored. Giant kelp forests provide essential habitat for a diverse assemblage of marine fishes and invertebrates and their loss would reduce the populations of many marine species. Kelp forests are also important to sport and commercial fishermen, kelp harvesters, recreational divers, photographers, sightseers, and for their highly-valued aesthetic quality.

John A. Tarpley
California Department of Fish and Game

Dale A. Glantz
Kelco Division of Merck & Co., Inc.

References

Foster, M.S. and D.R. Schiel. 1985. The ecology of giant kelp forests in California: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.2). 152 p.

McPeak, R.H. and D.A. Glantz. 1984. Harvesting California's kelp forests. Oceanus. 27(1)19-26.

McPeak, R.H., D.A. Glantz, and C.R. Shaw. 1989. The amber forest. Watersport Publishing. 144 p.

North, W.J. In press. Review of Macrocystis Biology. In I. Akatsuka (ed.). Biology of Economic Seaweeds.

Wilson, K.C., P.L. Haaker, and D.A. Hanan. 1977. Kelp Restoration in Southern California. Pages 183-202 in R.W. Krauss (ed.) The marine plant biomass of the Pacific Northwest coast. Oregon State University Press, Corvallis.

AGAROPHYTES AND CARRAGEENOPHYTES

History

The term agar is derived from a Malayan word, although its initial discovery and use are steeped in a Japanese folk legend that originated about 1670. A Japanese Emperor and his Royal Party were lost in the mountains during a snow storm, and, arriving at a small inn, they were ceremoniously treated by the innkeeper, who offered them a seaweed-jelly dish with their dinner. Maybe the innkeeper prepared too much jelly or the taste was not so palatable, but some jelly was thrown away. It froze during the night and crumbled afterwards by thawing and draining, leaving a cracked substance of low density. The innkeeper took the residue and, to his surprise, found that, by boiling it up with more water, the jelly could be remade. Thus, a trivial historical incident created the basis for a billion dollar seaweed industry. Similarly, carrageenan was originally derived from the red alga, *Chondrus crispus* (Irish Moss), and has a 600 year folk history in Ireland that includes milk puddings thickened by boiling sweetened milk with the dried alga. The root word of carrageenan is the Irish *carraigeen* meaning rock moss. Since the 1940's, the best known use of carrageenan has been in products such as chocolate milk and ice cream. The California agar industry was developed initially by Matsuoka in 1921 with U.S. patents for the extraction and processing. Horace Selby (the founder of American Agar & Chemical) and C.K. Tseng added additional information and refined methods prior to and during World War II, when agar was not available from Japan. The German microbiologist, Dr. Robert Koch, first established the use of agar in preparing solid culture media for bacteriological research in 1881.

Status of Biological and Technical Knowledge

Agar and carrageenan are derived from galactan polysaccharides of marine red algae. Galactans are the major polysaccharide constituents of the cell walls of most marine red algae. The types and quantity vary from species to species and this is an important character in biosystematics. The amount present also varies with ecological factors such as light, nutrients and temperature. Polysaccharides have an important role in the general biology of these algae: protection from wave action, physical support of cells, ion exchange system, water binding for protection from desiccation. The galactans have a common backbone which consists of galactose units linked alternately by α (1-3) and β(1-4). The alpha (α) unit is with either D- or L-galactose whereas the beta (β) unit is always D-galactose. In agar the α-linkages are all with L-galactose and in carrageenan they are all with D-galactose. All this contributes to a complex chemistry.

Agar is available in several different types for different products. The less expensive types ($8-$15 per pound) are used for their gelling and water barrier properties in food products (frozen foods, bakery icings, meringues, dessert gels, candies

SMB-26741

and fruit juices). As a gelling agent in foods, it is used at greater than one per cent concentration. For viscosity control and stabilization, lower levels (0.2-0.8%) are used. Agar is not assimilated by the human digestive system and, in fact, serves as a laxative. Industrial applications are paper sizing/coating, adhesives, textile printing/dyeing, castings, impressions, etc. The mid-quality ($100/pound) agars are used as the gel substrate in biological culture media. Most agar media are made at a 1.0-1.5 percent concentration in water, melt above 185°F and gel at 105°F. They are also important in medical/pharmaceutical fields as bulking agents, laxatives, suppositories, capsules, tablets and anticoagulants. The most highly purified and upper market types (>$250/pound) are now used in molecular biology for separation sciences (immunodiffusion, diffusion, electrophoresis and gel chromatography).

Carrageenans are far more widely used than agar as emulsifiers/stabilizers in numerous foods, especially milk-based products. Kappa and iota carrageenans are especially important for use in milk products such as chocolate milk, ice cream, evaporated milk, infant formulas, puddings, whipped cream toppings and egg nog, because of their thickening and suspension properties. For these uses, concentrations range from about 0.01 to 0.2 percent. In water-based food products (jellies, jams, salad dressings, syrups, dessert gels, meat products and pet foods), carrageenan concentrations are somewhat higher (0.2-0.5%). Kappa carrageenan forms a firm, brittle gel and iota yields a flexible and very dry gel. Blending of these in different ratios is used for different products. Most recently, it has received substantial publicity as a binder in low-fat hamburger meat of fast-food chains and other low-fat meat products. Industrial products incorporating carrageenans are air freshener gels, cleaners, etc. Pharmaceutical and medical applications are similar to those of agar. Kappa, iota and lambda carrageenans differ in gelling and milk reactivity and are the three most widely used types in commercial products.

Status of Populations

The agarweeds most frequent to California are *Gelidium*, *Pterocladia*, and *Gracilaria*. Of the six species of *Gelidium* in California, only *G. robustum* is available in sufficient wild stocks to warrant limited harvest for agar production. Before and during World War II and until American Agar and Chemical Company in San Diego closed in about 1986, *G. robustum* was collected by divers along the southern California coast. Resource management of wild stock of *G. robustum* was investigated carefully to establish control of season, amount and method of harvesting, but it proved difficult to enforce regulations. Today, there is no harvest of wild stocks for commercial agar production. Wild stocks are still harvested in Baja California, Mexico, by local fisherman for processing in Ensenada and subsequent export of refined agar. It is very slow growing in nature and even slower in mariculture, thus making it unlikely as a major resource. Several other species, including *G. coulteri*, show much faster growth in nature and in tank culture, providing an acceptable quality agar. Unfortunately, the cost of these culture systems in California is too high for competition with either wild stock harvest or cultivation in other countries. The *Gracilaria* species in California and elsewhere offer considerable potential, because of their fast growth and yield of agar. Several species are extensively cultivated in Chile, China and Thailand, for example. The best candidate for large scale culture in California is *G. lemaneformis*. Although extensively cultivated in open bays of other countries, it is unlikely that such cultivation could occur in California, because of government restrictions.

There are many other genera of red algae in California that yield agars and carrageenans.

Compared to agars, carrageenans generally are more plentiful and less costly, because the carrageenan weeds are more widely available from harvest of wild stocks and extensive cultivated stocks (e.g., *Eucheuma* and *Kappaphycus* in the Philippines, Indonesia, Malaysia, China and Thailand). The carrageenan weeds common in California are *Gigartina*, *Iridaea*, *Masto-carpus*, *Rhodoglossum* and *Sarcodiotheca*. Several California species can be grown successfully in mariculture, but the low value of carrageenan makes both wild harvest and culture economically unrealistic.

John West
University of California, Berkeley

References

Abbott, I.A. & G.J. Hollenberg. 1976. Marine algae of California. Stanford University Press. Stanford.

Craigie, J.S. 1990. Cell Walls. *In* K.M. Cole & R.G. Sheath (eds.) Biology of the Red Algae, pp. 221-257. Cambridge University Press. New York.

Lewis, J.G., N.F. Stanley & G.G. Guist. 1988. Commercial production and application of algal hydrocolloids. *In* C.A. Lembi & J.R. Waaland (eds.) Algae and human affairs. pp. 205-236. Cambridge University Press. New York.

Myslabodski, D.E. 1990. Red-algae galactang:isolation and recovery procedures -effects on their structure and rheology. Ph.D. Thesis. Norwegian Institute of Technology. Trondheim.

MARINE PLANTS: DISCUSSION

The decline of once-luxurious kelp forests has been variously attributed to major storms, prolonged periods of nutrient-drought, over-grazing by sea urchins, sewage outfalls, power plant cooling water, oil drilling and oil production water discharge. Considerable sums have been spent on studies trying to understand why our marine plant resources are not what they used to be. Many such studies have been documented only in unpublished reports which are hard to find and have not been subjected to careful scientific review. Moreover, some fail to answer the question of why our marine plant resources are not thriving as in the past. Obviously, this situation must change if we are to protect and restore our marine plant resources.

Californians have not yet tried to domesticate and cultivate marine plant resources on a large scale. In China, Japan and the Philippines macroalgal cultivation is a multi-million dollar busi-

SMB-26742

ness employing thousands of people and producing exports that are marketed world-wide. As the preceding discussions indicate, the harvest of natural stands of both agarophytes and kelps in California has been financially rewarding, and kelp is still harvested. The enormous productivity of the giant kelp forests was demonstrated during the first world war, when over 400,000 tons per year were harvested and used for the production of acetone and other products. Kelp domestication and cultivation has been achieved in California, but only a few acres have been farmed to date.

The commercial cultivation of agarophytes has been attempted both in the sea and in tanks on land with somewhat encouraging results, particularly with regard to the red alga, *Gracilaria*. However, the most valuable agar and agarose producing *Gelidium* has been cultivated in California only on an experimental scale. Nonetheless, a commercial source of high-value agar and agarose would be a boon for the growing California biotechnology industry, where these substances are used.

There is little disagreement among those who harvest abalone and sea urchins in California that an abundant supply of kelp and other macroalgae is an essential element for the maricultural production of these valuable herbivores. Indeed, it is the shortage of macroalgal foods that limits the present Japanese and Chinese abalone mariculture industries. Given the fact that the south-flowing California Current, and the upwelling it produces along the coast of California, provide year-round cool and nutrient-rich water, growing conditions for macroalgae are good here and large-scale year-round commercial cultivation of kelp is possible. California giant kelp is perennial and long-lived. A small experimental kelp bed established in 1981 is still flourishing ten years later.

The allocation of resources for the management and experimental farming of California marine macroalgae could provide a sound basis for preserving natural submarine kelp forests enjoyed by sport fishermen and recreational divers, as well as providing an important resource for mariculture. Large scale, commercial macroalgal cultivation could provide raw materials for the production of agar and alginates, as well as maricultural feeds for a sustained abalone and sea urchin industry.

Michael Neushul and Peter Neushul
University of California, Santa Barbara

References

Bird, K. and P. Benson, Eds. 1987. Seaweed Cultivation for Renewable Resources. Elsevier, Amsterdam.

Melo, R.A., Harger, B.W.W. and M. Neushul. 1991. *Gelidium* cultivation in the sea. Hydrobiologia 221:91-106.

Neushul, P. 1989. Seaweed for war: California's world war I kelp industry. Technology and Culture, 30:561-583.

Neushul, M. and B.W.W. Harger. 1885. Studies of biomass yield from a near-shore macroalgal test farm. Jour. Sol. Energy Eng. 107:93:96.

SMB-26743

OCEAN SHRIMP

History of the Fishery

The commercial fishery for ocean shrimp (*Pandalus jordani*), also called pink shrimp, started in 1952 after commercial quantities were found by California Department of Fish and Game (CDFG) research vessels in 1950 and 1951. Regulations for the new fishery, including net type with mesh restrictions and a season, were established by the California Fish and Game Commission in 1952. The first catches were made later that same year. Three regulation areas were also designated and catch quotas established for each. The three regulatory areas were Area A, Oregon border to False Cape; Area B, False Cape to Pigeon Point; and Area C, Pigeon Point to the Mexican border. In 1956, Area B was divided into two areas; B-1 extended from False Cape to Point Arena and B-2 from Point Arena to Pigeon Point.

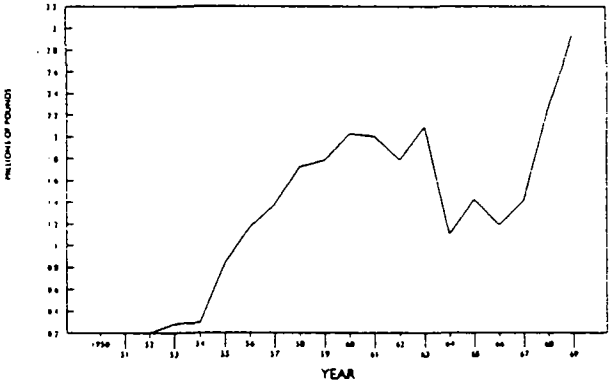
Catch quotas governed the shrimp take from 1952 to 1976. Quotas were based on recommendations of the CDFG and were set each year by the Fish and Game Commission. In 1976, all quotas were dropped in favor of four criteria believed to protect the resource. The criteria were: 1) a season from April 15 through October 31 designed to protect egg-bearing females; 2) a net mesh size of 1 3/8 inches to allow escapement of small 0- and 1-year-old shrimp; 3) a count per pound of 170 or less intended to protect one-year-old shrimp; and 4) a minimum catch rate of 350 pounds per hour to protect shrimp when the population is at a low level. If these requirements were not met, the CDFG had the option to close the fishery. In 1981, the regulations were changed again to bring them into accord with an agreement with Oregon Department of Fish and Wildlife and Washington Department of Fisheries to have uniform regulations. The new regulations included a season from April 1 through October 31, a maximum count per pound of 160, and a minimum mesh size of 1 3/8 inches measured inside the knots. These regulations are still in effect. From 1952 to 1963, shrimp fishermen were limited to the use of beam trawls with a minimum mesh size of 1.5 inches between the knots. In 1963, shrimpers were permitted to use otter trawls with the same size mesh. The mesh size was reduced from 1.5 inches to 1 3/8 inches in Areas A, B-1, and B-2 in 1975.

Prior to 1974, all shrimp boats in California pulled a single rig of one net and two doors, but starting with the 1974 season vessels which towed a double rig from outriggers, one on each side of the boat, entered the fishery. The double-rigged vessels are approximately 1.6 times more effective than single-rigged vessels.

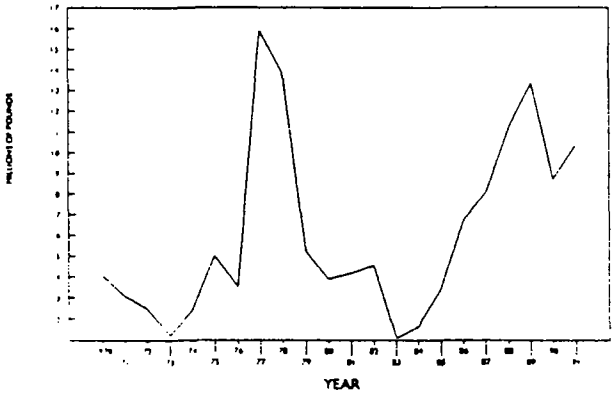
During the first year of the fishery, only six boats participated. The number of boats increased to 27 by 1960, then averaged 24 boats per season over the next 16 years until the record catch in 1977 started a rapid influx of boats into the shrimp fishery. A record high of 104 vessels fished for shrimp during 1980, but the number declined to 33 during 1983 when the catch fell to a low of 1,176,000 pounds. As the catch recovered from that El Niño-induced low, many boats reentered the fishery. The number of vessels per season averaged 63 from 1983 through 1990.

California landings have averaged 3,720,000 pounds annually from 1952 through the 1990 season, ranging from a low of 206,000 pounds in 1952 to a high of 15,640,000 pounds in 1977. Average landings have increased each decade since the start of the fishery in the 1950's: 969,000 pounds in the 1950's, 1,810,000 pounds in the 1960's, 5,679,000 pounds in the 1970's, and 5,871,000 pounds in the 1980's. Area A has been the most consistent producer and, since 1954, has had the highest annual landings. The only exception was the El Niño year of 1983, when Area C had the highest landings. Since the inception of the fishery, 84.3 percent of the shrimp have been landed in Area A ports, 6.1 percent in Area B-1, 4.4 percent in Area B-2, and 5.1 percent in Area C.

The price paid to the fishermen (ex-vessel price) has ranged from a low of $0.07 per pound in 1955 to a high of $0.87 per pound in 1987. The ex-vessel price remained fairly constant at $0.10 per pound during the 1950's and 1960's, increased in price from $0.12 per pound to around $0.30 per pound in the 1970's, and since has fluctuated around $0.50 per pound.



California commercial landings of ocean shrimp, 1952-1969.



California commercial landings of ocean shrimp, 1970-1991.

SMB-26744

Catch of ocean shrimp comes aboard a trawler.

The largest portion of ocean shrimp landed in California is picked and sold frozen in vacuum cans. Small amounts are sold fresh unpicked, as cooked picked meat or, most recently, as individually quick-frozen shrimp. Most of California's shrimp catch was hand picked until 1969, when machines were introduced in the Eureka area. Shrimp machines have enabled the shrimp industry to pick much smaller shrimp than was possible with hand picking.

Status of Biological Knowledge

Ocean shrimp are found from Unalaska in the Aleutian Islands to off San Diego, California, at depths from 150 to 1200 feet. In California, this species is generally found from depths of 240 to 750 feet. Spawning probably occurs throughout the range, but commercial harvest is limited to the area between Vancouver Island, British Columbia, and Point Arguello, California.

Concentrations of shrimp generally remain in well defined areas or beds from year to year. These areas are associated with green mud and muddy-sand bottoms. Although there is evidence of onshore-offshore and coastwide movement within the confines of a bed throughout the year, no set pattern is apparent. Horizontal movements probably are governed by feeding activities and prevailing currents. Ocean shrimp also exhibit vertical migrations. These movements towards the surface during periods of darkness appear to be associated with feeding on plankton. Adults from the different beds probably intermix rarely, but the planktonic larvae undoubtedly intermingle, as there are no indications of genetically distinct subpopulations. Genetic stock identification work on ocean shrimp has failed to isolate any genetic differences between ocean shrimp from off the coasts of California, Oregon, Washington and British Columbia.

Ocean shrimp feed mostly at night on planktonic animals. The stomach contents of shrimp taken at night indicated that the most common food items were euphausiids and copepods, while the stomachs of shrimp collected during daytime contained little food. Identifiable food items included polychaete worms, sponges, diatoms, amphipods, and isopods.

Many species of fish prey on ocean shrimp. Major fish predators include Pacific hake, arrowtooth flounder, sablefish, petrale sole and several species of rockfish.

Ocean shrimp are protandric hermaphrodites; that is, during their first year and a half of life most will function as males, then pass through a transitional phase to become females. During some years, a large percentage (up to 60 percent) of the one-year-old shrimp become females and never mate as males. Female shrimp usually carry between 1,000 and 3,000 eggs. Small individuals in their second year have been found carrying as few as 900 eggs, whereas larger shrimp in their third or fourth year of life have been found with up to 3,900 eggs. Mating takes place during September and October, and the external fertilization of the eggs takes place when the females begin extruding eggs in October. The female carries the eggs between the posterior swimming appendages until the larvae hatch. The peak of hatching occurs during late March and early April. Ocean shrimp go through a larval period which lasts 2.5 to three months. Shrimp grow in steps by molting or shedding their shells. Growth rates for ocean shrimp vary according to region and also by sex and year class. There is a clear pattern of seasonal growth despite the variations mentioned, with very rapid growth during spring and summer and slower growth over the winter. The growth rate decreases as the shrimp age. Ocean shrimp may reach 5.5 inches in total length, but the average catch size is about four inches. In California, few shrimp survive beyond their fourth year. Studies on natural mortality have indicated that the survival between fishing seasons (over winter) is estimated to be 46 percent, 76 percent, and 43 percent for ocean shrimp during their first, second, and third winters of life, respectively.

Status of Population

Population estimates of the various shrimp beds were obtained by CDFG sea surveys from 1959 to 1964; catch quotas were set at one quarter of the estimated population. Area A sea survey continued until 1969. The highest Area A population estimate from sea surveys was 10,700,000 pounds in the fall of 1967. Because the cost of sea surveys was quite high, another method of estimating population was needed. A mathematical population model designed by CDFG statisticians was used to estimate the population size and set the quota from 1969 until 1976, when the model was dropped and no further attempts to estimate the population were made. It was established that the ocean shrimp population abundance off California is determined by environmental conditions which cause natural fluctuations in recruitment that are apparently unrelated to commercial fishing effort. Since the abandonment of quotas, the shrimp population, as evidenced by the commercial catch, has gone through two extreme highs (1977 - 15,600,000 pounds; 1989 - 13,300,000 pounds) and one low (1983 - 1,200,000 pounds - primarily in Area C). The landings are apparently headed for another low in 1991, due to a year-class failure in 1989.

Patrick C. Collier
California Department of Fish and Game

References

Dahlstrom, W.A. 1970. Synopsis of biological data on the ocean shrimp *Pandalus jordani* Rathbun, 1902. FAO Fish. Rep., 57(4):1377-1416

SMB-26745

_____. 1973. Status of the California ocean shrimp resource and its management. Calif. Dept. Fish and Game, Mar. Resour. Tech. Rep. 14. 17 p.

Pacific Fishery Management Council. 1980. Draft of the fishery management plan and environmental impact statement for the pink shrimp fishery off Washington, Oregon and California. Pac. Fish. Mgmt. Council, 526 S.W. Mill St., Portland, OR. 191 p.

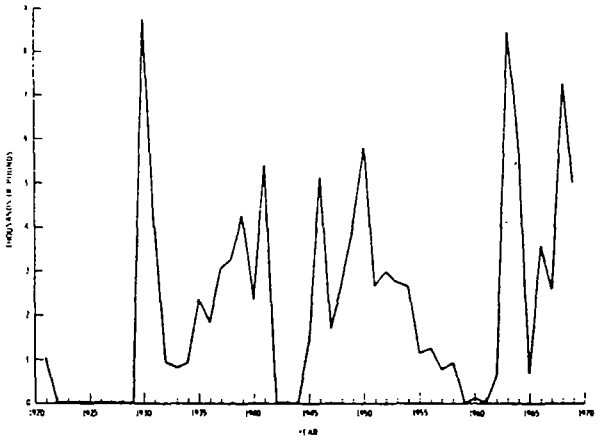
Pearcy, W.G. 1970. Vertical migration of the ocean shrimp, *Pandalus jordani*: a feeding and dispersal mechanism. Calif. Fish and Game, 56:125-129.

SPOT PRAWN

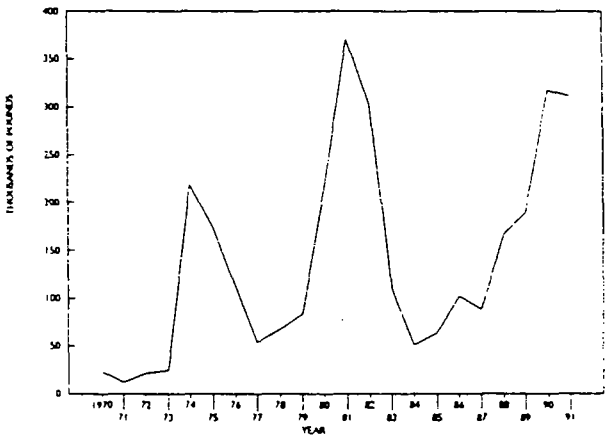
History of the Fishery

The fishery for spot prawn (*Pandalus platyceros*) originated nearly 60 years ago in Monterey when prawns were caught incidentally in octopus traps. It was a minor fishery with landings averaging around 2,000 pounds annually until the early 1970's; but, in 1974, trawl fishermen fishing out of Santa Barbara caught over 182,000 pounds. The Santa Barbara area became the major center for spot prawns and trawl gear the main method of capture. Landings continued to increase following a decline in 1977. By 1981, landings reached a record high of 370,536 pounds, most of this total coming from the Santa Barbara-Ventura area. Catches began to decline in 1982, and fell significantly in 1984, when a closed season for trawl gear was imposed by the California Department of Fish and Game (CDFG). Reasons for the periodic declines in landings may have been overfishing, market conditions, or natural cyclic fluctuations due to environmental conditions. Trawl fishermen also began fishing for ridgeback prawns during the period. With a closed season on trawl gear, interest developed in a trap fishery in southern California beginning in 1986. Trap fishermen began fishing off Catalina and San Clemente Islands, as well as in submarine canyons. Soon, this mode of fishing became profitable and popular. With traps, prawns could be kept alive using holding tanks set at optimum water temperatures, and a market for live prawns developed primarily for the restaurant and Asian markets. Price for live prawns ranged from $5.00 to $6.50 per pound, whereas dead (heads-on) prawns brought only $3.50 per pound. Landings again increased in 1986, reaching a near record total of 311,000 pounds by 1990. Currently, trap gear accounts for nearly 75 percent of all prawns landed, while 25 percent is taken by trawl gear.

The trawler fleet consists of 20 to 25 vessels operating out of Morro Bay, Santa Barbara, and Ventura. Standard gear is a single-rig shrimp trawl of a semi-balloon, or Gulf Shrimp Act, design. Occasionally, double-rig shrimp trawls are used. The minimum mesh requirement is 1.5 inches, but many fishermen use larger-mesh nets. Trap fisheries are located in Monterey Bay and in southern California. The Monterey Bay trap fishery continues to produce prawns, although it has never reached the large volume of the southern California fishery. Monterey-area boats are about 30 to 40 feet in length and usually fish for salmon during the summer. Currently, there are only a few boats



California commercial landings of spot prawns, 1921-1969.



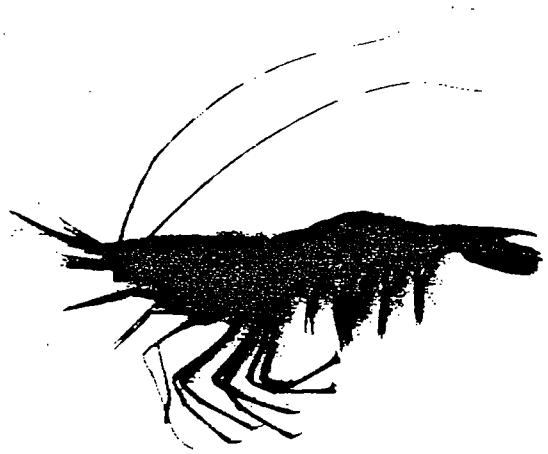
California commercial landings of spot prawns, 1970-1991.

fishing the Monterey Bay area and they fish only three to four months a year. The Southern California trap fleet numbers between 30 and 50 boats. These boats range in size from 30 to 60 feet. Trap designs are variable, with plastic oval-shape traps and rectangular wire traps being most popular. Normally, a long line or string contains 25 to 50 traps. In both fishing areas, traps are set at depths of 500 to 900 feet along submarine canyons.

Status of Biological Knowledge

The distribution of spot prawn ranges from Alaska to San Diego, California, in depths of 150 to 1,600 feet. Major concentrations of populations in California waters occur off Monterey and the Channel Islands. This species is a protandric hermaphrodite beginning life as a male. Sexual maturity is reached during the third year when they average 1.5 inches carapace length (CL). By the fourth year, many males begin to change sex to the transitional stage. By the end of the fourth year, the transitionals become females averaging 1.75 inches CL. Maximum observed age is estimated at over six years. There are considerable differences in age and growth of spot prawns between areas. Animals from Canada live no longer than four

years, whereas the prawns from southern California can reach six years. Studies indicate that prawns grow faster in a temperate environment than in a cold environment.



Spot prawn, *Pandalus platyceros*

Spawning occurs once a year, and each individual mates once as a male and once or twice as a female. Females spawn at four years and older at a carapace length of 1.75 inches. Spawning takes place at depths of 500 to 700 feet. September appears to be the spawning month, when the eggs are extruded onto the female's swimmerets. She carries the eggs for a period of four to five months before they hatch. By April, only 15 percent of the females still carry eggs. Fecundity varies with size, ranging from 1,400 to 5,000 eggs for the first spawning down to 1,000 eggs for the second spawning. Eggs hatch over a 10-day period and the larvae are pelagic. As the animals develop to the juvenile stage, they begin to settle out at depths of 175 feet, but move deeper when they reach adulthood.

Spot prawns feed on other shrimp, plankton, small mollusks, worms, sponges and fish carcasses. They usually forage on the bottom throughout the day and night.

Status of Population

Exploratory surveys conducted by the CDFG during the 1960's revealed the presence of prawns along the coast, but no estimates of population size were made. During the 1980's, additional surveys were conducted along southern California for distribution and range. Fishermen began using traps during this period, locating prawns in new areas, and now this species appears to be more numerous than previously believed. A substantial fishery has now developed in southern California.

John S. Sunada
California Department of Fish and Game

John B. Richards
University of California
Sea Grant Extension Program

References

Butler, T.H. 1964. Growth, reproduction, and distribution of pandalid shrimps in British Columbia. J. Fish. Res. Bd. Canada. 21:1403-1452.

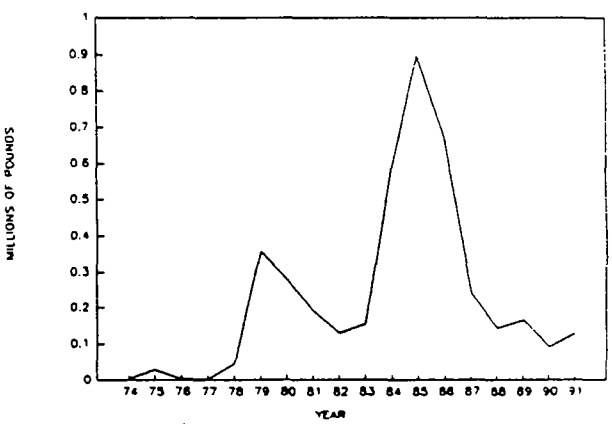
Sunada, J.S. 1984. Spot prawn (*Pandalus platyceros*) and ridgeback prawn (*Sicyonia ingentis*) fisheries in the Santa Barbara Channel. Calif. Coop. Oceanic Fish. Invest. Rep. 25:100-104..

_____. 1986. Growth and reproduction of spot prawns in the Santa Barbara Channel. Calif. Fish and Game. 72:83-93.

RIDGEBACK PRAWN

History of the Fishery

The fishery for ridgeback prawn (*Sicyonia ingentis*) is comparatively young. Until recently, interest in the species was lacking because of the absence of demand. Prior to 1966, trawl fishermen in the Santa Barbara area occasionally observed small numbers of ridgeback prawns in their bottomfish catches. Fishing started in 1966 after regulations were formulated to harvest this resource with small-mesh nets. Landings in 1966 totaled about 30,200 pounds, but the fishery quickly faded as a result of poor marketability. Annual landings were below 5,000 pounds from 1974 to 1977, except in 1975 when they were 28,000 pounds. The catch increased to 356,000 pounds in 1979, but declined to 129,000 pounds three years later. In 1985, landings peaked at nearly 900,000 pounds, but they subsequently declined to 142,000 pounds in 1988 following several year-class failures.



California commercial landings of ridgeback prawns, 1974-1991.

The fishery is centered in the Santa Barbara Channel and off Santa Monica Bay. Twenty trawlers ranging from 33 to 73 feet (average 48 feet) engage in the fishery. Standard gear has been a single-rig shrimp trawl with a mesh size of 1.5 inches or greater. Seasonally, as many as seven Pacific northwest shrimp trawlers have entered the fishery. These boats, which averaged 67 feet, used a double-rig shrimp trawl, increasing the fishing efficiency by 60 percent. When the fishery declined in the early

SMB-26747

1980's, many of these boats left the area. Following the decline in landings in 1981, a summer closure (June 1 through September 30) was adopted by the California Fish and Game Commission for the protection of spawning female and juvenile ridgeback prawns. An incidental take of 50 pounds of prawns is allowed during the closed period. Other regulations include a three-mile closure to trawling and a minimum mesh size of 1.5 inches for single-walled codends or three inches for double-walled codends.

Demand for this resource continues to be high, as its sweet flavor and low price make it a favorite among fresh fish buyers. As this species does not freeze well, it is primarily sold fresh.

Ridgeback prawn, *Sicyonia ingentis*

Status of Biological Knowledge

Ridgeback prawns occur from Monterey, California to Cedros Island, Baja California, at depths ranging from less than 145 feet to 525 feet. Major population concentrations are the Ventura-Santa Barbara Channel area, Santa Monica Bay, and off Oceanside. Other pockets of abundance are found off Baja California. This species occurs on substrates of sand, shell and green mud. As these animals are relatively sessile, little or no intermixing occurs. Their maximum life span is five years and sexes are separate. Females reach a maximum length of 1.8 inches carapace length (CL), and males 1.5 inches CL.

These shrimp are free spawners, as opposed to other shrimps which carry eggs. Both sexes spawn as early as the first year, but most spawn during the second year at a size of 1.2 inches CL. The spawning period is more seasonal than with other penaid shrimp. Studies suggest that this species undergoes multiple spawning during June through October. Following spawning, both sexes undergo molting and continue molting throughout winter and spring. The number of eggs produced averages 86,000.

Food habits of the ridgeback prawn are not known, but it may be a detritus feeder like closely related species.

Status of Population

Yearly sea surveys have been conducted over the past eight years to document relative abundance and year-class strengths of juvenile ridgeback prawns. Relative abundance in terms of numbers of animals per 15-minute tow began increasing from 66 animals per tow in 1982 to 1,200 animals per tow by 1984, but began to decline in 1985 when the catch fell to 132 per tow. These trends mirrored the rise and fall of yearly commercial catches. The population of ridgeback prawn in the Ventura area increased dramatically during 1983 to 1985, but subsequently began declining. Potential causes for this increase are the effects of El Niño, which provided optimum conditions; reduced predator populations; and regulatory restrictions on the fishery. No population estimates were available for any of the major fishing grounds, although the majority of catches consisted of two- and three-year-old animals.

John S. Sunada
California Department of Fish and Game

John B. Richards
University of California
Sea Grant Extension Program

References

Anderson, S.L., L.W. Botsford, and W.H. Clark, Jr. 1985. Size distributions and sex ratios of ridgeback prawns (*Sicyonia ingentis*) in the Santa Barbara Channel (1979-1981). Calif. Coop. Oceanic Fish. Invest. Rep. 26:169-174.

Anderson, S.L., W.H. Clark, and E.S. Chang. 1985. Multiple spawning and molt synchrony in a free-spawning shrimp (*Sicyonia ingentis*: Sicyoniidae). Biol. Bull. 168:377-394.

Herkelrath, J.M. 1977. Some aspects of the growth and temperature tolerance of ridgeback prawn, *Sicyonia ingentis* (Burkenroad), in southern California waters. M.S. thesis. Department of Biology, Whittier College.

Pérez Farfante, I. 1985. The rock shrimp genus *Sicyonia* (Crustacea: Decopoda: Penaeoidea) in the eastern Pacific. Fish. Bull., U.S. 83:1-79.

Sunada, J.S. 1984. Spot prawn (*Pandalus platyceros*) and ridgeback prawn (*Sicyonia ingentis*) fisheries in the Santa Barbara Channel. Calif. Coop. Oceanic Fish. Invest. Rep. 25:100-104.

BAY SHRIMP

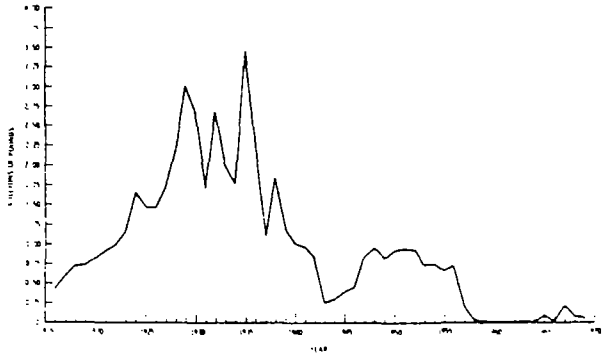
History of the Fishery

The commercial fishery for bay shrimp in San Francisco Bay began in the early 1860's. Historical accounts differ concerning the circumstances and earliest participants; they may have been Italians using small-meshed bag seines. By 1871, the Chinese had set up fishing camps along the shores of the bay and introduced Chinese shrimp nets. These funnel-shaped nets were anchored in place and shrimp were captured as they were carried into the nets by the tide. Between 1890 and 1895, fishing camps also existed in Tomales Bay. By 1897, 26 Chinese fishing camps operated up to 50 nets in San Francisco Bay with daily landings of 400 to 8,000 pounds of shrimp. Since the 1870's, these camps had been supplying large quantities of dried shrimp meat and shrimp meal (dried heads and shells) to an export market for China. At the height of the fishery in the 1890's, annual landings exceeded five million pounds.

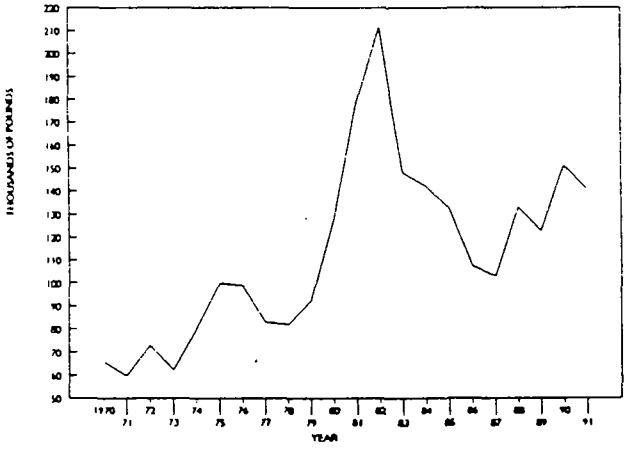
Between 1897 and 1911, studies were required by the California Fish and Game Commission to respond to concerns that many young fish, particularly striped bass, were being

SMB-26748

killed in the shrimp nets. This led to a May to August season closure and eventually the prohibition in 1911 of Chinese shrimp nets. In 1915, the Legislature again allowed their use, but only in south San Francisco Bay. About this time, beam trawl nets began to be used by commercial shrimp harvesters in northern San Francisco Bay and San Pablo Bay. Annual landings gradually increased over the next two decades and peaked at 3.4 million pounds in 1935. A steady decline then began in response to a decline in demand for fresh and dried shrimp as food. In the early 1960's, annual landings averaged about 1,500 pounds, and in 1964 no shrimp were landed.



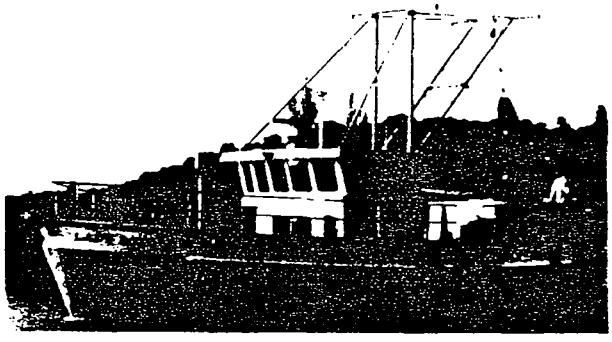
California commercial landings of bay shrimp, 1916-1969.



California commercial landings of bay shrimp, 1970-1991.

In 1965, a new fishery developed to supply bay shrimp as live bait for sturgeon and striped bass sport fishing. Since then, the commercial harvest has been entirely by beam trawl. Annual landings exceeded 100,000 pounds in 1980 and since then have averaged 142,000 pounds. A small percentage of the catch is still consumed fresh as food.

In 1990, 14 vessels participated in the bay shrimp fishery. Most boats are between 25 and 40 feet long. The shrimp trawls are spread by either a wooden or galvanized steel pole. Nets are 20 to 25 feet wide with a mesh of 7/8 to one inch in the cod end. Live tanks are used on all vessels, and shrimp are transported to local bait shops by truck in either live tanks or iced-down wooden trays with burlap lining.



Vessel using beam trawl to harvest bay shrimp in San Pablo Bay.

Primary fishing locations are southern San Francisco Bay, including Coyote Creek and Redwood Creek, northern San Pablo Bay, and Carquinez Strait. There is relatively little movement between northern and southern shrimping grounds by fishermen. Fishing generally occurs in waters less than 20 feet deep in the channels of the estuary's shallow reaches.

Regulation changes in the 1980's eliminated fishing in most of Suisun Bay due to the high incidental catch and associated mortality of small striped bass in shrimp trawls. No quota or season closure is in effect for the commercial fishery, and landings are influenced primarily by demand. Sport regulations allow the use of hand-powered shrimp trawls no greater than 18 by 24 inches at the mouth and a daily bag limit of five pounds.

Status of Biological Knowledge

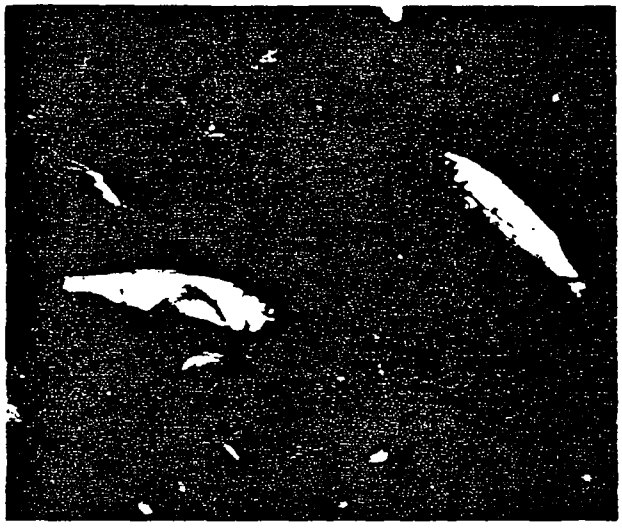
Bay shrimp, also known as grass shrimp, are actually an aggregate of four species. The primary component of the commercial landings is the California bay shrimp (*Crangon franciscorum*). Although it ranges from southeast Alaska to San Diego to a depth of 180 feet, it is found primarily in estuaries and enclosed bays. The blacktail bay shrimp (*C. nigricauda*) ranges from Alaska to Baja California to a depth of 200 feet and is common in bays and estuaries. The blackspotted bay shrimp (*C. nigromaculata*) is a very minor component of the catch in San Francisco Bay. It ranges from the Gulf of the Farallones to Baja California at depths of 10 to 100 feet and is uncommon in estuaries. The fourth species, the oriental shrimp (*Palaemon macrodactylus*), has become an increasingly large component of the catch since its accidental introduction into San Francisco Bay.

Fishermen have long known that shrimp migrate within the estuary. Bay shrimp larvae hatch in high salinity waters, including the lower portions of San Francisco Bay and the nearshore ocean area, in winter and spring. Small, post-larval shrimp migrate into the bay and upstream to the brackish-water nursery area in spring and early summer. In late spring and summer, most commercially-caught shrimp are small (1.0 to 1.5 inches) as large numbers of juvenile shrimp enter the fishing

SMB-26749

grounds. In fall and winter, large adults are the primary component of the catch, and during this time they begin their downstream migration.

California bay shrimp reach a total length of about 3.0 inches, while the blacktail and blackspotted bay shrimps rarely exceed 2.0 inches. In all three species of bay shrimp, females grow more quickly and reach a larger size than males. Maximum length of the oriental shrimp is just over 2.5 inches.



Catch of bay shrimp with bycatch of a few small sculpin and striped bass.

California bay shrimp tolerate a wide range of salinity and temperature, and juveniles may be found throughout the estuary where salinity is greater than one part per thousand. Blacktail bay shrimp prefer higher salinity and lower temperature and generally occur where salinity exceeds 15 parts per thousand and temperature is less than 68° F. The blackspotted bay shrimp prefers even higher salinity waters and in the San Francisco Bay estuary is limited to the area downstream of central San Pablo Bay. All three species occur in the ocean, but the California bay shrimp is uncommon there. The oriental shrimp prefers more brackish water than the above species and is most common in the extreme southern portion of San Francisco Bay, northern San Pablo Bay, and the areas upstream of San Pablo Bay. It occurs more frequently where salinity is less than 10 parts per thousand.

Although egg-bearing California and blacktail bay shrimp may be found throughout the year, the main egg-bearing season for the California bay shrimp extends from December to May. For ovigerous blacktail bay shrimp there are two peaks of abundance, spring-summer and fall. In years with high freshwater inflow to the estuary, the majority of the reproductive population of California bay shrimp migrates out of the bay. Egg-bearing oriental shrimp occur from March to September in the bay.

Bay shrimp are an important component in the diets of nearshore and estuarine fishes. Twenty-four predator species have been identified in the San Francisco Bay estuary and 20 in the adjacent ocean environment. Major predators include green and white sturgeon, striped bass, leopard shark, brown smoothhound, big skate, white croaker, staghorn sculpin, starry flounder, English sole, pile and rubberlip surfperch, Pacific tomcod and brown rockfish. Bay shrimps and the oriental shrimp are opportunistic feeders, consuming a wide variety of organisms such as bivalves, polychaetes, amphipods, mysids, copepods, crustacean larvae, fish larvae and insects, as well as animal detritus and plant material.

Status of Populations

The absolute abundance of bay shrimp has not been estimated. However, relative abundance indices during the past decade have shown population changes of a factor of ten. The abundance of California bay shrimp increases with increased river inflow to the estuary, probably because of the increased low-salinity habitat for the rearing of juveniles. Abundance of blacktail bay shrimp has increased recently during a series of years with lower river inflow, although it has not replaced California bay shrimp in abundance. Given the short life cycle of bay shrimp (1.5 to 2.5 years) and the relatively low level of the present harvest compared with the sustained high level of the 1930's, it is unlikely that the bait fishery is negatively impacting the biomass of bay shrimp in the San Francisco Bay estuary. However, the current overall abundance of the bay shrimps may be lower due to loss of, or change in, habitat during the last 60 years.

Paul N. Reilly
California Department of Fish and Game

References

Bonnot, P. 1932. The California shrimp industry. Calif. Div. Fish and Game, Fish Bull. 38. 20 p.

Brienes, M. 1983. China Camp and the San Francisco Bay shrimp fishery. Calif. Dept. Parks and Recreation, Sacramento. 154 p.

Israel, H.R. 1936. A contribution toward the life history of two California shrimps, *Crago franciscorum* (Stimpson) and *Crago nigricauda* (Stimpson). Calif. Div. Fish and Game, Fish Bull. 46. 28 p.

Siegfried, C.A. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest). Crangonid Shrimp. Fish and Wildlife Service Biol. Rep. 82(11.125). 18 p.

Skinner, J.E. 1962. Historical review of the resources of the San Francisco Bay area. Calif. Dept. Fish and Game, Water Proj. Br. Rept. (1):1-225.

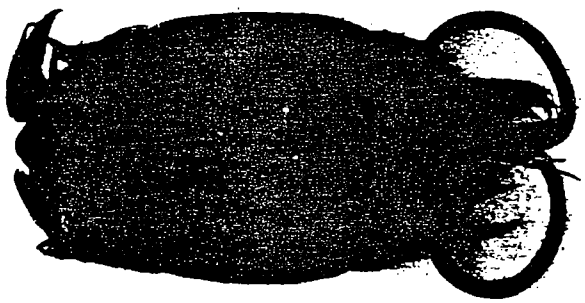
SAND CRAB

History of the Fishery

The first complete commercial catch records for sand crabs (*Emerita analoga*) were collected in 1963, when 4,673 pounds were landed. By 1967, landings totaled over 8,300 pounds of sand crabs worth $17,152 to the fishermen. Since 1977, catch records indicate a greatly reduced utilization of sand crabs for bait. This is probably due to reduced effort directed at harvesting them and replacement of sand crabs with other baits such as ghost shrimp, clams and mussels.

SMB-26750

Sand crabs are collected in a wire mesh net measuring 30 to 36 inches in width. Mesh size varies from .25 to 0.5 inch. The fisherman wades into the surf and places the net on the bottom as a wave begins to recede. The backwash carries the sand crabs into the net, from which they are removed and placed in a container held on a belt around the fisherman's waist. Usually only "soft shelled" crabs (those that have molted recently) are saved. These are sold, and priced, by the dozen. Size varies widely, depending on season and location where the crabs are caught. Though price per dozen has remained quite constant, price per pound varies with the size of the crabs. When only small sand crabs are available, the price per dozen may drop. Demand for sand crabs remains high through the winter months because of the presence of barred surfperch along the coast. The demand is increased by frequent perch fishing contests (derbies) sponsored by bait stores. In winter, when soft shelled sand crabs are difficult to find, hard shelled crabs can also be sold. These are usually sold by the gallon. There is a limited but constant market for sand crabs as bait.



Sand crab, *Emerita analoga*.

Status of Biological Knowledge

The sand crab occurs from British Columbia to Panama. Although found on nearly all open-coast sandy beaches, there are gaps in this range where no sand crabs can be found.

When feeding, sand crabs burrow tail-first into the sand leaving only the tip of their heads and the large feathery antennae protruding. The antennae are extended into the backwash of a receding wave and strain food particles from the water. Food particles are transferred to the mouth by wiping the antennae through the mouth parts. It is the extended antennae which produce characteristic V-shaped ripple marks on the beach that indicate the presence of sand crabs.

Mating occurs mostly in spring and summer, but some mating and egg-bearing females are seen year-round. Females are larger than males, reaching 1.5 to two inches in length; males seldom exceed .75 inch in length. A two-inch female may produce 11,000 eggs. The number of eggs varies with the size of the animal as well as with temperature and food availability. The eggs are carried on the female's abdomen (pleopods) until hatched. The young pass through five larval stages before they resemble adults. The various larval stages drift at the mercy of the currents and may be carried for long distances. Shifting currents, which carry the larvae "off course," account for population fluctuations on a given beach. In southern California the megalops larvae arrive on the beach in the greatest numbers from May to July. Sand crabs reproduce during their first year of life and may not live more than two or three years. Sand crabs that settle in suboptimal habitat may not survive their first winter.

Many animals eat sand crabs, including surf fish, such as corbina, croakers and barred surfperch, and many shore birds. For this reason, they make excellent bait for sport fish, especially for fishing from sandy beaches. They also make good bait when fishing from rocky shores or breakwaters for opaleye.

Status of Population

The reported harvest in 1967 was 8,303 pounds or about two million sand crabs. Most of the catch came from about 20 miles of beach in the southern part of the state. California has over 200 miles of sandy beaches, and the total population of sand crabs, while undetermined, is extensive. Since only the recently-molted soft shelled sand crabs are usually taken and the hard shelled crabs are returned, there is little danger of overfishing. A high market demand for hard shell crabs, however, perhaps for purposes other than bait, could result in a fishery that would be detrimental to the population. Though extensive in range, sand crabs are vulnerable to capture because of their habit of forming dense aggregations, especially at night, frequently near piers and jetties. Although population sizes are not well known and the number of sand crabs on any given beach may fluctuate from year to year, the resource appears to be in good condition.

Kevin Herbinson
Southern California Edison

References

Cubit, J. 1969. Behavior and physical factors causing migration and aggregation of the sand crab *Emerita analoga* (Stimpson). Ecology 50:118-23.

Dillery, D. G., and L. V. Knapp. 1977. Longshore movements of the sand crab, *Emerita analoga* (Decapoda, Hippidae). Crustaceana 18:233-40.

Efford, Ian E. 1970. Recruitment to sedentary marine populations as exemplified by the sand crab, *Emerita analoga* (Decapoda, Hippidae) Crustaceana 18:293-308.

Fusaro, C. 1978. Growth rate of sand crabs, *Emerita analoga* (Hippidae), in two different environments. Fish. Bull. 76:369-75.

DUNGENESS CRAB

History of the Fishery

SMB-26751

Dungeness crabs (*Cancer magister*), also known as market crabs or edible crabs, were first taken commercially off San Francisco in about 1848. The fishery blossomed early, and now the harvest of this important marine resource occurs from Avila

to the Oregon border. Before the 1944-1945 season, the fishery was centered around San Francisco and the average annual statewide production was 2.6 million pounds. The fishery expanded into the Eureka-Crescent City area as World War II ended. In the early 1940's, crab traps replaced the hoop net, leading to significantly increased landings with strong contributions from northern California. Average annual statewide production since the 1945-1946 season has been 9.9 million pounds.

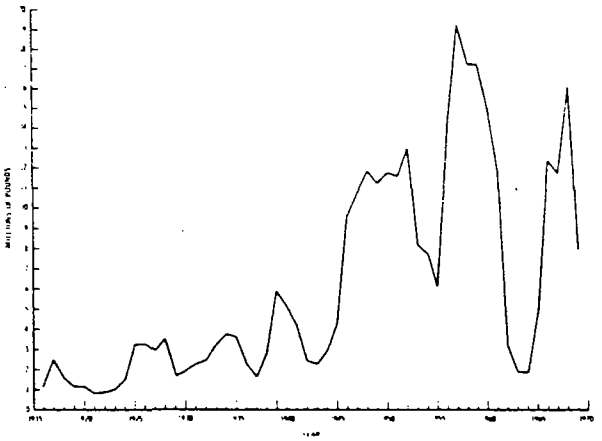
A small fishery developed in the Morro Bay-Avila area in 1947 and production there peaked at 434,000 pounds in the 1950-1951 season. Landings were good through the 1950's, declined sharply in the 1961-1962 season, and have remained at low levels since.

The small fishery around Monterey reached its peak before 1945, continued on a small scale through the 1950's, and in 1961-1962 followed the same downward pattern as Morro Bay. Landings reached a low of 300 pounds in 1971-1972 and have never recovered.

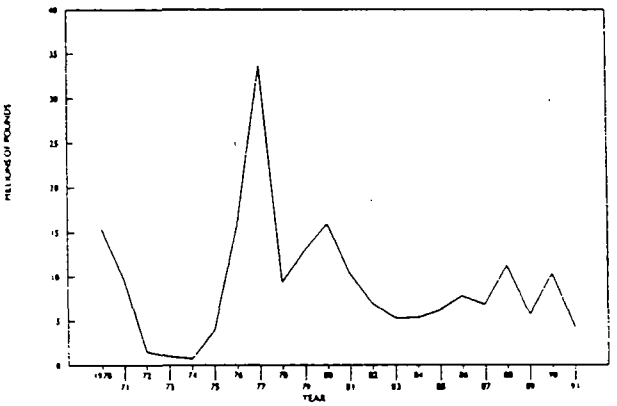
San Francisco landings were relatively stable from 1945-1946 to 1955-1956, and peaked at 8.4 million pounds in the 1956-1957 season. The fishery then declined at a rate of more than one million pounds per season until 1961-1962, when only 710,000 pounds were landed. Subsequent seasonal landings have averaged less than one million pounds, although 3.1 million pounds were landed in 1987-1988.

Unloading a day's catch of Dungeness crabs at Fishermen's Wharf in San Francisco.

The Eureka-Crescent City fishery increased substantially after 1945. Landings reached a peak in the late 1950's but, unlike other areas which peaked and then experienced sustained low levels, the north coast exhibited 10-year cyclic patterns of production. Six-year periods of good landings as high as 25.6 million pounds were followed by four years of poor landings as low as 350,000 pounds. This pattern changed in 1982-1983 with eight successive seasons averaging only five million pounds. The catch jumped to about 10 million pounds in 1990-1991, valued at more than 15 million dollars.



California commercial landings of Dungeness crab, 1916-1969.



California commercial landings of Dungeness crab, 1970-1991.

The commercial fishery for crabs occurs in two areas, northern and central California, with separate seasons for each. The seasons are established to allow harvesting only when crabs are in prime condition for the market. Other restrictions include no commercial harvest of female crabs and a minimum size limit on the males of 6.25 inches across the back.

The dividing line between the northern and central California areas is the Mendocino-Sonoma county line. The central California season opens the second Tuesday of November and continues through June 30. The opening and closing are two to three weeks earlier than the northern season, because crabs in central California molt earlier and reach prime condition sooner than in the north. Fishing areas include Avila-Morro Bay, Monterey, and San Francisco-Bodega Bay. The Morro Bay and Monterey fisheries have been of minor importance; the combined fleet for these two areas consisted of 35 to 40 boats during the 1950's but is now minimal.

The San Francisco region is the major production area for central California. The fishery utilizes an area of over 400 square miles, including the Gulf of the Farallones north to the Russian River. The fleet consisted of 200 to 230 boats during the 1950's. When the fishery declined in the 1960's, a reduction in the number of boats followed and the fleet now consists of about 100 vessels. The central California crab fleet has evolved from

SMB-26752

but still includes, the old "Monterey" style vessel. Larger multiple purpose vessels are now the norm.

The season in the northern California area (Mendocino-Sonoma county line to the Oregon border) is from December 1 to July 15. Although December 15 may be a more desirable opening date with respect to crab quality, fishermen believe that the opening date should coincide with Oregon's opening, which has been December 1 for many years.

The northern California fishing grounds are over twice the size of those in central California. They extend from Fort Bragg to the Oregon border with the prime area between Eureka and Crescent City. The northern California fleet fluctuated between 100 and 200 vessels in the 1950's and 1960's, dropped to a low of 61 in 1973-1974, then peaked at 410 during 1976-1977. Since then, effort has been high, averaging 330 vessels per season. Before the mid-1970's, most vessels were converted salmon trollers 30 to 60 feet in length; however, the complexion of the fleet changed during the record production years of the 1970's. Vessels ranging in size from 22-foot dories to otter trawlers in excess of 100 feet entered the fishery. There was also an increase in the number of traps per boat, averaging 200 but ranging up to 1,000 traps on some large vessels. Before 1980-1981, crab landings were normally spread throughout the season. Now, 80 percent of total landings are made in December because of increased effort and the ability of many vessels to fish during day and night, even in heavy seas.

Commercial gear for Dungeness crab is essentially the same throughout California. It consists of a circular steel trap three to 3.5 feet in diameter weighing 60 to 120 pounds. Each trap is required to have two 4.25-inch openings to allow small crabs to escape, and must possess a destruction device which allows crabs to escape should the trap be lost. The trap rests on the bottom and each is buoyed independently to the surface. Traps are left overnight or longer depending on fishing conditions.

Incidental catches of crabs are landed by otter trawlers. While these vessels are allowed 500 pounds per trip during the regular season, only a few thousand pounds of trawl-caught crabs are landed annually.

Dungeness crab, *Cancer magister*.

Depending on crab condition, the amount of meat ranges from 20 to 28 percent of the total weight of the animal. Because crab is highly perishable, it must be cooked while alive, then kept refrigerated. Approximately 75 percent of the catch is sold as whole crab (fresh or frozen) and the remainder is picked and vacuum packed.

There is limited sport use of Dungeness crabs in central and northern California. The sport size limit is 5.75 inches across the back, and a limit of 10 crabs of either sex may be possessed. The annual sport harvest is less than one percent of the commercial take.

Status of Biological Knowledge

Dungeness crabs range from the eastern Aleutian Islands, Alaska to perhaps Santa Barbara; however the species is considered rare south of Point Conception. Earlier reports from Magdalena Bay, Baja California, are now thought to be in error. Temperature apparently determines the distribution, and the 38-65° F surface isotherms are considered the limits of the range. The geographic range is probably more dependent upon the temperature tolerance of the larvae than of the adults. Optimal temperatures for larvae are 50-57° F.

This species has a preference for sandy to sandy-mud bottoms but may be found on almost any bottom type. Dungeness crabs may range from the intertidal zone to a depth of at least 750 feet, but are not abundant beyond 300 feet.

The resource off California has been demonstrated by tagging experiments to consist of five subpopulations: one each in the areas around Avila-Morro Bay, Monterey, San Francisco, Fort Bragg, and Eureka-Crescent City. Only the latter three are of commercial importance. California Department of Fish and Game surveys indicate the combined San Francisco and Fort Bragg populations are not as large as the population extending from Eureka into Oregon. Little or no intermixing occurs.

Tagging studies have also demonstrated random movement by both sexes. At times an inshore or offshore migration is observed, but most movement is restricted to less than 10 miles; travel up to 100 miles has been noted, however.

Mating occurs from March through July. Male crabs are able to sense when a female is about to molt. The male carries the female in a protective embrace for several days until she molts, then mates with the freshly molted, soft-shell female. Sperm deposited in the female may remain viable for up to 2.5 years. Eggs are spawned between October and December and are carried beneath the abdominal flap of the female. The number of eggs is dependent upon the size of the female. The smallest individuals will carry about 500,000 eggs and the largest from 1.5 to 2.0 million. There is evidence, however, that freshly molted females carry larger numbers of eggs than do gravid females which have missed a molt. The eggs range in diameter from 0.016 to 0.024 inches and are bright orange after extrusion, becoming progressively darker as they develop. Hatching occurs between November and February.

The newly hatched larvae pass through five zoeal and one megalops stage before metamorphosing into the adult form. Larval development is inversely related to water temperature, and in central California 105 to 125 days are required to complete the larval stages. Zoeae are hypothesized to have an offshore movement regulated by factors such as depth, temperature, salinity and ocean currents. They are found near the

SMB-26753

surface at night and as deep as 80 feet in daytime. Megalopae are transported to nearshore waters beginning in April. Metamorphosis occurs from April to June. Estuarine areas such as Humboldt Bay and San Francisco Bay are important nursery areas for young Dungeness crabs.

Growth is accomplished in steps through a series of molts. In northern California, Dungeness crabs of both sexes molt an average of six times during their first year and attain an average width of one inch. Six more molts are required to reach sexual maturity at the end of their second year, when they are approximately four inches across. Once maturity is reached, growth of the females becomes slower. Male crabs usually molt twice during their third year and once per year thereafter. The average size of males three, four and five years of age is six, seven and eight inches, respectively. Males may undergo a total of 16 molts during a lifetime, reaching a maximum size of nine inches and age of six years. A small fraction of females reach sizes exceeding the legal size limit for males.

Dungeness crabs are opportunistic feeders not limited by abundance or scarcity of a particular prey. Clams, fish, isopods and amphipods are preferred, and cannibalism is prevalent among all age groups.

Predators on the various life stages of Dungeness crabs include octopuses, larger crabs and as many as 28 species of fish, including coho and chinook salmon, flatfishes, lingcod, cabezon and various rockfishes.

Status of Population

Few total population estimates have been made; however, commercial landings have been used as a relative indicator of population size. Bay and ocean surveys conducted by the California Department of Fish and Game have shown that year-class strength of Dungeness crabs can fluctuate dramatically from year to year. Annual commercial fishing mortality of legal male crabs is thought to be as high as 87 percent, but during years of high abundance a significant carry-over to the following season can occur.

The general status of the subpopulations is known, but total size is not. The Eureka-Crescent City area supports the major population, accounting for as much as 95 percent of the statewide catch. A very small population exists in the vicinity of Fort Bragg, but most of the crabs landed there are caught off the Eureka coast. Landing trends in northern California indicate a healthy resource.

Central California stocks have remained at low levels of abundance since the decline of the fishery in the early 1960's. Causes for the decline are not known but have been the subject of considerable research into such factors as the effects of changes in oceanographic climate on crab eggs and larvae, the role of nemertean worm predation on crab eggs, and the effects of pollution in San Francisco Bay on juvenile crabs.

Ronald W. Warner
California Department of Fish and Game

References

Melteff, B.R. (coordinator). 1985. Proceedings of the symposium on Dungeness crab biology and management. University of Alaska Sea Grant Report 85-3. 424 p.

Pacific Marine Fisheries Commission. 1978. Dungeness crab project of the state-federal fisheries management program. 196 p.

Pauley, G.P. et al. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates. (Pacific Northwest). U.S. Dept. of the Interior, Fish and Wildlife Service. Biol. Rep. 82. 20 p.

Snow, C.D. and J.R. Neilsen. 1966. Premating and mating behavior of the Dungeness crab (*Cancer magister* Dana). J. Fish. Res. Board Can. 23:1319-1323.

Wild, P.W. and R.N. Tasto (eds.). 1983. Life history, environment and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Dept. Fish and Game, Fish Bull. 172. 352 p.

ROCK CRABS

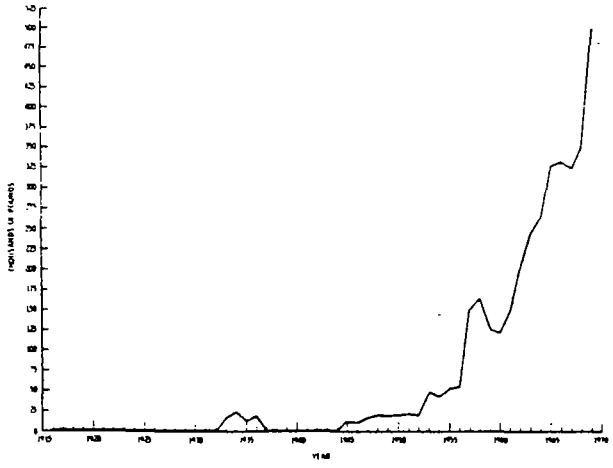
History of the Fishery

Rock crabs are fished along the entire California coast. The catch is made up of three species: the yellow rock crab (*Cancer anthonyi*), the brown rock crab (*C. antennarius*), and the red rock crab (*C. productus*). The commercial fishery is most important in southern California (from Morro Bay south), which produces 95 percent of the landings, and of lesser importance in northern areas (Monterey and Halfmoon Bay produce four percent), where a fishery for the more desirable Dungeness crab takes place. A major recreational fishery has not developed, but recreational crabbing is popular in many areas and is often conducted in conjunction with other fishing activities.

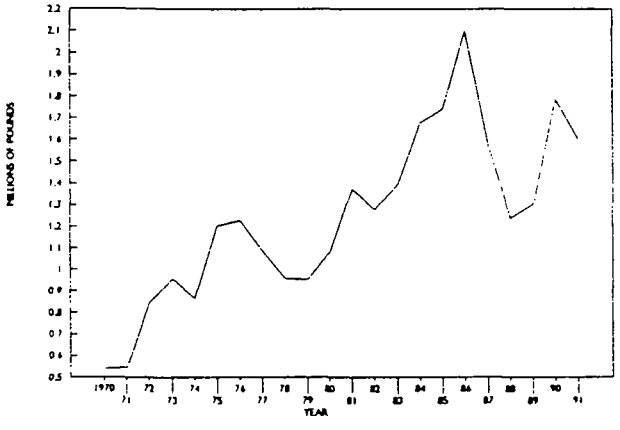
In 1950, a separate reporting category for commercial rock crab landings was established. Since then, landings have risen from 20,000 pounds to over two million pounds in 1986. Landings increased by 10 percent per year from 1957 to 1971, jumped by nearly 50 percent in 1972, and continued a steady increase to two million pounds in 1986. Prior to 1987, a portion of the landings was calculated whole-crab weights based on landings of claws only. Since then, whole crabs and claws have been reported separately, and whole crab landings have shown a commensurate decline. Rock crab landings for 1990 were 1.8 million pounds, including the landings of claws converted to whole weight.

Commercial crabbing has expanded from nearshore areas around major ports such as San Diego, San Pedro, Santa Barbara, and Morro Bay to more distant mainland areas and the Channel Islands. Most rock crabs are landed alive for retail sale by fresh fish markets. Often the crabs are cooked and eaten on site and, depending on the tastes of the consumer, muscle tissue, as well as other organs (ovaries in particular) are consumed. Rock crab meat has not been successfully marketed when frozen or canned. During 1990, ex-vessel prices for whole rock crabs averaged about $1.00 per pound, while claws brought $1.25 to $1.50 per pound.

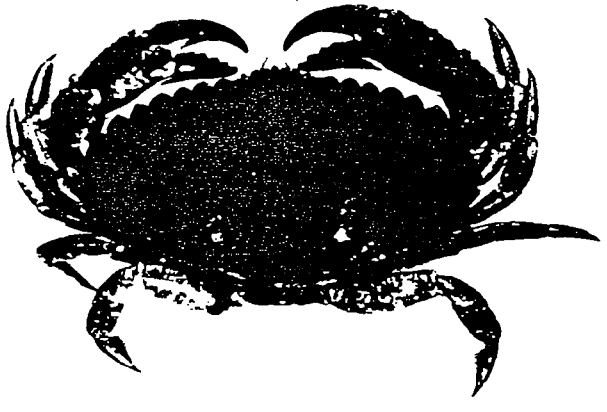
SMB-26754



California commercial landings of rock crab, 1916-1969.

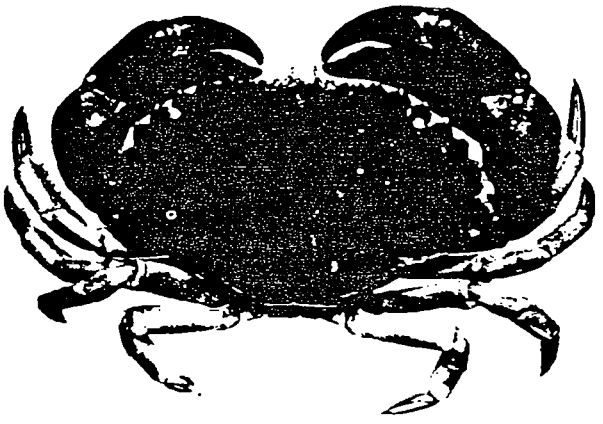


California commercial landings of rock crab, 1970-1991.



Red rock crab, *Cancer productus*.

Several trap designs and materials are used in the rock crab fishery. The most popular are single chamber, rectangular traps of 2x4- or 2x2-inch welded wire mesh. Several types of molded plastic traps are used by some because the traps are collapsible or nest together on a boat deck. Traps are set and buoyed singly



Brown rock crab, *Cancer antennarius*.

or, perhaps, in pairs if loss to vessel traffic is a concern. Most trapping occurs in depths of 90 to 240 feet on open sandy bottom or near rocky reef-type substrate. Two hundred or more traps may be fished by one boat, with a portion pulled up and emptied each day. Traps are usually "soaked" for 48 to 96 hours prior to pulling. Commercial crab boats are usually small, ranging from skiffs to vessels of 40 feet or more.

Recreational gear ranges from a diver's or shore picker's hand to baited hoop nets or collapsible star traps fished from piers, jetties, and boats. Most of this effort takes place along the shallow nearshore open coast and in bays.

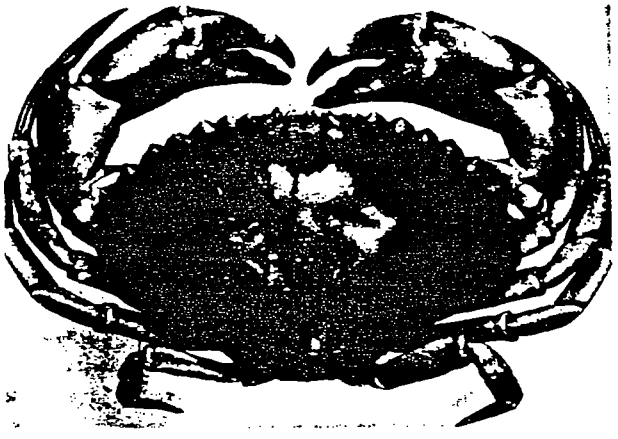
Commercial regulations have been enacted to protect crabs below reproductive size. Present regulations require a minimum harvest size of 4.25 inches carapace width and escape rings measuring 3.5-inches in diameter in each trap. Due to the multi-species nature of the fishery, the minimum size was chosen to accommodate the different characteristics of the three rock crab species. The recreational take is controlled by a four inch minimum carapace width and a personal bag limit of 35 crabs per day.

Status of Biological Knowledge

Yellow rock crabs range from Humboldt Bay into southern Baja California, brown rock crabs from northern Washington to central Baja California, and red rock crabs from Kodiak Island to Central Baja California. All three species inhabit waters from the low intertidal zone down to depths of 300 feet or more. Although these species may occur together throughout much of their range, yellow rock crabs are most abundant in southern California, brown rock crabs in central California, and red rock crabs in northern California. Yellow rock crabs prefer open sand or soft bottom habitat, while brown and red rock crabs prefer rocky or reef-type substrate.

Rock crabs, like other crustaceans, grow in a step-wise fashion with each molt of the external shell. Yellow and brown rock crabs molt 10 to 12 times before reaching sexual maturity at about three inches carapace width. Crabs of this size may molt twice a year, while crabs as large as six inches carapace width or more may molt once a year or less. Growth per molt, as

a percentage of size, decreases as the crab increases in size and age. Males of all three species attain sizes 10 to 15 percent larger than females. Yellow rock crabs grow to exceed seven inches in carapace width, brown rock crabs 6.5 inches, and red rock crabs eight inches. While the longevity of rock crabs is not well known, many crabs may reach five or six years of age.



Yellow rock crab, *Cancer anthonyi*.

Mating takes place after the females molt and are still in the soft shell condition. In southern California, mating is most common in the spring, but occurs throughout the year. About three months after mating, the eggs are laid, then fertilized from a sperm packet left by the male during mating. The developing eggs are carried in a mass under the abdomen of the female. Depending on size and species, nearly four million eggs may be carried by a female rock crab. After six to eight weeks, the eggs hatch into planktonic larvae which undergo seven developmental molts before settling to the bottom as juveniles.

Rock crabs are both predators and scavengers, feeding on a variety of other invertebrates. Strong crushing claws allow them to prey on heavily shelled animals such as snails, clams, abalone, barnacles, and oysters. The olfactory sense of crabs is well developed and allows them to detect and locate food at a distance.

Rock crabs, especially juveniles, are preyed upon by a variety of other marine organisms. Fishes such as cabezon, barred sand bass and several species of rockfish are known to feed on rock crabs. Important invertebrate predators include the octopus and certain sea stars. As rock crabs grow larger, they become less susceptible to predators except during the soft-shell post-molt period; however, the sea otter is one animal which is an effective predator on large rock crabs.

Rock crabs do not appear to migrate or to undertake large-scale movements. Tagged adults have moved several miles, but no pattern was apparent. Some local movements also may occur in relation to mating or molting. Egg-bearing yellow rock crabs are known to congregate in rock-sand interface habitats.

Status of Populations

Information is not available on stock sizes, recruitment and mortality rates, or potential yield of rock crab populations. The commercial fishery, however, has had a localized effect on crab abundance and size. Fishing areas intensively exploited over an extended period show a lower catch per trap and a reduced size-frequency distribution compared to lightly exploited areas. In Santa Monica Bay, an area closed to commercial crab fishing for decades, experimental catch rates were higher, crab sizes larger and size-frequencies broader than in adjacent areas. Future research should be aimed at a better understanding of fishery-related rock crab population parameters.

David Parker
California Department of Fish and Game

References

Carroll, J.S. 1982. Seasonal abundance, size composition, and growth of rock crab, *Cancer antennarius* Stimpson, off central California. J. Crust. Biol. 2:529-561.

Carroll, J.C. and R.N. Winn. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)—brown rock crab, red rock crab, and yellow crab. U.S. Fish Wild. Serv. Biol. Rep 82 (11.117). U.S. Army Corps of Engineers, TR EL-82-4. 16p.

Reilly, P.N. 1987. Population studies of rock crab, *Cancer antennarius*, yellow crab *Cancer anthonyi*, and Kellet's whelk, *Kelletia kelletii*, in the vicinity of Little Cojo Bay, Santa Barbara County, California. Calif. Fish and Game. 73:88-98.

Winn, R.N. 1985. Comparative ecology of three cancrid crab species (*Cancer anthonyi*, *C. antennarius and C. productus*) in marine subtidal habitats in southern California. Ph.D. dissertation. University of Southern California, Los Angeles. 235 p.

SHEEP CRAB

History of the Fishery

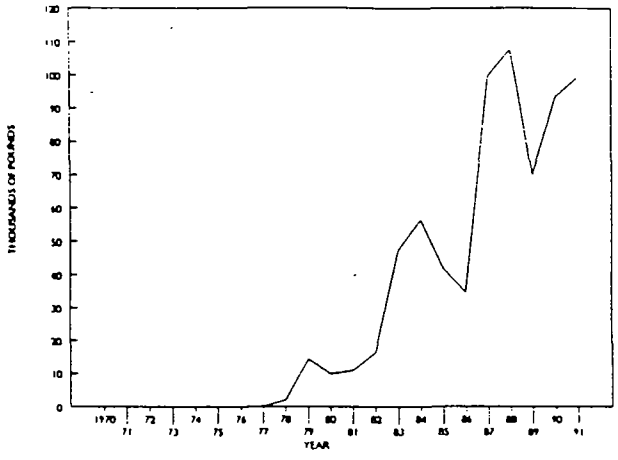
Until 1984, the sheep crab (*Loxorhynchus grandis*) was of little commercial or recreational value. Before that, they were occasionally landed as by-catch and were also taken by some recreational divers. Santa Barbara fishermen and processors began to experiment with marketing them and by 1984 30,000 to 40,000 pounds of whole crabs were landed. The fishery for this underutilized species expanded rapidly, stimulated by development of a market for claws. The fishery peaked in 1988 with landings of 107,609 pounds of live crabs and 385,886 pounds of claws (combination of sheep and rock crab claws). The sheep crab is the only fishery in the United States with sizable landings of both claws and whole crabs.

The California sheep crab fishery is centered in the Santa Barbara Channel and around the northern Channel Islands. The bulk of the landings are in Santa Barbara and Ventura counties. The fishery primarily operates over sandy bottom, where gear is set in shallow waters (30-70 feet) in spring and summer and then moved to deeper waters (120-240 feet) in fall and winter months.

Because of the heavily calcified carapace of the crab, processing the body meat is presently uneconomical. Alternatively, processors accept only the claws, while whole crabs

SMB-26756

continue to be used in live fish markets. Crab and lobster trap fishermen supply the bulk of live crabs. Halibut and angel shark gill netters contribute substantially to the claw market, usually killing the crab in the claw removal process.



California commercial landings of sheep (spider) crab, 1970-1991.

The retail value of the combined catch is about $1.9 million per year, with claws being sold for $5.75 per pound and whole crabs going for $3.00 per pound live and $4.25 per pound cooked in 1990. Claw landings and value far exceed those of the whole body fishery. Since fishermen generally have to establish their own live markets and have to be able to hold the crabs alive for periods of up to a week or more, only a few fishermen have targeted the whole body market.

Trappers fishing for sheep crabs use modified rock crab or lobster traps with an enlarged funnel. This permits entry of large adult male crabs as well as smaller adult female crabs. Sheep crabs were a nuisance to gill net fishermen because they become tangled in the gear and their removal from the nets is time consuming, usually resulting in damage to the animals. Since the development of the claw fishery, however, the crabs have become a valuable resource for gill netters. Claws are not taken from females, as only claws of adult male crabs reach marketable size. Prior to 1991, rock crab and spider crab claw landings were combined in the landings data. In 1991, a size limit went into effect for rock crabs, and fishermen were prohibited from taking any "part" of those crabs. The loss of supply of rock crab claws may increase demand for sheep crab claws.

Current landing patterns are expected to change due to a 1990 California state initiative which will ban the use of gill nets in shallow water by 1994. It is uncertain if claw landings will continue once the gill nets are completely phased out. New marketing efforts may help to further develop the live market, which uses the whole crab. In either event, there seems to be interest and demand for the continued expansion of the California sheep crab fishery.

Status of Biological Knowledge

Sheep crab is the common name of one member of a family of crabs (Majidae), which collectively are often called spider crabs. Consequently, the sheep crab is often called a spider crab. They range from Cordell Bank (Marin County) south to Cape Thurloe, Baja California, in water depths of 20 to 410 feet. It is not known whether the entire resource consists of just one or of a number of different populations. Sheep crabs appear to be most abundant off southern California.

Longevity is currently unknown, but many adults appear to be at least four years old. In contrast to most other commercially important crustaceans, most majid crabs are believed to cease molting upon reaching maturity. Studies of molt staging, limb regeneration and molting frequency support the existence of a terminal molt in sheep crab. After this molt, crabs do not increase in size nor do they regenerate limbs. This phenomenon is an important biological characteristic that may require development of a management scheme different from those of other California crab fisheries.

Maturation is defined only in morphometric terms. At maturity the relative width of the abdomen of females and the length of the claw of males increase markedly when compared to a standard measure of body size such as carapace length. Females become morphometrically mature between 4.2 and 6.8 inches carapace length (from margin of orbit). Adult males range in size from 4.2 to 9.6 inches. However, morphometrically juvenile male crabs can reach a length of 6.8 inches; thus, size alone is insufficient to determine maturity. The presence of a gap in the serrated gape of the claw of adult male crabs distinguishes them from juvenile males. It is uncertain how morphometric maturity relates to physiological and behavioral maturity.

Sheep crab, *Loxorhynchus grandis*.

The abundance of berried females peaks in late spring and remains high throughout the summer, although they can be

found throughout the year. Adult females are able to mate when soft or hard shelled. Sperm storage allows for multiple broods to be oviposited even in the absence of males. Egg numbers probably increase with size of brooding female crabs. Small broods contain 125,000 eggs, whereas large broods can have as many as 500,000 eggs. Laboratory observations suggest that sheep crabs feed on a variety of prey. They readily eat dead fish, crushed mussels and kelp. Cannibalism of newly molted animals occurs in the laboratory when crabs are not well fed. No observations are available on foraging behavior in nature, nor have gut contents been analyzed.

Predatory interactions have not been observed in the field either, but it is likely that small crabs are preyed upon by cabezon, sheephead, octopus, sharks and rays. Small sheep crabs disguise themselves by decorating their carapace with algae, sponges or other encrusting materials. Large crabs probably have few predators.

Two parasitic infections could potentially impact recruitment: an undescribed species of nemertean or ribbon worm and a rhizocephalan barnacle. The former consumes the developing embryo in the egg. The latter eliminates reproductive output and also inhibits growth of the crab. Preliminary observations indicate that certain areas contain a high prevalence of individuals parasitized by the rhizocephalan and that crabs are infected as juveniles.

Male crabs winter in deep water. Both sexes migrate onshore in early spring, and piles of adult females have been observed in spring and summer. Large adult males have been seen on the perimeter of these aggregations. The biological significance of the piles is unknown, but similar phenomena have been reported for other spider crabs.

Status of Population

The abundance of sheep crabs is unknown. Although this spider crab has been a by-catch for many years, there is no evidence of declining populations in the Santa Barbara Channel where most fishing takes place. Furthermore, abundant populations have been reported off Los Angeles and San Diego. If this fishery, which is presently unregulated, continues to expand, management of the resource may become necessary. Some unique features of the fishery require additional biological information to guide management policies, including its dual nature (whole body and claw markets) and the existence of a terminal molt.

Carolynn S. Culver
University of California
Sea Grant Extension Program

Armand M. Kuris
University of California, Santa Barbara

References

Anonymous. 1983. Guide to underutilized species of California. National Marine Fisheries Service Admin. Rept. T-83-01. 29p.

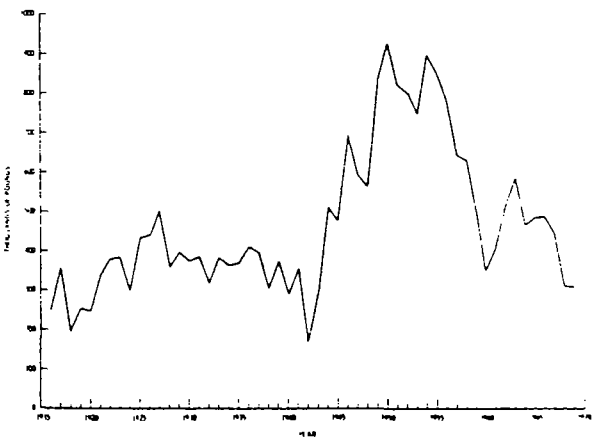
Culver, Carolynn S. 1991. Growth of the spider crab, *Loxorhynchus grandis*. M.A. Thesis, Univ. of Calif. Santa Barbara, California. 101 p.

Pleschner, D.B. 1985. Fish of the Month: Spider Crab. Pacific Fishing Magazine. 8(6): 33-39.

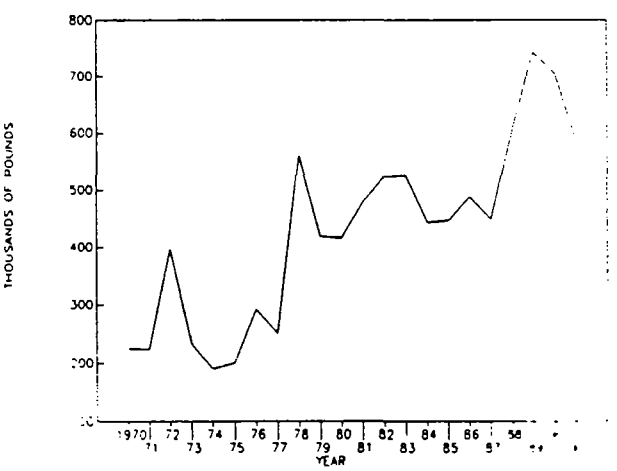
CALIFORNIA SPINY LOBSTER

History of the Fishery

The California spiny lobster (*Panulirus interruptus*) has been the object of a commercial fishery in southern California for over 100 years. Most commercial fishermen use box-like traps constructed of heavy wire mesh to capture spiny lobsters, but traps of other materials such as plastic are allowed. About 100 to 300 traps per fisherman is common, but some fish as many as 500 at the peak of the season. These traps are baited with whole or cut fish and weighted with bricks, cement or steel. They are fished on the sea floor, and each trap is marked with a buoy bearing the fisherman's permit number. High speed boats in the 18- to 30-foot size range are popular in this fishery, but everything from 15-foot skiffs to 50-foot fishing boats are used.



California commercial landings of spiny lobster, 1916-1969.



California commercial landings of spiny lobster, 1970-1991

SMB-26758

Commercial lobster fishing occurs in the rocky coastal areas from Point Conception to the United States-Mexico border and the islands and banks (such as Cortes and Tanner Banks) off southern California. Some marine life refuges and reserves are closed to the take of lobster, as are areas in Santa Monica and Newport Bays and at Santa Catalina Island. Improved loran and sonar equipment is enabling trappers to find lobster habitat in deeper water and relocate their traps there. Some traps have been fished as deep as 350 feet, but 90 percent are fished in waters of less than 90 feet.

From a modest beginning, seasonal landings rose following the second World War and peaked in the 1949-1950 season, when a record 1.1 million pounds were landed. A general decline followed for the next 25 years, reaching a low of 152,000 pounds in the 1974-1975 season. In the 15 seasons since then, landings have increased to 729,000 pounds in 1989-1990, the most recent complete season. During this period, however, landings remained between 400,000 and 500,000 pounds for nine consecutive seasons from 1979-1980 to 1987-1988.

About 90 percent of the legal lobsters taken in the commercial fishery weigh about 1.25 to 2 pounds each, which produces the size of tail desired for restaurant trade. The price paid the fisherman has continued to rise from an average of 70 cents per pound from 1959 to 1965 to around $6.00 per pound at present. An illicit market also exists for "shorts" (undersized lobsters), as shown by citations issued to commercial trappers and others for possession of these animals.

California spiny lobster, *Panulirus interruptus*.

Commercial and recreational lobster fishermen currently are restricted to a minimum size limit of 3 1/4 inches carapace length (CL). The season for both historically has run from early October to mid-March. Beginning in 1992, the sport season will open a few days earlier than the commercial season. Commercial fish traps, including lobster traps, must have a destruct device of a type approved by the Department of Fish and Game. This is to ensure that lost or abandoned traps do not continue to capture marine life indefinitely. Since the 1976-1977 season, it has been required that lobster traps be fitted with rectangular escape ports (2 3/8 by 11 1/2 inches) to minimize the retention of undersize lobsters. This requirement has been credited with reversing the downward trend in landings of legal lobsters which had occurred previous to that season.

Sport anglers need only a valid sport fishing license and may use hoop nets or bare (gloved) hand when skin or scuba diving for lobster. No appliance may be used, although occasionally some sport divers illegally employ a fish spear or a short hooked pole to snag the animals from deep crevices or caves. The daily bag limit for sport fishing is seven lobsters, reduced from 10 in 1971.

Status of Biological Knowledge

The California spiny lobster ranges from Monterey Bay, California, to Manzanillo, Mexico. There is also a small, isolated population of this species at the northwestern end of the Gulf of California. The majority of the population is found between Point Conception, California and Magdalena Bay, Baja California. Adult lobsters usually inhabit rocky areas from the intertidal zone to depths of 240 feet or more.

Mating of spiny lobsters generally occurs from November through May. The male attaches a putty-like packet of sperm to the underside of the female's thorax. When the female extrudes her eggs, they are fertilized by sperm from the packet. Egg extrusion takes place primarily in May and June in water less than 30 feet deep. Females are "berried", carrying the eggs on their tail, for about 10 weeks. The larger the size of the female, the more eggs she produces. Females sampled at San Clemente Island carried between 120,000 (2.6 inches CL) and 680,000 (3.6 inches CL) eggs.

Spiny lobster eggs hatch into tiny, transparent larvae known as phyllosoma that go through 12 molts. They have flattened bodies and spider-like legs and drift with the prevailing currents feeding on other planktonic animals. They may drift offshore out to 350 miles and may be found from the surface to a depth of over 400 feet. After five to nine months, the phyllosoma transform into the puerulus stage and may make a directed return to shallow coastal waters where they settle to the bottom. At this stage, they are still transparent but look like miniature adults. Growth rates are variable but appear to be size and sex dependent. An annual growth rate of 0.15 inch CL has been reported for male spiny lobsters ranging from 2.0 to 3.5 inches CL. For females in the same size range, the annual increase was 0.19 inch CL.

The spiny lobster's shell serves as its skeleton and is referred to as an exoskeleton. To grow, a lobster sheds its exoskeleton. This process is known as molting and is preceded by the formation of a new, soft shell under the old one. An uptake of water expands the new shell before it hardens. Right after a lobster molts, it is very vulnerable to predation and physical damage until its new shell hardens.

Molt rates for the California spiny lobster are assumed to be similar to those of the Japanese spiny lobster. A 0.24-inch CL specimen goes through 20 molts to reach 1.18 inches CL at the end of its first year. Four molts during the second year will take

the carapace length to two inches, and there are three molts in the third year. It takes a lobster from 7 to 11 years to reach a legal size of 3.25 inches CL. After spiny lobsters reach 2.5 inches CL, an annual molt following the reproductive period appears to be the norm. Growth rate or period between molts can be influenced by water conditions as well as by the age, health, and sex of the individual.

Juvenile lobsters usually spend their first two years in nearshore surfgrass beds. Subadults have also been found in shallow rocky crevices and mussel beds. Adult lobsters are found in rocky habitat, although they also will search sandy areas for food. During the day, spiny lobsters usually reside in a crevice or hole dubbed a den. More than one lobster is usually found in a den. At night, the animals leave their dens to search for a wide range of food. Adult lobsters are omnivorous and consume algae and a wide variety of marine invertebrates and fish. Lobsters are eaten by sheephead, cabezon, kelp bass, octopuses, California moray eels, horn sharks, leopard sharks, rockfishes and giant sea bass.

A large portion of the spiny lobster population makes an annual offshore-onshore migration that is stimulated by changes in water temperature. During winter months, male and female lobsters are found offshore at depths of 50 feet and deeper, although individuals of both sexes have also been found in shallow water in winter. In late March, April and May, lobsters move into the warmer onshore waters of 30 feet and less. The higher temperatures onshore shorten the development time for lobster eggs. Nearshore waters also have a more plentiful supply of food. In late September and October, the onshore waters cool and most lobsters move offshore. Winter storms that cause increased wave action in shallow water encourage this movement. Lobsters generally move after dark and in small groups across the sand.

California spiny lobsters of both sexes reach maturity at five or six years and 2.5 inches CL. After maturity, male lobsters grow faster, live longer and reach larger sizes than the females. Males can live up to 30 years, and females at least 17 years. There are records of bull California spiny lobster weighing over 26 pounds and attaining total lengths up to three feet. Today, lobsters over five pounds are considered trophy size.

Status of Population

It is not known how many California spiny lobsters there are. However, fishing regulations appear adequate to guarantee the existence of the population. Commercial landings generally have increased since the 1974-1975 season. No measure of the recreational catch exists.

Limiting the time of year when fishing occurs and the minimum size of lobsters taken helps to ensure the existence of the population. The closed season protects female lobsters while they are carrying eggs and protects both sexes while they are molting and vulnerable to damage. The size limit ensures that there will be several year classes of brood stock even if all legal-size lobsters are caught each season.

Kristine C. Barsky
Phillip G. Swartzell
California Department of Fish and Game

References

Dexter, D.M. 1972. Molting and growth in Laboratory reared phyllosomes of the California spiny lobster, *Panulirus interruptus*. Calif. Fish and Game 58:107-115.

Duffy, J.M. 1973. The status of the California spiny lobster resource. Calif. Dept. Fish and Game, Mar. Resour. Tech. Rep. No. 10. 15 p.

Engle, J.M. 1979. Ecology and growth of juvenile California spiny lobster, *Panulirus interruptus* (Randall). Sea Grant Dissertation Series, USCSC-TD-03-79. 298 p.

Lindberg, R.G. 1955. Growth, population dynamics, and field behavior in the spiny lobster *Panulirus interruptus*. Univ. Calif. Pub. Zool. 59(6):157-248.

Mitchell, C.T., C.H. Turner, and A.R. Strachan. 1969. Observations on the biology and behavior of the California spiny lobster, *Panulirus interruptus* (Randall). Calif. Fish and Game 55:121-131.

CRUSTACEAN RESOURCES: DISCUSSION

California's marine crustacean resources are numerous and diverse. In addition to the crab, shrimp and lobster resources presented in this volume, other crustacean resources range from the sand (mole) crab familiar to beach-goers, to mud flat burrow-dwelling ghost shrimp, to a variety of attached barnacles. Besides crustaceans which are the subject of commercial or recreational harvests, many other species of crustaceans inhabit California marine waters where they form important functional components of marine ecosystems.

The nine crustacean groups presented here are among the most important and well known in California. They cover the geographic range of our marine waters, with ocean shrimp and Dungeness crabs in the north and spiny lobster and ridgeback prawns in the south. Harvest methods range from trawls pulled by large ocean-going vessels (shrimp), to traps fished from smaller boats (lobsters, crabs, and prawns), to ring nets and bare hands (recreational lobsters and crabs).

Commercial crustacean harvests have grown in recent decades in terms of volume and number of species targeted. Total mean annual harvests during the decades of the 1970's and 1980's were 17.2 million pounds, up from 11.2 million pounds during the 1960's. The species or groups reported in the harvest have increased from six in 1960 to 15 in 1990. Crustaceans are traditionally high-value fishery products. In 1990, the total crustacean commercial harvest of over 24 million pounds represented only six percent of California's total commercial landings but made up over 18 percent of total landed value at $28.7 million.

Recreational harvests of crustaceans center around crabs and spiny lobster. Dungeness and rock crabs are targets of scattered recreational effort throughout California. However, it is the spiny lobster which supports an intense and popular recreational fishery in southern California. Most lobsters are caught by divers with their hands, while some are also taken in baited ring nets from skiffs, piers and jetties. Many divers have developed specialized techniques and vast stores of local knowledge in pursuit of lobsters. A commercial passenger fishing vessel industry which caters to divers schedules special

SMB-26760

trips during lobster season. The total size of the recreational lobster harvest is not known, but a recent Federal survey estimated over 115,000 individual trips targeting spiny lobster in 1989.

Management of crustacean resources in California has followed a traditional approach. Measures such as minimum sizes, closed seasons, gear or equipment restrictions, bag limits and closed areas have been used to help protect stocks, sustain harvests and allocate the resource. Commercial fisheries for crustaceans are currently not under limited access or entry regulations. However, opportunities to participate in many other California fisheries have been increasingly restricted. Under such conditions, the open-access crustacean resources have attracted increased attention and may be candidates for further management restrictions, including limited entry systems, to prevent over utilization.

A variety of life-history patterns which need to be considered when making management decisions are found in California's crustacean resources. Some appear to be long-lived and slow growing (spiny lobster, sheep crab); others have short life spans and can undergo rapid increases or declines in population size (ocean shrimp and ridgeback prawn). Separate subpopulations of Dungeness crabs and ridgeback prawns may exist within California. The spiny lobster population is shared with Mexico, and ocean shrimp and Dungeness crab populations span the Oregon border. Management and fishing practices in those political entities may affect California's portion of such shared resources.

Future management and research on California's crustacean resources should focus on more frequent and efficient resource assessment methods and a better understanding of the various factors, both natural and human-induced, which determine population levels and patterns of change. With such information at hand, resource managers will be better able to match the growing demands on California's crustaceans with their productive capacity.

David Parker
California Department of Fish and Game

SMB-26761

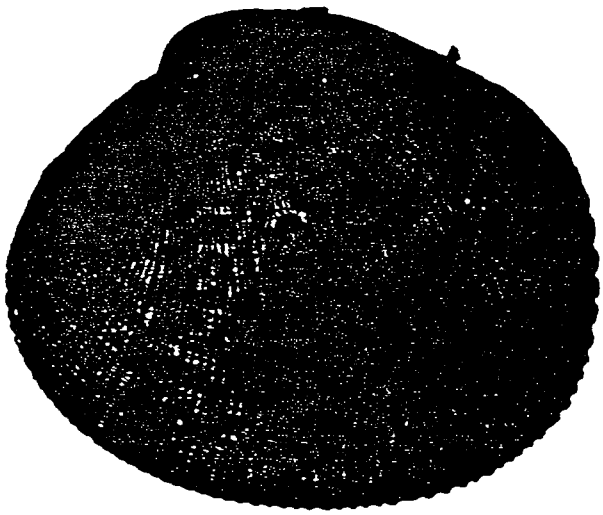
LITTLENECK CLAMS

History of the Fishery

There are seven species commonly known as "littleneck clams" or "chiones": banded chione (*Chione californiensis*), smooth chione (*Chione fluctifraga*), wavy chione (*Chione undatella*), rough-sided littleneck (*Protothaca laciniata*), common littleneck (*Protothaca staminea*), thin-shelled littleneck (*Protothaca tenerrima*) and Manila clam or Japanese littleneck (*Tapes philippinarum*). They are grouped here because they are regulated by an aggregate bag and size limit. All are members of the family Veneridae (Venus clams) and all but the Manila clam are native to California. The Manila clam is a native of the Orient and was introduced unintentionally into California waters in the 1930's.

Although seven species have been aggregated for regulating molluscan resources, only four (smooth chione, wavy chione, common littleneck and Manila clam) are of major importance; they comprise more than 95 percent of the littleneck clam harvest in California. Since commercial clammers are restricted to the same daily bag and size limits as sport fishers (50 clams, all species combined; minimum length 1.5 inches), it is not feasible for them to make a living harvesting these bivalves. Thus, most exploitation is by sport diggers.

All digging is by hand (with rake, shovel, garden hand fork, or trowel) and is carried out in intertidal areas during daylight hours, generally at low tides of 0.0 feet or less.



Common littleneck, *Protothaca staminea*.

Status of Biological Knowledge

The three species of chiones occur south of Point Conception on mud and sand flats of sloughs and bays, primarily in the intertidal zone. Banded and wavy chiones may, however, occur subtidally to a depth of 165 feet.

Thin-shelled and rough-sided littlenecks are both uncommon in California except in Alamitos Bay (Los Angeles County) where the latter species is abundant. Thin-shelled littlenecks occur throughout the state in firm, sandy mud of bays, in the low intertidal zone, and offshore to a depth of 165 feet. They occupy burrows up to 16 inches deep. Rough-sided littlenecks occur in California from Monterey Bay south to the Mexican border in sand or muddy sand in bays, the low intertidal zone, and in adjacent shallow subtidal areas. Larger individuals may burrow up to 12 inches below the surface. The locally abundant population in southern California is in water too deep for stand-up diggers, and the underwater visibility is too poor for skin divers to harvest them.

The common littleneck occurs throughout California in bays, coves and cobble patches along the outer coast in the middle and low intertidal zones. This species generally occurs within six inches of the surface and deep digging is not required for harvesting. Clam beds known to resident sport diggers receive relatively heavy exploitation during minus tides. Other clam beds remain underutilized due to difficulty of access or lack of public awareness. This is one of the most abundant clams on the west coast and is highly esteemed for food.

The Manila clam continues to expand its range on the west coast and now occurs from southern California to British Columbia. It is particularly abundant in San Francisco Bay and other estuaries to the north in the intertidal zone. It is easily dug, as it generally occurs within two inches of the surface. It prefers a substrate of coarse, sandy mud with a mixture of larger gravel and cobbles and may attach itself with byssal threads to any suitable substrate, including broken glass or ceramics. It also occurs sub-tidally in the extensive oyster shell beds of south San Francisco Bay.

Maximum length of the three species of chiones is approximately 2.5 inches. Of the four types of littlenecks, the thin-shelled is the largest, attaining a length of 4.3 inches. The other three species reach approximately three inches in length.

Of the seven species, life history information is best known for the Manila clam population in San Francisco Bay. By examining the length-frequency distribution of a strong year class over time, minimum legal size was estimated to be reached in 2.5 to 3 years. This was verified by examining internal and external growth rings on the shells formed each year in the fall as growth slows down or ceases. Maximum age is estimated to be eight or nine years.

Manila clams have a three-week planktonic larval period. They are first recognizable in the substrate at about 0.04 inch. At 0.75 to 1.0 inch, they are capable of reproducing and are repeat spawners. The primary spawning period is late spring to early summer, and they are known as dribble spawners, releasing eggs and milt over a prolonged time period. A secondary spawning period is thought to occur in the winter. Sexes are separate, as they are in all littleneck clams.

Natural mortality of sublegal Manila clams may be as high as 50 percent per year. Known predators include bat rays, mud

SMB-26762

crabs, lined shore crabs, *Cancer* crabs, channeled whelks and scoter ducks. Large clams are capable of movements of up to three feet during a single tidal cycle, although marking studies have shown virtually no net movement over a several-month period.

Common littleneck clams have a similar early life history and are capable of reproducing at about one inch in length. In southern California, they may reach the minimum legal size in one to 1.5 years. External growth checks are prominent on the shell, but these are not annual rings. The spawning season in southern California is generally from March through July.

Meat yield from harvested littleneck clams has been estimated. A limit of 50, 1.7-inch common littlenecks yields 9.5 ounces of meat, while a limit of 2.5-inch clams would provide 24.5 ounces. In contrast, a limit of 50 Manila clams from San Francisco Bay with a typical mean length of 1.6 inches would yield 6.4 ounces of meat.

In the past, littleneck clams have been cultivated and transplanted. Aquaculturists have reared the Manila clam from 0.25 inches to 1.5 inches in 10 months with 64 percent survival. Manila clams were transplanted in 1953 from San Francisco Bay to several southern California bays and sloughs. Many of the transplants survived for more than a year but there was no natural reproduction.

Status of Population

In 1981, population estimates of Manila clams were derived for beds in San Francisco Bay. In the 10 most important beds, the peak estimate in the summer was 19.3 million clams with 3.4 million of legal size. One bed in south San Francisco Bay, covering approximately 75,000 square feet, has been surveyed annually since 1980; population estimates have ranged from 80,000 to 1,525,000. For the highest estimate, only two percent of the population was of legal size. Since 1980, maximum density of legal-sized clams in this bed has been 2.5 per square foot. Densities of juvenile Manila clams may exceed 100 per square foot in the most productive intertidal beds. Typically, intertidal densities in San Francisco Bay range from 20 to 40 per square foot during years of good recruitment. In the subtidal shell beds, density averages one-tenth of that in the intertidal zone.

Surveys of clammers in San Francisco Bay in 1981 resulted in an estimated annual total effort of 900 user days. However, water quality problems have limited and still limit recreational harvest opportunities.

Small beds of common littleneck clams are generally the rule in northern California. One bed in San Mateo county has sustained an annual harvest estimated to exceed 10,000 clams. San Onofre, in southern California, contains an intertidal cobble bed over one mile in length and at least 115 feet wide. A 1967 population estimate yielded 4.5 million legal-size clams; however, the bed had never been open to the public before the survey. In terms of legal limits, this bed could have furnished 90,000 user days of recreation.

The cobble beach at San Onofre probably is the most productive bed of littleneck clams in the state. However, the population is unstable and fluctuates greatly even when unexploited. Heavy runoff from a nearby creek in 1969 caused expansive sanding-in of the cobbles and destroyed much of the bed. Recovery time was estimated at five years.

Little is known about the populations of the other littleneck species. The smooth chione is in danger of extinction in areas where harbors are being developed. Habitat loss or degradation, particularly by man-induced or natural siltation, can cause permanent population reductions. Extreme variations in physical conditions, such as rainfall, can depress populations dramatically.

Paul N. Reilly
California Department of Fish and Game

References

McAllister, R.D. and T.O. Moore Jr. 1982. Selected shellfish resources of San Francisco Bay: their distribution, abundance, use, public access, and recommended management alternatives. Calif. Dept. Fish and Game. Prepared for San Francisco Bay Regional Water Quality Control Board, Oakland, 168 p.

Tasto, R.N. 1974. Marine bivalves of the California coast. Calif. Dept. Fish and Game, Marine Resources Leaflet No. 6. 23 p.

PISMO CLAM

History of the Fishery

The Pismo clam, (*Tivela stultorum*) has been found in 25,000-year old Pleistocene (ice age) deposits and in Indian kitchen middens 200 to 2,000 years old. Indians used the clam for food and the shells for digging, scraping and ornaments. The name Pismo comes from the Indian word *pismu* meaning tar; deposits of tar are found in the Pismo Beach area.

Records of the commercial harvest of Pismo clams began in 1916 and were kept through 1947, when the commercial take in California was prohibited. During that period, approximately 3,137 tons were commercially harvested. The majority were harvested from the Pismo Beach and the Morro Bay areas, with a small percentage from Monterey Bay. Average annual harvest was 98 tons. Landings ranged from a high of 332.8 tons in 1918 to a low of 13 tons in 1945. Approximately 98,600 clams (average two pounds each) were harvested annually with a high of 334,700. They were purchased by restaurants, were sold whole and canned in markets, and were used as bait and animal food.

The importation of Pismo clams from Baja California occurred as early as 1919 and continued through 1962 (232.2 tons). Most of the imported meat was canned. After 1962, imports into the United States are not identified by species, but commercial clamming continues at several locations in Baja California. Hooka gear is used to harvest small (four inch) clams at a rate of 1,000 per hour at Bahia Tortugas.

The usual method of collection by today's recreational clammer is by means of a four- to six-tined garden fork. During low tide the clammer selects a section of beach with exposed wet sand or water of wading depth and probes in the sand until

SMB-26763

encountering a clam. Another method is to shuffle one's bare feet along the bottom until a siphon or shell is felt. Pismo clams can also be found by looking for the half-inch-long tufts of a hydroid which attaches to the shell and is exposed above the sandy surface. Divers search for the clams by probing with a knife or looking for exposed shells or siphons. Regulations require the immediate measuring and reburial if the clam is less than the minimum legal size.

Pismo clams have a distinctive and excellent flavor; they are prepared as chowder and seafood cocktail, and are also fried and eaten raw. Unfortunately, they have been implicated in several human fatalities involving paralytic shellfish poisoning. Pismo Beach presently provides the best Pismo clamming in California despite the loss of the fishery from 1982-1990 due to sea otter predation. The number of Pismo clammers in California is not known, but in late 1990 and early 1991 an estimated 500 clammers were on Pismo Beach at one time. Recreational clamming is regulated by bag limits, a minimum size, and closed seasons and areas. The objective of these regulations is to prevent the depletion of the clam population and to maintain a population of sexually mature clams that have a chance to spawn several times before being harvested.

Pismo clams, *Tivela stultorum*, have a variety of color patterns.

Status of the Biological Knowledge

The shell of the Pismo clam is thick, heavy and strong, and the outside is smooth with fine concentric growth lines. The inside of the shell is white and the outside has a varnish-like periostracum, usually yellowish, tan or greenish. Shells of individual clams vary considerably in both color and pattern, ranging from pale beige to brown, occasionally with brown radiating marks running from the umbo to the margin on a light background. The Pismo clam is about 0.009 inch at metamorphosis and may grow to over 7.3 inches in length.

The historic range of the Pismo clam was Half Moon Bay, California to Socorro Island, Baja California, including the Channel Islands off Santa Barbara. However, it has not been found at Half Moon Bay for decades and its present range extends only as far north as Monterey Bay. It is found in the intertidal zone and offshore to 80 feet on relatively flat, sandy beaches of the open coast. Occasionally it is also found in entrance channels to bays, sloughs and estuaries. Because of its short siphons, the Pismo clam generally lives close to the surface of the sand and seldom burrows deeper than six inches, but has been found eight to 12 inches deep in southern California. The clam characteristically orients vertically with the hinge and excurrent siphon toward the ocean, the mantle edge and incurrent siphon toward the beach, and the ligament at the center of the hinge oriented up. Burrowing is accomplished by moving the foot rapidly to loosen the surrounding sand. Then jets of water eject the loosened sand up along the shell sides, and the weight of the clam and pull of the foot together drag the clam down through the sand.

In the majority of Pismo clams the sexes are separate with equal numbers of males and females. They are mature at one year in southern California and two years in central and northern California. The smallest known mature clam in southern California was 0.7 inch and in northern California was 0.5 inch.

Spawning can occur anytime, but the majority spawn from June to September. The number of eggs per female increases with increased shell size and ranges from 10 to 20 million eggs per female, with an average of 15 million per five-inch female. In laboratory-held clams, egg numbers were roughly proportional to clam size. The number of eggs ranged from as many as 4.7 million in a 2.9-inch female to 0.4 million in a 1.2-inch female. Eggs range in diameter from 0.00296 to 0.00324 inch.

The larvae metamorphose, settle to the sandy bottom, and attach themselves to the sand grains by means of byssal threads. After several months, when the clam is more able to maintain a position on the sandy bottom, the byssal threads degenerate. In laboratory culturing experiments, fertilized eggs hatched into larvae in approximately 48 hours. Larvae 60 to 72 hours old displayed unusual behavior by settling to the bottom and remaining benthic or near-benthic throughout larval development. However, other species being cultured failed to exhibit this benthic phenomenon. If larval Pismo clams in nature also exhibit a benthic phase, larval transport by nearshore currents may be limited. Larvae larger than 0.009 inch and 22 to 50 days old have completed metamorphosis, developed a foot, and buried themselves in the sand. At day 120, post-larval clams (0.048 inch) have the triangular appearance of an adult. No byssal threads were observed on laboratory-cultured post-larval Pismo clams.

Little is known of post-larval conditions in nature; however, in laboratory cultures post-larval growth was relatively slow, and survival generally poor. Although spawning probably occurs every year, it is not always measurably successful. Considerable numbers of years have gone by during which virtually no young-of-the-year clams settled on beaches. Recruitment success appears to be influenced by oceanographic conditions (water temperature, currents), which in turn influence phytoplankton availability. Unfortunately, the necessary conditions for optimum spawning success are not known.

The Pismo clam is a filter feeder. Water taken in through the incurrent siphon passes over the gills, where food particles are removed. Food includes organic and inorganic particles

SMB-26764

such as phytoplankton, bacteria, zooplankton, eggs, sperm, and detritus from the disintegration of plants and animals. The inhalant siphon has a very fine net of delicately branched papillae across the opening, forming a screen that excludes the entrance of large particles but permits the intake of water and food particles. Despite this elaborate system, half of the stomach contents is sand. An actively feeding three-inch clam filters as much as 15 gallons of water per day.

The age of Pismo clams has been determined by observation of marked individuals and by growth rings on the shell. In California, a growth ring is generally formed during the winter months when water temperatures are cool and food abundance is relatively low. In Baja California, most clams form a growth ring during the August-October period, although some may form a ring at any time of the year. Growth is continuous throughout the clam's life, with the average length increasing by approximately 0.84 inch per year for the first three years. Increases in shell length are greatest in spring, summer and early fall. Growth of older clams is slow. At age 10, the increase in shell length is usually not more than 0.2 inch per year. The minimum legal size of 4.5 inches is reached in about five years but may not be reached until eight or nine years. At Pismo Beach, clams reach 4.5 inches between ages seven and eight.

The oldest and largest Pismo clams on record from California were both taken from Pismo Beach. The oldest, taken in 1929, was estimated to be 27 years old and was 6.88 inches long. The largest was taken in 1930, measured 7.32 inches, and was estimated to be 23 years of age. Several Pismo clams from Baja California have been aged at over 43 years. The smallest Pismo clam recorded from natural habitats was 0.92 inch long.

Pismo clams have many predators, including moon snails, rock crabs, sharks, round stingrays, some surf fishes such as the California corbina in southern California, gulls, sea otters and man. The extension of the sea otter's range to Monterey Bay (1972), Morro Bay (1973) and Pismo Beach (1979) precluded the recreational fishery for Pismo clams in those areas until the latter half of 1990. Otters were estimated to have eaten 520,000 to 700,000 Pismo clams in one year at Monterey Bay. A single sea otter was observed to eat 24 clams in 2.5 hours. In 1990, legal-size Pismo clams were again found at Pismo Beach, the first since 1981.

Parasites of the Pismo clam include a polychaete worm which bores into the clam shell and larval cestodes which have been found inside the clam as 0.15-inch diameter yellowish-white cysts. The cestodes can impair the clam's sexual development but are not harmful to man if eaten. Commensal pea crabs, occasionally found in the mantle cavity, feed on food particles collected by the clam's gills.

Status of Population

The Department of Fish and Game first examined Pismo clam recruitment in 1919, and annual surveys have been conducted from 1923 to 1991 to obtain information on age, recruitment, year class strength, and exploitation trends. Through 1948, only Pismo Beach was surveyed. Morro Bay, Cayucos, and beaches from San Diego County to Santa Barbara County were subsequently included.

During the storms of 1982-83, Pismo clam populations along southern California beaches were severely depleted, resulting in little or no clamming after 1983. The Pismo Beach clam populations had three successive strong year classes (1986, 1987, and 1988), resulting in the largest number of sublegal clams ever recorded from surveys on Pismo Beach. Because of the exceptional recruitment in the Pismo Beach area and low abundance in southern California, 10,000 clams were transplanted from the Pismo Beach area to Huntington State Beach in 1989. The first follow-up survey found only 142 clams, the second only 14 clams and three partial shells. Biologists are uncertain as to the fate of the clams. Also, approximately 1,000 clams were transplanted within the Channel Island National Park.

In 1990, recruitment of young Pismo clams appeared to be a widespread phenomenon along southern and central California from San Diego to Pismo Beach. Densities were documented at Pismo Beach and Ventura County beaches of 26 clams per square foot (one- to six-year olds) and five clams per square foot (one- to three-year olds), respectively.

No population estimates have been made for the total Pismo clam resource in California; however, it appears to be in a healthy state in a number of areas in southern and central California. Whether successful recruitment will result in ongoing recreational fisheries in light of continuing human and sea otter population growth is unclear.

Christine A. Pattison
California Department of Fish and Game

References

Coe, W.R. 1947. Nutrition, growth and sexuality of the Pismo clam, *Tivela stultorum*. J. Exp. Zool. 104(1):1-24.

Coe, W.R. and J.E. Fitch. 1950. Population studies, local growth rates and reproduction of the Pismo clam (*Tivela stultorum*). J. Mar. Res. 9(3):188-210.

Herrington, W.C. 1930. The Pismo clam: further studies of the life history and depletion. Calif. Div. Fish and Game, Fish Bull. 18. 69 p.

Searcy-Bernal, R. 1989. Periodicity of internal growth ring deposition in the Pismo clam (*Tivela stultorum*) from Playa San Ramon, B.C., Mexico. Ciencias Marinas 15(3):45-56.

Weymouth, F.W. 1923. The life-history and growth of the Pismo clam (*Tivela stultorum* Mawe). Calif. Fish and Game Commission, Fish Bull. 7. 120 p.

PACIFIC RAZOR CLAM

History of Fishery

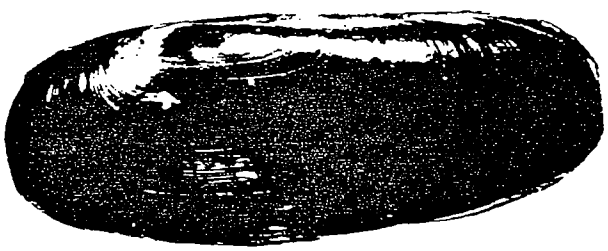
The Pacific razor clam (*Siliqua patula*) is one of the tastiest food clams in California and is diligently pursued by sportsmen on the beaches where it is abundant. The best California beaches for razor clams are in Del Norte and Humboldt counties. Before 1949, a small commercial fishery existed, but only a few pounds of clams were ever sold. Commercial fishing for razor clams is presently prohibited.

SMB-26765

There were no seasonal restrictions on razor clamming until 1953. Due to a decline in the numbers of larger clams at that time, Clam Beach in Humboldt County was divided into a north and south beach to limit fishing effort seasonally. The south beach was open to clamming only in odd-numbered years, while the north beach was open during even-numbered years. A similar restriction went into effect for the razor clam bed at Crescent City, Del Norte County in 1955.

A 1960 study on Clam Beach concluded that the alternate-year closures were responsible for a decline in older and larger clams on the south beach because of the concentration of clammers there. As a result, all of Clam Beach was opened to clamming from 1971 to 1973. During that three-year period, catch and effort were monitored and public reaction noted. It was found that instead of being evenly distributed, 86 percent of the clamming effort took place on the north beach. The high pressure on the north beach resulted from a combination of easy access to the north beach, difficult access to the south beach, and much greater clamming success on North Clam Beach than on South Clam Beach. There was also a strong sentiment among clam diggers to return to alternate year closures because of the declining average size of clams. In 1974, the alternate year fishing pattern was reinstated with the north beach open during odd-numbered years and the south beach open during even-numbered years. In the years immediately following the reinstatement, the catch per digger and the average clam size increased significantly.

A daily bag limit of 30 razor clams was changed to 20 in 1963. In addition, all clams dug were required to be kept regardless of size or broken condition.



Pacific razor clam, *Siliqua patula*.

Status of Biological Knowledge

The Pacific razor clam ranges from western Alaska to Pismo Beach, California, and is generally found on flat or gently sloping sandy beaches with a moderate to heavy surf. Razor clam shells are long and thin, with fragile, shiny valves, not what one would expect in a surf-loving animal. Being an excellent burrower, it depends on digging speed for protection from wave shock. Individuals laid on top of the sand have buried themselves completely in less than seven seconds. A digger must work quickly to capture a clam before it burrows to depths that are difficult to reach. At the surface of the sand, the clam assumes an almost vertical position with only siphons exposed. Water is drawn into the inhalant siphon by a current set up by the action of cilia lining the mantle cavity. As water is passed across the gills, planktonic food organisms are guided by cilia and a pair of palps to the mouth. Respiratory exchange takes place as the water passes over the gills, and waste products are passed out in the water through the smaller exhalant siphon.

The life cycle of the razor clam is typical of most clams. Sexes are separate, fertilization is external, and free swimming larvae develop three or four days after fertilization. Approximately eight weeks later, the larvae settle into the sand and the juvenile phase of life begins. Sexual maturity in razor clams may be related to size as well as age. While maturity is commonly achieved at a length of about four inches, the age at maturity varies with geographic location but is usually at an age of two years in California. The optimum temperature for razor clam spawning is around 55° F. Razor clams usually spawn in May and June in California, mid-May to July in Washington, and as late as August in Alaska.

Razor clams attain their maximum rate of growth during their first year of life. The growth rate remains high through the second or third year, after which it slows markedly. The largest razor clam on record in California was a seven-inch specimen taken from Clam Beach in 1979.

The mortality rate of razor clams on Clam Beach increases rapidly after the third year of life, with few clams living to be seven years old. In the northern part of the range, the maximum age is greater. Razor clams in Alaska live 18 or 19 years but the typical life-span is shorter.

Status of Population

There are only three areas along the coast of California which have had significant populations of Pacific razor clams. The Pismo Beach-Morro Bay area supported a very small sport fishery which has diminished over the years. Currently, this population is quite small and seems to consist mostly of one- or two-inch individuals. The Clam Beach and Crescent City fisheries are similar to each other in several respects. Both beds are divided into north and south beaches with alternate-year closures in effect. In both areas, the northern beach was more heavily fished and more productive than the southern beach for many years. This is no longer true in Crescent City as the southern beach has shown an increase in effort and in catch per digger during the 1980's.

No population estimates are available for any of California's razor clam beds. Beginning in 1974, a sampling scheme was initiated to provide estimates of total catch and effort for Clam Beach. Estimates of annual catch, number of diggers and annual catch per digger (C/D) were made for the years 1974 through 1989 for North and South Clam Beach and for the years 1980 through 1989 for Moonstone Beach. Estimates of annual clam catch for North Clam Beach ranged from 1,100 to 116,400; for South Clam Beach the range was from zero to 45,500; and for Moonstone Beach the range was from zero to 74,800. The annual estimated number of diggers ranged from 880 to 12,670 on North Clam Beach, from 220 to 6,900 on South Clam Beach, and from 50 to 5,510 on Moonstone Beach.

SMB-26766

Annual C/D for North Clam Beach, South Clam Beach and Moonstone Beach ranged from 1.3 to 9.5, 0.0 to 6.6 and 0.0 to 13.9 clams, respectively. Catch, effort and C/D exhibited no particular trends but fluctuated over time.

Patrick C. Collier
California Department of Fish and Game

References

Amos, M.H. 1966. Commercial clams of the North American Pacific coast. U.S. Dept. of the Interior, Bureau of Comm. Fish. Circular 237. 18 p.

McMillin, H.C. 1924. The life-history and growth of the razor clam. Wash. Dept. of Fisheries. Olympia, Wash. 52 p.

Sims, C.W. 1960. A study of the fishery and the population of the Pacific razor clam, *Siliqua patula*, of Clam Beach, California. Thesis, Humboldt State University. 81 p.

Wolotira, R.J., Jr., M.J. Allen, T.M. Sample, C.R. Iten, S.F. Noel, and R.L. Henry. 1989. Pacific razor clam, *Siliqua patula* (Dixon, 1789). Pages 73-79 in Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Vol. 1: Shelled Molluscs. NOAA Tech. Memorandum NMFS F/NWC-160, 7600 Sand Pt. Way N.E., Seattle, WA 98115.

GAPER CLAMS

History of the Fishery

The fishery for the gaper clams, the Pacific gaper (*Tresus nuttalli*) and the fat gaper (*Tresus capax*), is almost exclusively sport; however, the Fish and Game Code provides that these clams may be harvested commercially in Humboldt Bay for daily restaurant or market orders and by special bag limits. For the 20-year period from 1950 to 1970, annual commercial landings averaged 1,000 pounds with a maximum of 6,000 pounds and a minimum of 200 pounds. More stringent public health regulations concerning the marketing of shellfish and the retirement of a long-time commercial clammer essentially eliminated the commercial clam fishery in the early 1980's.

These species are the object of a heavy sport fishery that takes place in intertidal areas of bays with sand and mud bottoms. Humboldt Bay, Bodega Bay, Tomales Bay, Drakes Estero, Elkhorn Slough and Morro Bay are popular digging areas. At Tomales Bay, which is one of the major producing areas, as many as 1,200 people have been counted during one low tide on the two sand bars. These popular areas are called Clam Bar and Seal Bar and can be reached only by boat. With a legal limit of 10 gaper clams per day, an estimated 11,000 people dig there each year and take about 55,000 clams. The gaper clam catch in other areas of Tomales Bay is quite small compared to this area.

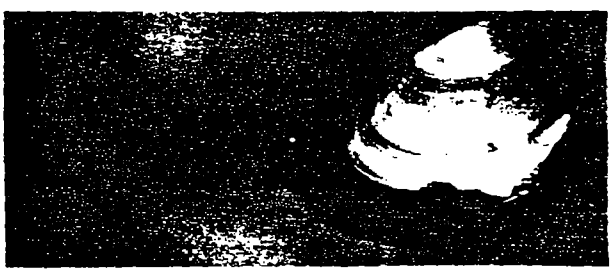
Gaper clams are also abundant in Humboldt Bay, where the number of sport fisherman has averaged about 4,300 diggers for the past 10 years. While the number of sport fishermen is not as great as in central California areas, especially Tomales Bay, the estimated take (56,000) is approximately the same, as the bag limit in Humboldt Bay is higher.

Utilization of gaper clams has increased through the years, and it appears that it will continue to increase in proportion to population growth in the coastal counties where these clams occur. There is no season or size limit, but there are bag limits set for sport and commercial harvesting. An angler may take 10 clams per day throughout the state, except in Elkhorn Slough where the limit is 12 clams per day and in Humboldt Bay where a take of 25 clams per day is allowed. The fact that gaper clams have relatively thin shells which do not close tightly enough to maintain their moisture restricts the commercial use of these clams to a fairly local market.

Showing off gaper clam catch from Tomales Bay.

Diggers generally use skiffs to get to the better clam digging areas. Transportation by barge is available to Seal Bar and Clam Bar in Tomales Bay. Shovels are used to dig the clams, which may be as deep as four feet in sand or mud. In more muddy areas, PVC pipes about 12 to 15 inches in diameter are often used to assist in getting to deep clams by preventing the hole from caving in.

Gaper clams generally are used in clam chowder or fried and served as a main meat dish.



Pacific gaper clam, *Tresus nuttalli*.

Status of Biological Knowledge

Gaper clams are found from Alaska to Scammon's Lagoon, Baja California. Both species live in fine sand or firm sandy-mud bottoms in bays, estuaries and more sheltered outer coast areas. They are found from the intertidal zone to depths of

SMB-26767

at least 150 feet. The Pacific gaper is the most commonly taken gaper clam in California. A closely related species, the fat gaper, is the predominant gaper clam taken in Humboldt Bay, where it is very common in the intertidal zone. Further south, the fat gaper occurs mostly subtidally but can make up to five percent of the catch taken in the intertidal zone at Tomales Bay.

Reproduction occurs year around in central California but is predominant during spring and peaks in the months of February and April. Upon completion of a free-swimming larval stage, the young gaper clam settles down to a fixed position and comparatively inactive existence. About the only movement is downward as the clam grows older and increases in size. After reaching a size of about three inches, little downward movement occurs.

Age and growth studies reveal that most gaper clams taken in central California range from about three to eight years old. For the first four years, the clams average about one inch of growth in length per year. The growth rate appears to slow down after this period. Gaper clams live to a maximum age of 17 years and can attain a length of 10 inches and a weight of around five pounds.

The gaper clams reach sexual maturity and spawn at about two to three years of age. At this time, they are two to 2.75 inches in size. Spawning appears to begin in the spring, coinciding with the seasonal water temperature minimum.

Gaper clams are suspension feeders, feeding on suspended particles which include phytoplankton and detritus. In intertidal beds, feeding occurs during the high tide period.

Status of Population

Although densities of gaper clams in areas of certain bays have been determined, complete intertidal and subtidal population estimates have not been made. Gaper clams have been found in densities of up to 20 clams per square foot, with a density of two clams per square foot considered commercially viable. Intertidal siphon counts by biologists using a stratified random sampling design on Clam Bar in Tomales Bay supplied data for estimating intertidal population sizes of 540,000 gaper clams in 1968 and 430,000 in 1969. No population estimates have been made for the total gaper clam resource in California; however, both the intertidal and subtidal resource appears to be in a healthy state. Subtidal populations are relatively unavailable and unused by sport clammers and may provide a spawning refuge. Spawning stock reserves seem adequate to sustain the population.

Thomas O. Moore
California Department of Fish and Game

References

Campbell, A., N. Bourne., and W. Carolsfeld. 1990. Growth and maturity of the Pacific gaper *Tresus nuttallii* (Conrad 1837) in southern British Columbia. J. Shellfish Res. 9(2):273-278.

Machell, J.R., and J.D. DeMartini. 1971. An annual reproductive cycle of the gaper clam, *Tresus capax* (Gould), in south Humboldt Bay, California. Calif. Fish Game. 57:274-282.

Moore, T.O. 1991. Distribution, abundance and use of clam populations in coastal Marin and Sonoma counties, California. Calif. Dept. Fish and Game, unpublished.

Wendell, F., J.D. DeMartini, P. Dinnel, and J. Sieke. 1976. The ecology of the gaper or horse clam, *Tresus capax* (Gould 1850) (Bivalvia: Mactridae), in Humboldt Bay, California. Calif. Fish and Game. 62:41-64.

WASHINGTON CLAMS

History of the Fishery

The Washington clam fishery is almost exclusively a sport fishery. The Fish and Game Code provides for commercial fishing in Humboldt Bay by daily market or restaurant order and by special bag limits. These clams are highly perishable and are dug as required and consumed locally. From 1954 to 1963, commercial landings averaged 5,000 pounds per year, with a high of 11,000 pounds in 1956 and a low of 2,000 pounds in 1960. Landings decreased following this period, and by the early 1980's commercial landings of Washington clams had ceased.

Two species are involved in the take. The Washington clam (*Saxidomus nuttalli*) is the principal species sought, and the best yielding localities are Humboldt Bay, Bodega Bay, Tomales Bay, Drakes Estero, Bolinas Lagoon, Elkhorn Slough and Morro Bay. Another species, the butter clam (*Saxidomus giganteus*), formerly known as the smooth Washington clam, is seldom taken south of Humboldt Bay. In only one California locality, near Fields Landing in Humboldt Bay, is this clam common enough to support a minor fishery. Results of a sport clamming survey of Humboldt Bay from 1975 through 1989 produced a mean estimated total take of both clams of 42,000 per year.

Washington clam, *Saxidomus nuttalli*.

The Washington clam catch is considerably less than that of gaper clams, mainly because the latter are more predominant in most bays, and Washington clam siphon holes are more difficult to locate. The recent Humboldt Bay survey found that

SMB-26768

the Washington clam and the butter clam comprised 20 percent and 13 percent, respectively, of the total estimated harvest of all species taken in that bay. In Bodega Bay, Washington clams are the predominant take, comprising an estimated 30 to 40 percent of the total clam harvest, with an occasional butter clam also taken.

Sport clammers may take 10 Washington clams per day throughout the state except in Elkhorn Slough, where the limit is 12 in combination with gaper clams, and in Humboldt Bay, where the limit is 50 in combination with no more than 25 gaper clams.

Skiffs are used to transport diggers to intertidal areas where these clams occur , but some locations have populations accessible by foot. The clams are dug by shovels to a depth of 12 to 18 inches near the low tide line. Washington clams may be used in clam chowder, or fried and served as a main meat dish.

Status of Biological Knowledge

The range of the Washington clam is from Humboldt Bay, California, to San Quentin Bay, Baja California. This species lives at depths of 12 to 18 inches in mud, sandy mud or sand of bays, lagoons and estuaries. Its shell is thick and firm, oval in outline, and roughened on the outer surfaces by numerous concentric ridges. Inside, the shells are shiny white with dark purple markings at the posterior end. Though the harvest is from bottoms exposed at low tide, this clam also occurs subtidally in the same general area.

The butter clam ranges from Sitka, Alaska, to San Francisco Bay, California, but is infrequently taken south of Humboldt Bay. Its shell is thick and firm, oval in outline, but more rounded than that of the Washington clam. The interior of the shell is entirely white with no purple markings. This clam lives at depths of 10 to 14 inches in mud or sandy mud of bays, lagoons and estuaries in areas that are usually exposed at low tide.

Spawning occurs during a period from spring to fall, presumably as a result of warmer water temperature. A study of the Washington clam in British Columbia revealed that about half of these clams spawned at the end of their third year. The larvae appeared as bivalve veligers in two weeks and, at the end of four weeks, when less that 0.2 inches long, settled to the bottom. Tidal currents play an important role in the distribution of these animals because of their pelagic larvae. Successful spawning and settlement may be somewhat sporadic, with a period of years between settlements of consequence. Upon completion of a free swimming larval period, both species settle down to a fixed position and a comparatively inactive existence. About the only movement is downward as the clams grow older and increase in size. Age studies reveal that most Washington clams harvested in central California are from four to eight years old. Occasional individuals of both species up to 10 years old are found in California, while some butter clams over 20 years old have been found in British Columbia. The Washington clam grows to a length of nearly seven inches and attains a weight of about two pounds. The butter clam may attain a length of five inches.

Status of Population

Densities and distributions of these clams have been determined for some of the more frequently used bay and estuarine intertidal areas, but knowledge is lacking about subtidal densities and distribution. Estimates have not been made of the total population size of the Washington clam resource in California; however, the present level of harvest can be easily sustained. Pollution of areas such as Bolinas Lagoon, where a public health warning for possible sewage contamination is posted, can affect their utilization by man.

Thomas O. Moore
California Department of Fish and Game

References

Collier, P.C. 1990. Sport clamming survey of Humboldt Bay from 1975 through 1989. Calif. Dept. Fish and Game, unpublished. 15 p.

Fitch, J.E. 1961. Common marine bivalves of California. Calif. Dept. Fish and Game, Fish Bull. 90. 102 p.

Mello, J.J. 1981. A one year survey of recreational clamming on the Morro Bay mud flats for the period of April, 1979 to March, 1980. Calif. Polytech. State Univ., Dept. Bio. Sci., San Luis Obispo, Calif. 18 p.

Moore, T.O. 1991. Distribution, abundance and use of clam populations in coastal Marin and Sonoma counties, California. Calif. Dept. Fish and Game, unpublished.

Spratt, J.D. 1982. Results of sampling clammers in Elkhorn Slough during 1978 and 1979. Calif. Dept. Fish and Game, Mar. Resour. Admin. Rep. 82-11. 12 p.

ABALONES

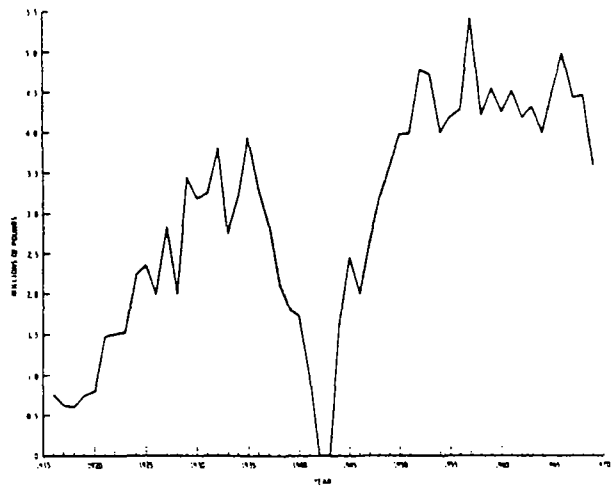
History of the Fishery

Archaeological evidence indicates that California Indians fished abalones extensively from coastal areas and the Channel Islands prior to European and Asian settlement of California. During the 1850's, Chinese Americans started a fishery in California that targeted intertidal green (*Haliotis fulgens*) and black (*H. cracherodii*) abalones, with peak landings of 4.1 million pounds of meat and shell in 1879. The Chinese worked shallow waters with skiffs, gaffing abalones dislodged by a long pole with a wedge on the end. This fishery was eliminated in 1900 by closure of shallow waters to commercial harvest. Japanese divers followed the Chinese by exploiting virgin stocks of subtidal abalones, first as free divers from surface floats and later, more successfully, as hard-hat divers. California Department of Fish and Game statistics showed an increase in landings from 1916 to a peak in 1935 of 3,900,000 pounds followed by a decline to 100,000 pounds in 1942 as fishermen of Japanese heritage were moved to relocation camps during World War II.

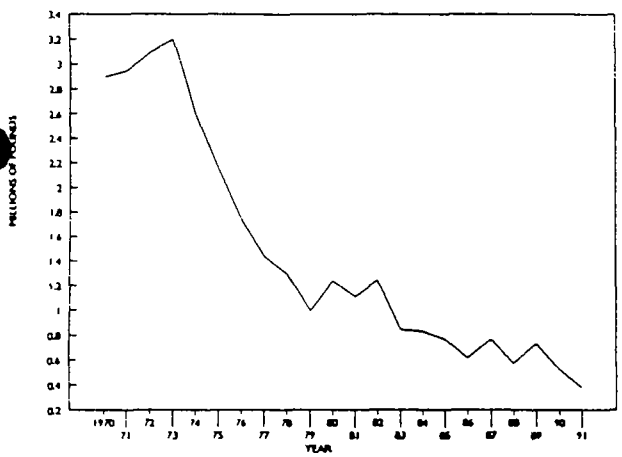
The red abalone (*H. rufescens*) was the only species reported in landing figures from 1916 to 1943. By 1960, the center of the fishery had moved from Monterey to the Morro Bay area, where the regions from Cape San Martin to Cayucos in the north and Point Buchon to Pecho Rock in the south were fished. Declining stocks of red abalones, caused largely by competition with a growing population of sea otters, forced a shift southward in the late 1960's. More recently landings have

SMB-26769

increased in the San Francisco area; this area supplied 34 percent of the 1988 red abalone landings. Evidence indicates that some of these abalones may have been poached from noncommercial grounds north of the Farallon Islands. The 1990 landings of red abalones declined to 17 percent of the 1931 to 1967 average of 2,135,000 pounds.



California commercial landings of abalone (all species), 1916-1969.



California commercial landings of abalone (all species), 1970-1991.

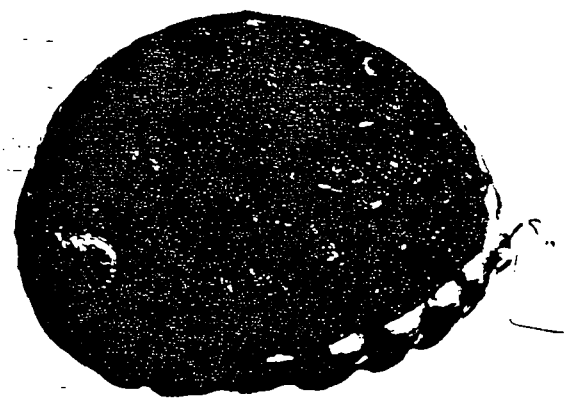
Commercial harvest of abalones was prohibited in southern California from 1913 through 1943, then reopened to increase wartime food production. The fishery in this area has undergone successive development and decline as increasingly less desirable species were exploited. The fishery proceeded from red to pink (*H. corrugata*), to green, and finally to black abalones. The combined-species landings reached a record 5,422,000 pounds in 1957. Pink abalone landings reached a maximum 3,385,000 pounds in 1952 and in 1990 were one percent of the 2,146,000 pounds averaged from 1948 to 1970. Green abalones peaked in 1971 at 1,147,000 pounds, declining rapidly to a current six percent of their 1968 to 1972 average catch of 488,000 pounds. Black abalones peaked in 1973 at 1,913,000 pounds, declining in 1990 to 13 percent of their 1972 to 1984 average catch of 687,000 pounds. A minor white abalone (*H. sorenseni*) fishery started in 1968, increased to a peak landing of 143,000 pounds in 1972, and has since declined to 0.02 percent of the 1972 to 1976 average landings of 99,000 pounds.

The efficiency of taking abalones has increased dramatically with the development in the late 1950's of "hooka" gear, which supplied air from the surface to divers using light masks, fins and neoprene suits. Between 1965 and 1970, hooka divers, having largely abandoned hard-hat gear, began using boats without tenders to reduce costs. Since the 1970's, multi-hose hooka gear and high-speed, seaworthy boats have become the mainstay of the fleet, allowing ease of access to the Farallon and Channel Islands.

In recent years, demand for abalones has increased throughout the world. In California, the fisherman's price-per-pound in the shell for red abalones has increased from $0.50 in 1973 to $3.80 in 1988 or 2.7 times the rate of inflation based on the Consumer Price Index.

Prior to World War II, most sport fishing was by "shorepickers" wading into tide pools during low tides. The advent of rubber skindiving suits following the war accelerated sport diving effort throughout California.

In southern California, where SCUBA is allowed for sport take, little information is available on the extent and success of the red abalone fishery. Effort in the pink, green and black abalone fisheries has been reported only for commercial passenger fishing vessels, increasing from 1,700 to 30,000 diver-days between 1958 and 1986. Catch success has declined from an average 1.2 abalones per diver in 1968 to 0.8 abalones per diver in 1986.



Shell of red abalone, *Haliotis rufescens*.

Sport fishing for abalones north of Yankee Point in Monterey County is restricted to free diving and shorepicking. Abalone diving effort has increased in relation to shorepicking and has shifted northward with the expansion of sea otters in central California. In 1960, an estimated 11,000 diver-days were expended to take 118,000 pounds of red and black

SMB-26770

abalones, compared with 29,000 diver-days to take 192,000 pounds in 1972. By 1985 to 1988, an average 202,000 diver-days and 92,000 shorepicker-days per year were focused on red abalones in central and northern California, with 93% of this effort north of Santa Cruz County. Estimated landings of red abalones in northern and central California for combined divers and shorepickers reached a high of 3,472,000 pounds in 1986 and have decreased to 1,161,000 pounds by 1989.

Status of Biological Knowledge

In addition to the five species which have been commercially fished, flat (*H. walallensis*), threaded (*H. assimilis*) and pinto (*H. kamtschatkana*) abalones are also found in California; all have limited distributions and none is common. Depth and geographical distributions of all California haliotids are best described by seawater temperature. Black abalones are found from Oregon to southern Baja California and are largely intertidal, extending to a depth of about 20 feet in southern California. Red abalones, which also extend from Oregon into Baja California, are intertidal and shallow subtidal in northern and central California but are exclusively subtidal in southern California, where they are restricted to upwelling locations along the mainland and the northwestern Channel Islands. Pink, green, white and threaded abalones are characteristic of the warmer waters south of Point Conception extending into Baja California and the southeastern Channel Islands. These species further sort out by temperature in their depth distributions: greens are centered at shallower depths than pinks, which are shallower than white abalones. Flat and pinto abalones are generally found in the cooler waters north of Point Conception.

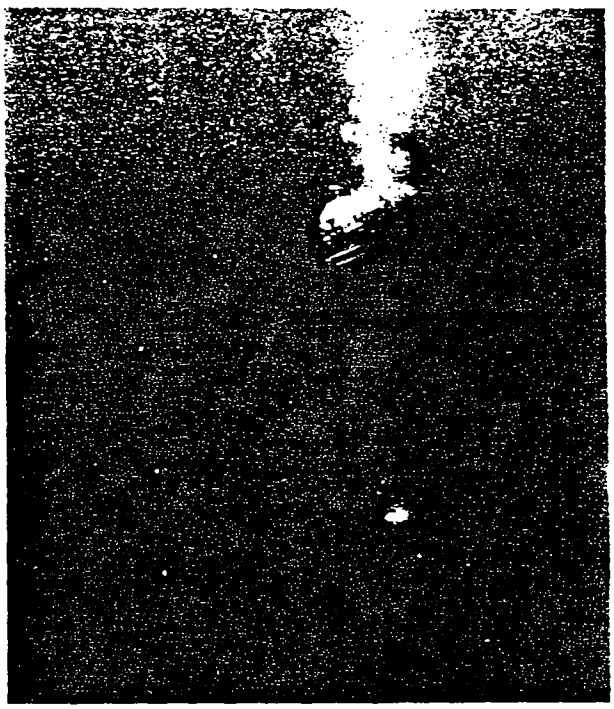
Limited growth information from tagging studies of a full size range of animals is available for the commercial species. Sport fishing size limits of six inches for pinks and greens and seven inches for reds are reached after a minimum of eight years. Commercial sizes of 6.25 inches for pinks, seven inches for greens and 7.75 inches for reds are reached after a minimum of 10 to 15 years in southern California. There is considerable inter-annual and between-site variability. Sexual maturity is reached at a small size, and fecundity, which increases exponentially with size, is high. Spawning season varies among species with black, green and pink abalones spawning between spring and fall (greens and pinks several times during that period). Red abalones in some locations may spawn throughout the year. Settling rates also appear to be quite variable.

California abalones feed primarily on algal drift, fragments of macrophytes moved by currents and surge; foraging on attached plants is rare. They feed preferentially on giant kelp and other laminarians; minor variations in preference appear to reflect the habitat where each is found. Specialization on drift algae puts abalones in competition with three species of sea urchins. Sea urchin grazing has been reported to limit kelp and abalone distributions in many regions of the state.

Abalones, especially juveniles, are preyed upon by a wide variety of animals including crabs, lobsters, gastropods, octopuses, seastars and fishes; larger abalones achieve a partial refuge in size from most of these. However, two predators, the bat ray in southern California and the sea otter in central California, prey selectively on larger abalones.

California abalones prefer high energy, open coastal environments with good water circulation. Abundance is highest where physical conditions allow good kelp growth and the substrate promotes trapping of drift kelp. Central and southern California, with their perennial giant kelp forests, offer a more constant food supply for abalone growth than do northern regions, where algal drift availability is highly seasonal. In the late 1950's, abalone populations on the Palos Verdes Peninsula in southern California apparently crashed in concert with their food supply when giant kelp disappeared during a period of unregulated sewage disposal.

Storms can be an important source of mortality and may limit abalone distributions in areas of greatest exposure. Although freshwater runoff and siltation associated with storms can be lethal, the broken condition of most shells after storms is evidence for mortality by wave-induced rock rolling.



Recreational diver searching for abalone at Catalina Island. Scuba gear is allowed only in southern California for taking abalone.

Status of Populations

Current stocks of most species of abalone in central and southern California are overutilized. This is the combined result of commercial harvest efficiency, increased market demand, sport fishery expansion, an expanding population of sea otters, pollution of mainland habitat, and loss of kelp populations associated with El Niño events. Management efforts to protect stocks through size limits and limits on the number of commercial abalone fishermen have been ineffective. Stock declines have continued in spite of the reduction of commercial

fishing permits from 499 in 1976 to 130 by 1990. Yield-per-recruit and egg-per-recruit models of red and pink abalones suggest that current sport and commercial size limits should have allowed adequate egg production; thus, simple recruitment overfishing alone cannot satisfactorily explain the decline.

Adding to the decline of black abalone populations in southern California have been unexplained mortalities due to a condition known as "withering syndrome." Mass mortalities have spread among populations on several of the Channel Islands and the mainland coast since 1987. While a potential pathogen has been found, its role is not clear. Speculation as to the cause also includes environmental stresses such as temperature and low food availability. The high mortalities, nearly 100 percent in some cases, suggest that fishing pressure should be severely reduced or eliminated for this species to maintain the potential for future stock recovery.

The poor survival rates observed in most abalone seeding experiments suggest that seeding will not be a panacea for restoration of depressed stocks in southern California. Effort should be expended to protect remaining stocks from further decline. Closure of already denuded areas such as the Palos Verdes Peninsula has proven ineffective. Spawning reserves or refugia in areas with viable stock have been suggested and could be created while such areas are still available in southern California. An alternative to permanent refugia are temporary area closures, or "pulse fishing," which combined with size and effort restrictions would produce a more conservative management approach.

In northern California, the exclusion of commercial fishing and restriction of sport harvest to shorepickers and free-divers have protected a significant portion of fishable red abalones, even in traditional heavy use areas. Nevertheless, timely management changes may be needed to reduce the level of harvest in this area considering: 1) legal take by the sport fishery alone may already exceed sustainable levels, 2) the additional suspected illegal commercial take, and 3) lower levels of recruitment and growth rates than are found in southern California.

Emergent abalone distributions that have allowed sport and commercial fisheries in California are probably recent phenomena resulting from the demise of the sea otter in most of California in the 18th and 19th centuries. These fisheries may be eliminated if the otter range is not contained. While debate continues as to whether overfishing or sea otters caused the decline of abalone stocks in central California, size structure data from a fishery reserve in this area make it clear that even protected populations cannot support a fishery within the sea otter range in central California today.

Konstantin A. Karpov
California Department of Fish and Game

Mia J. Tegner
University of California, San Diego

References

Karpov, K.A. 1991. A combined telephone and creel survey of the red abalone, *Haliotis rufescens* (Swainson), sport fishery in California from Monterey to the Oregon border, April through November 1989. Calif. Dept. Fish and Game, Mar. Resour. Div., Admin. Rep. 91-2. 72 p.

Karpov, K.A., W.D. Maxwell, and E.J. Smith, Jr. 1991. Draft environmental document; abalone ocean sport fishing. Calif. Dept. Fish and Game, Mar. Resour. Div. Rep.

Parker, D.O., P.L. Haaker, and H.A. Togstad. In Press. Case histories for three species of California abalones, *Haliotis corrugata, H. fulgens* and *H. cracherodii*. *In*: S.A. Shepherd, M.J. Tegner, and S. Guzman del Proo (eds.). Abalone of the world: biology, fisheries and culture. Blackwell Scientific.

Sluczanowski, P.R. 1984. A management oriented model of an abalone fishery whose substocks are subject to pulse fishing. Can. J. Fish. Aquat. Sci. 41:1008-1014.

Tegner, M.J. 1989. The California abalone fishery: production, ecological interactions, and prospects for the future. Pages 401-420. *In*: J.F. Caddy (ed.) Marine invertebrate fisheries: their assessment and management. John Wiley and Sons, New York.

Tegner, M.J. and R.A. Butler. 1989. Abalone seeding. Pages 157-182. *In*: K. Hahn (ed.) Handbook of culture of abalones and other gastropods. CRC Press, Boca Raton, FL.

Tegner, M.J., P.A. Breen, and C.E. Lennert. 1989. Population biology of red abalone, *Haliotis rufescens*, in southern California and management of the red and pink, *H. corrugata*, abalone fisheries. Fish. Bull., U.S. 87:313-339.

CALIFORNIA MARKET SQUID

History of the Fishery

The fishery for California market squid (*Loligo opalescens*) began in Monterey Bay in 1863 when a Chinese fishing village was established near Mussel Point. A skiff with a blazing torch at the bow was rowed about the bay at night until a school of squid was attracted to it. Two accompanying skiffs would then set a small hand-held purse seine around the school. Large numbers of squid were taken in this laborious manner, sun-dried, and exported, chiefly to China. In 1905, lampara nets capable of taking 20 tons in a single haul were introduced by Italian fishermen. The Italians took control of squid fishing using this superior equipment, although the Chinese and Japanese continued drying and marketing the catch.

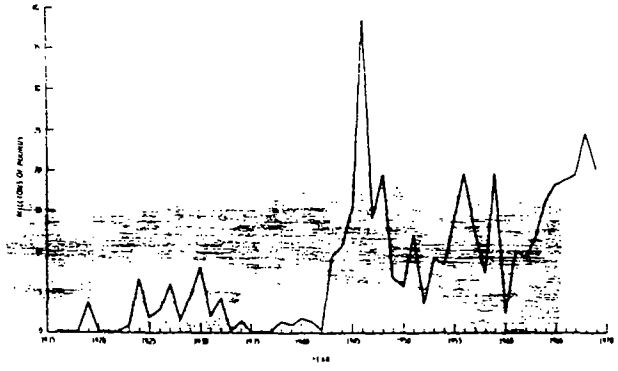
From 1916 to 1923, annual statewide landings only once exceeded 600 tons (1919). Landings averaged over 2,000 tons per year from 1924 to 1932, most of which was dried and shipped to China. During the 1920's, canning and freezing squid began for the domestic market. In 1933, the Asian market was closed due to financial conditions, and virtually no squid has been dried since then.

Canned and frozen squid for the domestic market supported the fishery after 1932, with annual landings averaging 578 tons from 1933 to 1942. In 1943, annual landings began to rise, reaching a peak in 1946 when just over 19,000 tons were landed. This was due to an abnormal demand by various United States and international aid programs.

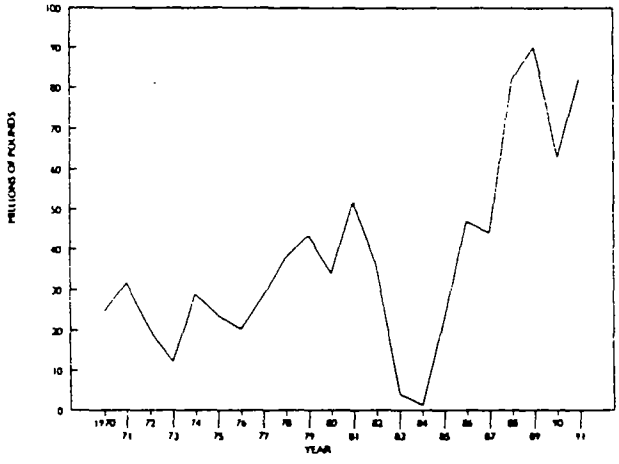
Statewide landings from 1947 to 1967 fluctuated greatly, with a high in 1959 of 9,822 tons and a low of 1,281 tons the

SMB-26772

following year. Annual landings for this period averaged 6,200 tons. Most recently, landings have fluctuated widely from a low of 622 tons in 1984 to a record high of 45,076 tons in 1989.



California commercial landings of market squid, 1916-1969.

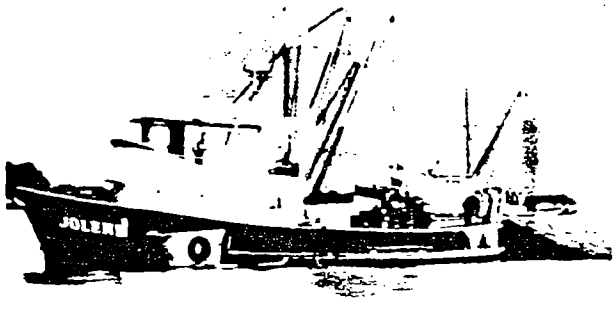


California commercial landings of market squid, 1970-1991.

Large-scale fluctuations are characteristic of the fishery and may be due, in part, to the short life span of the squid combined with fishing pressure of the previous year. Another probable reason for the fluctuations is climatological changes. A correlation has been suggested between temperature and squid catch 18 months later in Monterey Bay. Warmer than usual water temperatures usually preceded good landings. However, El Niños, periodic extreme temperature elevations, were followed by substantial declines in squid landings, notably in 1958, 1973, 1983 and 1984.

Since 1961, the California squid fishery has experienced a major change. Prior to 1961, the fishery had been centered mainly in the Monterey Bay area, while a much smaller fishery existed off southern California. Starting in 1961, the southern California squid fishery began to expand with a dramatic rise in landings in Santa Barbara area ports. From 1961 to 1982, the southern California annual landings averaged slightly more than those in central California. During 1983 and 1984, annual landings in both areas dropped below 1,000 tons following the 1982-83 El Niño. Since 1985, the southern California fishery has dominated statewide landings, averaging over 22,000 tons annually, while those of central California averaged about 5,700 tons. Southern California landings reached a record high in 1989, when 37,200 tons were landed. In 1990, southern California landings dropped to approximately 22,500 tons as some buyers and processors limited their daily purchase from each boat because smaller, less marketable squid prevailed throughout the area.

Central California landings recovered from the 1982-1983 decline with a peak in 1990, when 8,728 tons were landed. Annual landings, however, did not increase as dramatically as those of southern California, and did not exceed average historical levels. Monterey Bay squid also apparently decreased in average size from 1989 to 1990, but this did not affect market demand as in southern California.



Fishing for squid in Monterey Bay.

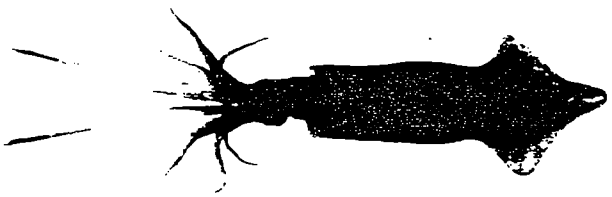
Southern California fishermen have, in recent years, expanded the area fished for squid. Much more effort is now being directed toward catching squid around the Channel Islands off the coast of Santa Barbara, resulting in the increased landings of the 1980's.

The California squid fishery targets schools moving into shallow waters (about 50 to 100 feet deep) to spawn. Most of the boats use strong lights to attract squid to the surface, where they are caught using roundhaul nets or brails. Nearly all squid in southern California are taken by purse seine or brail vessels. A small amount also is taken by the live bait fleet using either lampara or drum seine gear.

While attracting lights have been used in the southern California fishery continuously for many years, in the central California fishery a regulation was enacted which prohibited their use between 1959 and 1988. Fishermen sponsored the ban for protection from dealers who used lights in conjunction with dip nets on their piers and floating unloading platforms. In this manner, they had effectively eliminated the need for many fishing boats. Some fishermen also believed that attracting lights disrupted squid spawning activity, but no studies to date have addressed that issue. In 1988, fishermen were allowed to use attracting lights in the Monterey Bay area, except in the southern portion of the bay. The following year, attracting lights were permitted throughout the area.

Starting in 1989, fishermen were allowed to use all types of roundhaul gear (purse seine, drum seine, etc.) in the southern bight of the bay, which previously had been restricted to lampara nets for squid. By the end of 1990, nearly the entire fleet had switched over to purse seine or drum seine gear and the use of lampara nets had virtually ceased in Monterey Bay.

Currently, the vast majority of squid is frozen for human consumption. Much of this is exported to Japan and Europe. Other uses include fresh and canned squid for human consumption, and fresh or frozen squid for bait.



Market squid, *Loligo opalescens.*

Status of Biological Knowledge

The California market squid ranges from southeastern Alaska to Bahia Asunción, Baja California, Mexico. This pelagic mollusk attains a length of 12 inches, including its eight arms and two feeding tentacles. Several other squid species occur off the California coast, but these are normally associated with deeper offshore waters.

Spawning market squid tend to congregate in semi-protected bays, usually over a sand bottom with rocky outcroppings. Mass spawning starts around April in central California waters and ends about November. In southern California waters, mass spawning starts around October and ends about April or May. During some years, however, squid spawning, and landings, may occur throughout most of the year.

Adults typically spawn at one to 1.5 years and die after spawning. Some may delay spawning and live to a maximum age of two years. The male transfers a bundle of spermatophores with a specialized left ventral arm into the female's mantle cavity near the oviduct. The eggs are laid in elongate capsules, each of which may contain as many as 300 eggs embedded in a gelatinous matrix. Each female produces from 20 to 30 egg capsules, attaching one end of each capsule to the sea floor or other suitable site. Females are visually stimulated to lay their eggs by the presence of other egg masses, resulting in egg capsule clusters covering areas as large as 700 to 1,100 square feet. Several hundred to many thousand capsules may be laid together to form massive clusters. Small red polychaete worms have been observed boring in the capsules' gelatinous substance, but apparently do not feed on the developing embryos. The eggs, however, are preyed upon by bat stars and sea urchins.

Eggs hatch in three to five weeks. Newly hatched larvae are about 0.12 inches long, already resembling miniature adults. Schools often are composed of animals with a similar body size. Schools of smaller animals are not as cohesive as those of older animals.

Squid feed predominantly on euphausiids and copepods, as well as other small crustaceans, gastropods, polychaete worms, small fishes and smaller squid. Squid are prey for many fishes, birds and marine mammals. Several studies indicate the market squid plays an important role in the food web of many organisms along California's coast.

Packing squid at a processing plant in Monterey Bay area.

Status of Population

Little is known about the present size, structure or status of the population, but historical evidence from research cruises, as well as recent catch data, indicate the biomass is large. The California fleet fishes only spawning populations and in limited geographic areas, mostly in central and southern California. Other fishable concentrations of squid have been found occasionally along the coast from central California to British Columbia and southeastern Alaska, and short-term fisheries sometimes have developed in these areas.

Historically, the squid resource was considered by some to be underutilized; recently demand has sometimes exceeded the catch. Until more objective estimates of abundance are available, the true status of the population will remain unknown.

In 1977, the California Department of Fish and Game proposed yearly limits of 16,500 short tons each for the central California and southern California fisheries. These limits were designed to be conservative and allow for adjustment up or down, depending on how much biomass was assessed. However, appropriate assessment methods were never developed and this proposal was not adopted.

During the past several years, little work has been done to design squid population assessment methodology for Califor-

SMB-26774

nia. Past work, and work elsewhere, has included acoustic surveys and various collection techniques. Acoustical assessment of squid has been attempted off the central Oregon coast.

Squid can be more intensively harvested than can long-lived animals. But the fishery is often subject to extreme fluctuations based on each previous year's recruitment. However, as typically seen in short-lived, highly fecund animals, the squid population seems to have the ability to recover fully in a relatively short period of time.

Terri Dickerson and Robert Leos
California Department of Fish and Game

References

Cailliet, G.M. and D.L. Vaughan. 1983. A review of the methods and problems of quantitative assessment of *Loligo opalescens*. Biological Oceanography 2:2-3-4 (379-400).

Fields, W.G. 1965. The structure, development, food relations, and life history of the squid *Loligo opalescens* Berry. Calif. Dept. Fish and Game, Fish Bull. 131. 108 p.

Hurley, A.C. 1977. Mating behavior of the squid *Loligo opalescens*. Marine Behavior and Physiology 4:3 (195-203).

Kato, S. and J.E. Hardwick. 1975. The California squid fishery. Pages 107-127 *in* Expert consultation on fishing for squid. FAO Fish. Rep. 170, Suppl. 1.

Recksiek, C.W. and H.W. Frey. (eds.) 1978. Biological, oceanographic, and acoustic aspects of the market squid, *Loligo opalescens* Berry. Calif. Dept. Fish and Game, Fish Bull. 169. 185 p.

MOLLUSK RESOURCES: DISCUSSION

In 1990, California mollusk resources were valued at over $7.4 million to commercial fishers. Squid accounted for 99 percent of the total landed weight of 63.3 million pounds but only 68 percent of the total value. The five species of abalone accounted for 0.8 percent of the total landed weight but 31 percent of the total value. Other harvested molluscan species are of relatively minor commercial importance; local markets have developed for them due to availability and regional taste preferences.

Sport harvest for bait or human consumption exceeds commercial harvest for most molluscan species except squid, octopus, and probably whelks. Other species not considered in this section, such as limpets, jackknife clams, mussels and rock scallops, are frequently harvested by sport fishers.

Water quality problems, both natural and man-made, may prevent commercial and sport harvest of bivalve mollusks, primarily clams and mussels. Since most bivalves are filter feeders, they ingest microscopic plant and animal matter from the water column. At certain times during the year, particularly during the spring and summer upwelling season, heavy plankton blooms occur in nearshore waters, and filter feeders may ingest and concentrate toxins which are harmful to humans if consumed. California sea mussels are in this category, and each year the California Department of Health Services (CDHS) imposes a quarantine on them from May 1 to October 31. The mussel toxin can cause paralytic shellfish poisoning (PSP), and sampling and analysis of mussel tissue occurs throughout the year. The CDHS may impose other temporary quarantines if elevated PSP levels are found outside of the normal quarantine period.

A new toxin called domoic acid was discovered in central California in September 1991 and was linked to the deaths of pelicans and cormorants near Santa Cruz. This toxin is produced by a single-celled marine organism (diatom) unrelated to those which produce the PSP toxin, and it may be concentrated by mussels feeding on this organism. The toxin causes amnesic shellfish poisoning (ASP) and has caused deaths in persons consuming contaminated mussels from Prince Edward Island, Canada. It is likely that the toxin has always been present in California waters but until now has never been at a level high enough to cause problems. The CDHS began routine testing of mussels for domoic acid in October 1991.

Man-made water quality problems continue to prevent or discourage harvest of bivalves in the urbanized areas adjacent to California's coast and estuaries. Although wastewater treatment standards have significantly reduced the amount of pollutants entering California's waters, bio-accumulation processes still result in certain bivalve populations being unsafe to eat. For example, a potentially significant resource of Manila clams exists in the San Francisco Bay estuary, but water quality problems discourage public use in many clam beds.

California's molluscan resources are subject to a wide range of natural factors affecting their relative abundance. Annual recruitment of young-of-the-year animals is highly variable, and single year classes, such as that of the Pismo clam in 1990, may comprise a significant proportion of the total population for many years.

Severe storms may destroy local populations, either directly due to wave action on exposed coastlines, or indirectly. For example, lowered salinity in estuaries due to excessive rainfall and stream and river outflow may cause mortality in sedentary clam populations. Oceanic phenomena such as El Niño events may adversely impact squid stocks.

Rock crabs, starfish and rays prey heavily on clams and mussels. Many species of fish and birds are successful in foraging on bivalves. Natural predation may significantly reduce a population if a prey species increases its density or range. A well documented example is the effect of the extension of the sea otter population on central California's Pismo clam and abalone resources.

Disease has not often been implicated in reducing populations of California's mollusks. However, the "withering syndrome" in the black abalone population, coupled with fishing pressure, has resulted in a drastic decline in the southern California stock.

It is extremely difficult or impossible to obtain total population estimates for any of California's molluscan resources. Because of this, management recommendations regarding sport and commercial harvest rely primarily on bag limits, minimum size limits and season closures. If accurate population estimates are obtained, a management system based on annual or seasonal quotas and a fixed harvest rate may be more desirable.

SMB-26775

Specific Management Recommendations

(1) Continue to investigate the use of marine reserves in which no sport or commercial harvest is permitted, as a tool for enhancing mollusk populations.

(2) Conduct hydroacoustic surveys of the squid resource to determine absolute population abundance.

(3) Continue to work with the U.S. Fish and Wildlife Service to develop an effective management strategy for the California sea otter in regard to its potential impact on the northern California red abalone population.

(4) Continue to investigate causes of the "withering syndrome" in southern California black abalone.

(5) Continue to conduct studies of recruitment of red abalone in northern California.

(6) Change the sport limit for red abalone in northern California to three per day and six in possession.

Paul N. Reilly
California Department of Fish and Game

SMB-26776

SEA URCHINS

History of the Fishery

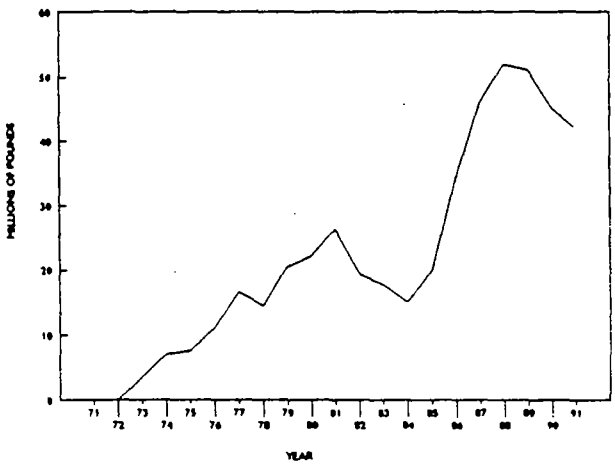
Sea urchins have been used by humans in California for thousands of years. Archaeological evidence shows that coastal Native Americans harvested sea urchins frequently. In the more recent past, prior to the early 1970's, relatively few people harvested sea urchins for local consumption. Only in the last 20 years has a large commercial fishery developed for sea urchins.

A commercial fishery for red sea urchins (*Strongylocentrotus franciscanus*) began in southern California during 1971 in the Avila and San Diego areas, as part of a National Marine Fisheries Service program to develop fisheries for underutilized marine species. A fishery was also seen as a way to reduce the population of red sea urchins, which were regarded as pests due to their destructive grazing on giant kelp. Since then, sea urchin landings have increased greatly and effort has expanded throughout the nearshore areas of southern California.

By 1973, sea urchin processing technology and connections with Japanese markets had developed sufficiently to support landings of more than 3.5 million pounds. In 1974, the southern California landings were twice those of 1973 and, by 1981, increased to nearly 25 million pounds. Contributing to the rapid escalation of the fishery was a ready pool of fishermen and boats involved in the similar, but declining, commercial abalone fishery. The 1990 ex-vessel value for whole sea urchins in southern California is estimated at nearly $14 million.

The majority of sea urchin landings in southern California have come from the northern Channel Islands off Santa Barbara, where large and accessible stocks occur. During the period 1973 through 1977, 80 to 90 percent of total landings came from these islands. In more recent years, however, there has been a relative decrease in the contribution from the northern Channel Islands as harvesting effort has increased at other locations such as San Clemente Island, San Nicolas Island, the Palos Verdes Peninsula, and the San Diego area. The smaller purple sea urchin (*S. purpuratus*) has fishery potential, but has been harvested on only a limited, experimental scale. A minor recreational fishery for sea urchins takes place in southern California.

A small commercial sea urchin fishery began in northern California in 1972, but it remained insignificant until 1977, when 386,000 pounds were harvested in the Albion to Fort Bragg region. An exponential increase in landings began in 1985, due partly to a more favorable monetary exchange rate for exported goods. Northern California (Half Moon Bay north) landings jumped from 1.9 million pounds in 1985 to 30.4 million pounds in 1988. Northern California landings exceeded those of southern California from 1987 through 1989. Northern California sea urchin landings were worth an estimated $8.3 million ex vessel in 1989. Virtually all of the northern California sea urchin landings had been red sea urchins until 1990, when a small fishery for purple sea urchins began. Northern California sea urchin landings began to decline in 1989, and preliminary landings data for 1991 show a 45 percent decline from the high of 1988. In northern California Fort Bragg remains the center of the fishery. The ports of Point Arena, Bodega Bay, and Half Moon Bay soon became active, expanding the fishery from the San Mateo coast and Farallon Islands north to the Shelter Cove area. The reefs around Crescent City also support a small fishery. There is a very minor recreational fishery for sea urchins in northern California.



California commercial landings of sea urchin, 1971-1991.

Commercial divers harvest sea urchins using conventional "hooka" gear, consisting of a low-pressure air compressor which feeds air through a hose to the diver. Harvesting takes place in depths of five to 100 feet, with most effort in the 20- to 60-foot range. Sea urchins are harvested from the ocean bottom with a hand-held rake or hook and put into a hoop-net bag or wire basket which is winched onto the boat and emptied into a larger net bag. Most boats used for harvesting sea urchins are small, ranging from 25 to 40 feet in length, and capable of holding one to three tons of sea urchins, an amount usually harvested in a day's fishing by one to three divers. In areas far from port, such as the outermost southern California islands, a larger "pick-up" boat may, for a fee, take the day's catch from several boats back to port.

Sea urchin processing is labor-intensive and involves cracking open the shell, gently removing and cleaning the gonads, and firming them in an alum-salt solution. The gonads of both sexes are equally valuable and are collectively referred to as "roe" or "uni". Roe quality is very important and depends on gonad size, color, texture, and firmness. Major factors affecting these criteria are the sea urchins' food supply and the stage of gonadal development. Sea urchins lacking a good food supply may have small, dark, coarse-textured gonads, unacceptable for the market. Gonads that are very ripe or spawned-out are of poor quality. A low price is often paid for sea urchins with marginal roe quality, and those with poor quality roe may be rejected by the processor. Divers frequently check roe quality while har-

SMB-26777

vesting to ensure that it is marketable. Southern California processors are located in the Ventura-Oxnard, Los Angeles-Long Beach, and San Diego areas. Northern California sea urchin processors are in Fort Bragg, Sacramento, and the San Francisco Bay area. It is estimated that over 90 percent of fresh sea urchin roe is air-freighted to Japan.

Packing sea urchin gonads or "uni" for export to Japan.

Management of the sea urchin fishery has evolved since 1987, when the fishery expanded into northern California, and more than doubled in size. A limited-entry permit system for divers, minimum size limits, and seasonal closures are used for reducing harvest effort and landings, to protect the resource and stabilize the fishery.

Status of Biological Knowledge

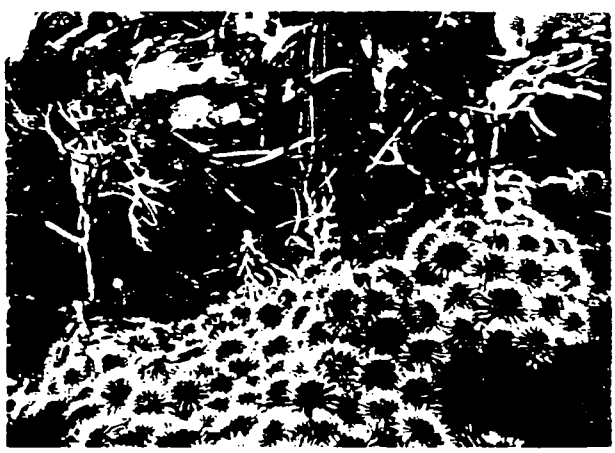
Sea urchins, which are members of phylum Echinodermata, possess a hard shell, called a test, which is covered with a thin epithelium and is armed with spines. The spines are used for locomotion, protection, and for trapping drifting algae for food. Between the spines project tube feet, which are used in food capture, locomotion, and for holding to the substrate. The bottom, or oral, side of the sea urchin contains the mouth, consisting of five calcareous jaws called Aristotle's lantern. Chewed food enters the digestive system and is excreted as pellets through the anus on the top, or aboral, side of the test. In addition to spines and tube feet, sea urchins possess small pinchers called pedicellariae, used for defense and for clutching food.

Four species of sea urchins occur in the nearshore waters of California. The red sea urchin is the largest and supports the present fishery. Both the red sea urchin and the purple sea urchin, a smaller species, occur statewide. The two remaining species occur mostly in southern California. The white sea urchin (*Lytechinus anamesus*) and the Coronado sea urchin (*Centrostephanus coronatus*) are both small, limited in distribution, and consequently of no interest to the fishery.

The red sea urchin is probably the most abundant herbivore of the kelp forest community in both numbers and biomass. It plays an important ecological role in kelp forest ecology and can affect the distribution and abundance of other nearshore species through its feeding behavior and physical presence.

Red sea urchins provide protection and living space for a variety of smaller marine animals. A microhabitat exists under sea urchins where shrimps, crabs, brittle stars, fish, abalone, juvenile sea urchins, and other invertebrates can be found. Although most of these animals may not depend solely on the spine-canopy habitat, the sea urchin's presence contributes to their abundance in the kelp community.

Red sea urchins feed mainly on algae. The perennial giant kelp is the preferred algal food in southern California, whereas sea urchins in northern California feed on the annual bull kelp and perennial brown algae. Red sea urchins feed mainly on sloughed or broken drift algae produced in the kelp bed. If preferred algae are lacking, sea urchins will eat other algae or small animals. Sea urchins may also resorb their own tissues in times of prolonged food shortage. Some evidence suggests that red sea urchins can subsist on dissolved nutrients in sea water. The red sea urchin's ability to survive during long periods of very low food availability is probably responsible for dense sea urchin populations persisting in many areas with poor algal growth.



Sea urchin feeding on kelp.

Although sexes are separate, the sex of a sea urchin is difficult to differentiate without microscopic examination of the gonads. Studies indicate that, under most conditions, red sea urchins become sexually mature at 1.5 to 2.0 inches (test diameter, exclusive of spines), which may be two years of age.

SMB-26778

Fecundity is high: female sea urchins spawn up to several million eggs. Following fertilization, a multistage planktonic larval period ensues which may last six to eight weeks. As the larvae mature and encounter suitable habitat, they settle to the bottom and metamorphose to the familiar spined benthic form. Owing to the relatively long planktonic phase, recruitment of juvenile sea urchins at a given location may not necessarily be dependent upon adult spawning at that location.

Sea urchin spawning appears to be cyclic. The spawning season can vary from year to year and from one locality to another. Food supply plays a role in the timing and magnitude of spawning. In most southern California locations, spawning generally occurs in winter. In northern California, major spawning occurs in spring and summer, with some spawning activity also in December.

Recruitment of juvenile red sea urchins in southern California is high and relatively constant in many areas. Over a three-year period, almost 50 percent of the population was less than two years old in the San Diego area. In northern California, recruitment seems to be lower and more sporadic. At several sites in 1989, juveniles made up only seven to 13 percent of the population. Sea urchin growth rates depend on an adequate food supply. Growth to a harvestable size of 3.5 inches probably requires four to five years or more. A reliable method of determining the age of adult sea urchins is not available, but sea urchins are comparatively long-lived, capable of reaching at least 30 years of age.

Several significant predators of red sea urchins are known. For example, California sheephead and California spiny lobsters both prey on them, and recent studies show that red sea urchin populations in habitats with sheephead and lobsters may be regulated to some degree by these two predators. In addition, starfishes, crabs, white sea urchins, and other fishes are known to eat red sea urchins. The most effective predator of red sea urchins is the sea otter; within the otter's present range, the red sea urchin resource has been reduced to a level which precludes fishery utilization.

Competition between red sea urchins and other benthic invertebrates is a matter of some conjecture. Red sea urchins are frequently mentioned as competing with abalone for both space and food. Sea urchins may be more successful in competing for limited food because of their aggressive foraging behavior; abalone may be more successful in competing for preferred living space if food is not limited. No doubt, intensive harvesting of abalone or sea urchins could alter these relationships.

Competition has been shown to occur between red sea urchins and purple sea urchins. Red sea urchins may also compete with white and Coronado sea urchins. Present patterns of distribution and abundance suggest that red sea urchins outcompete the others in middepth (15 to 65 feet) habitats. The response of small, nonharvested sea urchin species to intense harvesting of red sea urchins is unknown but may include an increase in the distribution and abundance of these small species. Sea urchin social behavior manifests itself in the formation of aggregations, which in some instances form fronts or masses of urchins that move through and overgraze stands of foliose algae. Juvenile sea urchins are often found in association with larger sea urchins, apparently gaining feeding benefits and protection from predation under the spine canopy of the larger sea urchins.

Status of Population

In southern California, the red sea urchin resource remains productive. Although fishing has significantly reduced density in many areas and catch per unit of effort has declined, strong juvenile recruitment has supported harvesting pressure. The high recruitment in southern California may be partly due to ocean current patterns in the Southern California Bight, which increase the chances for larvae to encounter habitat suitable for settlement. Continued high recruitment, however, is not guaranteed; in fact, intensive sea urchin harvesting in northern California and Baja California, Mexico could result in a decrease in sea urchin larvae in southern California in the future.

The northern California fishery has been characterized by rapid growth and decline. Catch per unit of effort declined during this period, as did mean test diameter of landed red urchins prior to the establishment of the 3.5-inch size limit. Low recruitment combined with intensive harvesting on the north coast could have a serious impact upon future harvests. The recently established size limit and seasonal closures may help prevent fishery collapse but may not improve recruitment, particularly if its success is primarily a function of oceanographic factors. Research efforts are underway to determine whether stocks can be augmented by seeding of hatchery-reared juvenile red sea urchins.

A notable consequence of intensive harvesting of north coast red sea urchins is an increase in size and number of kelp beds in intensively harvested areas.

David Parker
Peter Kalvass
California Department of Fish and Game

References

Himmelman, J.H. and H. Nedelec. 1990. Urchin foraging and algal survival strategies in intensely grazed communities in eastern Canada. Can. J. Fish. Aquat. Sci. 47:10011-1026.

Kalvass, P., I. Taniguchi, P. Buttolph, and J. DeMartini. 1991. Relative abundance and size composition of red sea urchin, *Strongylocentrotus franciscanus*, populations along the Mendocino and Sonoma county coasts, 1989. Calif. Dept. Fish and Game, Mar. Resour. Div. Admin. Rep. 91-3. 103 p.

Kato, S. and S.C. Schroeter. 1985. Biology of the red sea urchin, *Strongylocentrotus franciscanus*, and its fishery in California. Mar. Fish. Rev. 47(3):1-20.

Rush, E. 1988. Diving for gold: the saga of the sea urchin. Outdoor California. 49(5):1-5.

Tegner, M.J. and J.P. Barry. 1989. Size structure of red sea urchin (*Strongylocentrotus franciscanus*) populations in southern California: effects of growth, recruitment, predation and oceanography. Scripps Inst. Oceanography, Draft Rep. 50 p.

SEA CUCUMBERS

History of the Fishery

The first recorded commercial landings of sea cucumbers in California were made in 1978 in the Los Angeles area. Annual landings remained under 100,000 pounds until 1982 when the principal fishing area shifted to the Santa Barbara Channel. In that year 140,000 pounds were landed with an ex-vessel value of about $25,000. Recorded landings fluctuated from over 160,000 pounds the following year to almost nothing in several years, finally reaching 147,000 pounds in 1990 at an ex-vessel value of $36,000. Over 90 percent of the sea cucumbers harvested in California are caught by trawling, mostly in the Santa Barbara Channel. Two species of sea cucumbers are harvested in California: the giant red sea cucumber (*Parastichopus californicus*), also called the California sea cucumber, and the warty sea cucumber (*P. parvimensis*). The warty sea cucumber, which yields a more desirable product and brings a higher price, is generally harvested by divers and makes up a small percentage of the total landings. The giant red sea cucumber is largely caught by trawling in southern California, but is the object of dive fisheries elsewhere. Most of the California product is shipped to Hong Kong, Taiwan, and Chinese markets within the United States. The most common product form is dried.

There is no significant sport fishery for sea cucumbers in California due in part to regulations restricting take of certain marine invertebrates in nearshore tidal areas and because at present relatively few sport fishermen have shown an interest in sea cucumber as a food item. The possession of a special permit to fish for sea cucumbers commercially will be required beginning with the 1992-1993 fishing season. Qualification for the permit will be based upon meeting a minimum landing requirement in previous years.

Status of Biological Knowledge

Although sea cucumbers are in the same phylum as sea stars, sand dollars, and sea urchins, their cylindrical shape gives them the appearance of being misplaced in this group. Rather than possessing the dorso-ventral compression with mouth on the bottom and anus on top which is characteristic of other echinoderms, sea cucumbers are elongate with mouth and anus at opposite ends and have the appearance of lying on one side. Both species of *Parastichopus* possess tube feet on their ventral side which are used for locomotion, respiration, and sensory perception. The dorsal side contains papillae which are modified tube feet. The giant red sea cucumber is the largest California species and can grow up to 16 inches in length. It possesses fewer papillae than the warty sea cucumber, whose papillae are short and black-tipped. These sea cucumbers both are surface deposit feeders, using tentacles to ingest mud, sand, and detritus. Large amounts of indigestible debris are ingested at the oral end with the aid of tentacles and voided via the anus.

The giant red sea cucumber is found on the west coast of North America from Baja California to the eastern Gulf of Alaska. The warty sea cucumber is found from Monterey Bay to Baja California. Although the giant red sea cucumber is found in low intertidal and subtidal waters in the northern part of its range, it is usually subtidal to 300 feet in California. The warty sea cucumber is commonly found intertidally to at least 90 feet. It is uncommon and subtidal north of Point Conception.

Giant red cucumber, *Parastichopus californicus*.

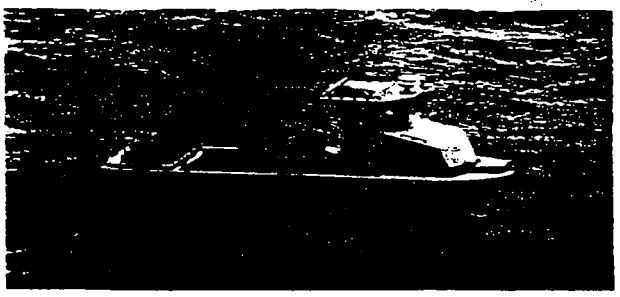
Both species are unusual in that they undergo seasonal gains and losses in weight. During the winter they lose up to 25 percent of their weight due to a process called auto-evisceration. During this process animals undergo visceral atrophy during which the gonad, water circulatory system, respiratory trees, and digestive system are reduced to primordial tissue by late winter. Regeneration starts soon after and condition is recovered during the feeding period in spring and summer months.

Like other echinoderms, sea cucumbers are broadcast spawners, with mature giant red sea cucumber females releasing up to several million eggs during a spawning period. Reproduction is associated with spring and summer warming trends. Length of the larval period has been shown to be quite variable with laboratory estimates at between 51 and 127 days from egg fertilization to larval settlement. Settlement tends to occur in areas where adults are present, though population densities of the giant red sea cucumber are generally low, much less than 0.05 per square foot in northern latitudes. Age of first maturity ranges between four and eight years and the maximum age is thought to be 12 years.

The giant red sea cucumber prefers areas without strong wave action. Adults tend to clump in rocky intertidal and subtidal areas with the largest individuals apparently found on sand; juveniles are thought to prefer mats of filamentous red algae away from adults. Sea cucumbers are preyed upon by sea stars and occasionally by sea otters, kelp greenling, and hermit crabs. Some species can crawl up to 300 feet per day and the giant red sea cucumber can avoid predators by a type of swimming motion.

SMB-26780

Status of Populations



A typical vessel used by divers in the sea urchin, abalone, and sea cucumber fisheries.

There is presently very little known about sea cucumber populations in California. Distributions on rocky or sandy substrates are characterized as patchy, without any apparent seasonal aggregating spawning or feeding behavior. Sea cucumbers have a relatively short life span, a low maximum weight, a low age at first maturity, and undergo sporadic recruitment and a relatively high natural mortality. Species with these traits tend to have a low maximum yield per recruit and are particularly vulnerable to overfishing. While it appears, based upon catch data, that southern California populations can sustain a small fishery, northern California populations, particularly in Sonoma and Mendocino counties, could be rather limited.

Peter Kalvass
California Department of Fish and Game

References

Anonymous. 1983. Guide to underutilized species of California. Natl. Mar. Fish. Serv. Admin. Rept. No. T-83-01. p.24.

Mottet, M.G. 1976. The fishery biology and market preparation of sea cucumbers. Wash. Dept. Fish., Shellfish Program, Tech. Rep. 22. 57 p.

SMB-26781

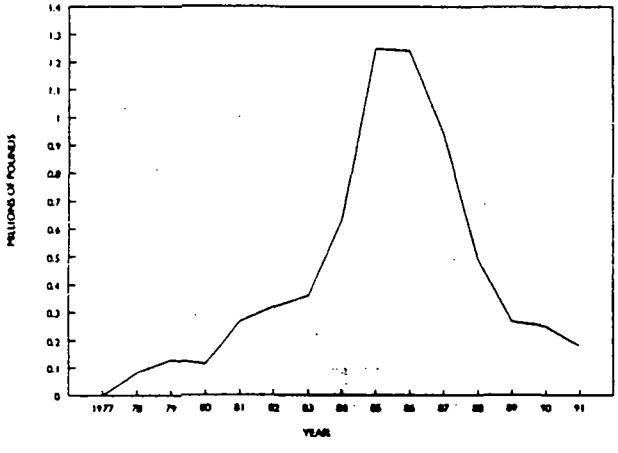
SHARKS, SKATES AND RAYS

PACIFIC ANGEL SHARK

History of the Fishery

Discarded as a nuisance species by halibut gill net fishermen for several decades, the Pacific angel shark (*Squatina californica*) became one of the most sought after commercial shark species in the Santa Barbara Channel during the 1980's. Changes in consumer acceptance of sharks as high quality food fish and a concentrated marketing effort by an innovative processor working with local fishermen, stimulated development of the angel shark fishery in the Santa Barbara Channel area in 1976. Two key elements led to the rapid growth of this fishery: maintenance of quality and freshness of the shark by cleaning and dressing (removal of head and fins) at sea; and development of a method to fillet this irregularly shaped shark to satisfy retail distributors and consumers.

In 1977 landings of dressed angel shark totaled 328 pounds. By 1981, landings rose to 258 thousand pounds, and by 1984, to 610 thousand pounds. Landings of angel shark exceeded one million pounds annually in 1985 and 1986, replacing the thresher shark as the number one species of shark taken for food in California.



California commercial landings of angel shark, 1977-1991.

Fishing effort throughout the early development and expansion phase was concentrated off Santa Barbara and Ventura counties and around the Northern Channel Islands, especially Santa Cruz and Santa Rosa Islands. Landings began to decline in 1987, dropping to 940 thousand pounds with an ex-vessel value of $542,000 and further declining to 248 thousand pounds ($166,000) in 1990. Most of the catch continues to come from the Channel Islands with increasing effort at Santa Catalina.

The ex-vessel price for angel shark in 1977 was 15 cents per pound. The price rose to 35 cents per pound in 1982 ($1.60 to $1.70 per pound at retail markets) as demand increased for the firm, white fleshed shark. With continued market demand and lower landings, ex-vessel prices in 1991 are 75 cents per pound dressed (head off) and 55 cents per pound whole. Retail prices have increased to $3.50 per pound.

Market development was linked to the popular but seasonal thresher shark, which is caught by the drift gill net fleet in the summer and fall. As supplies of thresher shark diminished in the winter, angel shark was promoted as a viable substitute. Local demand grew rapidly as Santa Barbara seafood retailers and restaurant owners found ready acceptance among consumers. In addition, angel shark taken by the set gill net fleet is available throughout the year.

Nearly every part of this shark, with the exception of skin, cartilage, and offal is utilized. The head and fins are sold as crab bait, large fillets are cut from the trunk, and portion-controlled pieces from the tail are used in fish and chips dishes. Small irregular shaped pieces are used to make shark jerky. A yield of 50 percent of the dressed shark (25 percent of the live weight) is generally expected.

The development of markets for angel shark was a significant benefit to halibut fishermen, providing them with a supplemental source of income. As demand increased for angel shark, innovative fishermen developed nets to harvest them specifically. Now most nets are 16-inch mesh (stretched diagonally), as such nets yield better results with less incidental catch. Because of their selectivity for market-sized angel shark, these nets catch only a few large California halibut. Nonetheless, 8 1/2 inch mesh gill nets designed for halibut continue to be used to take angel shark. Vessels used in the fishery are generally in the 25 to 40 foot range, suited for inshore coastal operations.

The inshore set net fishery will be allowed to continue only through 1994 due to the passage of Proposition 132, which bans gill nets in California state waters (inshore of the three mile line). Trawl vessels often catch a few angel shark incidentally, but landings are insignificant compared to the set gill net harvest. Fishing methods for small commercial boats which duplicate the ease of operation, efficiency, size selectivity, and return on investment of set gill nets have not, as yet, been developed. The periodic catch of marine mammals is a factor which contributes to a negative public perception of gill nets.

A cooperative fisheries research effort between Santa Barbara Channel angel shark fishermen, processors, Department of Fish and Game (DFG) biologists, university researchers and extension personnel began in 1979 to obtain information on angel shark distributions, migrations, growth rates, and eventually reproductive rates. Members of the commercial fishing industry, some of whom had experienced the dramatic decline of the soupfin shark fishery in the 1940's, helped initiate the investigations. Coupled with university research, the investigations helped fisheries managers develop a management plan in 1986, with the participation and cooperation of the fishing community. Development of regulatory guidelines for this, and a few other fisheries, is an example of a "co-

SMB-26782

management" approach involving a partnership of managers and resource users. The drop in landings after 1986 was partially attributed to a new size limit, though fisheries biologists and fishermen agree that management regulations were initiated too late to maintain a sustainable yield angel shark fishery with the harvest levels experienced in the mid-1980's.

Pacific angel shark, *Squatina californica.*

Status of Biological Knowledge

The Pacific angel shark is reported to occur only in the eastern Pacific ocean from southeastern Alaska to the Gulf of California and from Equador to southern Chile. A gap in distribution separating subpopulations of *S. californica* occurs between the equator and 20° north latitude. The southern population was earlier reported as a separate species, *S. armata.*

Angel sharks are relatively small, bottom-dwelling elasmobranchs, attaining a recorded maximum length of five feet and a weight of 60 pounds. Angel sharks caught commercially in the Santa Barbara Channel generally range in size between three and four feet total length, although size limits now allow the take of females 42 inches and above and males 40 inches or more. Angel sharks are reported to range in depth from three to over 600 feet. Researchers observed the species frequently between 50 and 130 feet around Santa Catalina Island and fishermen working the northern Channel Islands report that most of their catches are between 30 and 240 feet.

Pacific angel shark are usually found lying partially buried on flat, sandy bottoms and in sand channels between rocky reefs during the day, but they may become active at night with tagged specimens near Catalina moving from a few feet to four nautical miles per night. However, individual sharks have been observed to remain in the same place with no apparent movement for up to 10 days.

Sonic tagging studies conducted at Santa Catalina Island indicated that 11 sharks with transmitter tags remained near the Island for up to 90 days, although movement around the Island was extensive. Conventional tagging experiments have also been conducted at Santa Cruz Island, Santa Catalina Island, and along the Santa Barbara County coastline. Recovery of 30 tags indicate that all but one angel shark remained in the same general vicinity in which they were tagged. The lone exception was a shark tagged on the coast and captured three and a half years later at Santa Cruz Island. Without further evidence from tag and recovery data, resource managers are assuming that isolated stocks may exist near islands, separated from the mainland and other islands by deep water channels (including San Clemente, San Nicolas, Santa Barbara, and Santa Catalina Islands).

Several techniques have been utilized in an effort to age angel shark, but to date aging this species has been unsuccessful. Researchers have observed that angel sharks are born with six to seven bands in their vertebral centra, but growth curves based on size and band counts were found to be atypical. Both centrum edge histology and size frequency analysis have proven inconclusive. Sharks grown in the laboratory, along with field-tagged, tetracycline-injected returns, indicated no periodic basis for band deposition in the vertebrae, but indicated that calcified band deposition is more related to rapid somatic growth.

Using combined tag and recapture data from several sources, along with juvenile growth data, estimated parameters of the von Bertalanffy growth equation were determined for the angel shark. These were utilized to plot growth curves to aid in constructing life tables and in developing management recommendations.

Reproductive studies using specimens collected from commercial gill net boats off the Santa Barbara County coast showed that sexual maturity in both males and females occurs between 35 and 39 inches total length. Embryos present per female range between one and 11, with a mean of six pups produced annually from March to June. A 10 month gestation period was estimated for this species.

Major prey items of angel shark reported by researchers at Catalina include queenfish and blacksmith in the summer and market squid in the winter. Fishermen in the Santa Barbara Channel report that mackerel and Pacific sardines are found in angel shark stomachs during the fall and early winter, along with squid which predominates during the winter and spring.

Status of Population

The rapid increase in angel shark landings between 1983 and 1986 led to concern that stocks were being over-exploited. Over 79,000 individual angel sharks were reported to have been taken during the 1985-86 season (March to April). Considering the low fecundity and apparent lack of significant migrations of angel sharks, the need to develop a management plan became critical. A minimum retention size limit was proposed by DFG in 1987 and became law in 1989. Because these sharks are nearly always retrieved alive, limiting retention size is a viable regulation. However, landings had decreased before the inception of the regulation, indicating a declining population along the Santa Barbara-Ventura County coastline and around the Northern Channel Islands. The minimum size restriction is believed to have been effective in decreasing the numbers of immature sharks harvested, and also to have decreased harvest pressure on exploited stocks. However, additional population studies are needed to confirm this effect.

John B. Richards
University of California, Santa Barbara
Sea Grant Extension Program

References

Bedford, D.W. 1987. Pacific angel shark management information document. California Department of Fish & Game, Long Beach (unpublished document).

Cailliet, G.M. 1990. Elasmobranch age determination and verification: an updated review. In: Elasmobranchs as living resources: Advances in the biology, ecology, systematics, and the status of fisheries. H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.) NOAA Tech Rept. 90 (1990)

Natanson, L.J., G.M. Cailliet, and B.A. Weldon. 1984. Age, growth, and reproduction of the Pacific angel shark (*Squatina californica*) from Santa Barbara, California. Am. Zool. 24(3):130A.

Richards, J.B. 1987. Developing a localized fishery: the Pacific angel shark, p. 147-160. *In*: Sharks: an inquiry into biology, behavior, fisheries, and use. S. Cook (ed.) EM 8330. Oregon State University Extension Service, Corvallis, OR.

LEOPARD SHARK

History of the Fishery

The leopard shark (*Triakis semifasciata*) is valued as both a food and game fish in California; it is not uncommon in fresh fish markets and has a firm, mild-tasting flesh. The distinctive markings and hardiness of this fish also make it desirable for aquarium displays.

The scope of the fisheries for leopard shark is difficult to estimate for two reasons: an unknown portion of the commercial catch may be landed under the general category "shark, unspecified"; and statistics on leopard sharks caught by recreational anglers have been inadequate until the beginning of the last decade.

Total commercial landings for California reported under the "leopard shark" category have ranged from 9,270 pounds in 1958 to 101,309 pounds in 1983. The value to fishermen averaged around $37,000 per year in the 1980's. These landings, while not extensive, have increased in the south and decreased in the north over the past decade. Landings in southern California began increasing in 1981, and in 1985 surpassed landings in northern California for the first time since the collection of statistics began in the 1940's. Legislative curtailment of inshore gillnetting in the San Francisco/Monterey Bay area probably contributed to much of the decline in northern California landings after 1986.

Judging from estimates made since 1980 by the National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistics Survey, the recreational leopard shark catch appears to be greater, although these estimates are subject to large sampling variability. According to the survey, sport landings in California between 1980 and 1987 averaged over 270,000 pounds per year and were estimated at 719,608 pounds in 1987.

The importance of recreational anglers as users of the resource in central California was confirmed by analysis of recovery patterns of 948 tagged fish released in the San Francisco Bay area in 1979 by the NMFS. About 82 percent of the 108 recoveries were returned by sport anglers, while only 12 percent were returned by commercial fishermen. Of the recreationally caught returns, 54.5 percent came from skiff/private boat anglers, 40.9 percent came from shore anglers, and only 4.5 percent came from partyboat anglers. Leopard sharks are commonly taken from piers and jetties, and are known to congregate around the warm water outfalls of power plants.

A variety of fishing methods and gear types are used in the fisheries for leopard sharks: angling with baited hooks, spearfishing by divers, gillnetting along the coast, and some commercial longlining. Recreational spearing reportedly occurs in Humboldt Bay in shallow water. Gillnet catches will probably continue to decline with increasing legislation restricting use of these nets in coastal waters. Some leopard sharks are also taken incidentally in ocean bottom trawl catches.

Because of its slow growth rate, late sexual maturity, low fecundity, and easy accessibility to fishermen, this species is considered susceptible to fishing pressure. Fishing mortality rates and life history parameters indicate that with the current amount of fishing pressure, some measure of protection would be necessary to assure population replenishment.

Leopard shark, *Triakis semifasciata*.

Status of Biological Knowledge

The leopard shark, also known as "tiger shark" and "cat shark," ranges from Mazatlan, Mexico, into the northern Gulf of California, and north to Oregon. Abundant in cool to warm temperate zones, it is most common in shallow water from the intertidal down to 15 feet and less so in deeper water down to 300 feet. This species seems to favor enclosed muddy bays and sloughs, especially in northern California, although it is not unusual to find it along the open coast and around islands off southern California, where it frequents kelp beds and sandy bottoms near rocky reefs.

The population structure throughout its range is not clearly understood, but is thought to consist of regional stocks among which there is relatively little exchange. Nevertheless, tagging studies in central California have shown that there is some mixing between stocks in San Francisco Bay and Elkhorn Slough in Monterey County. There is no information on exchange among other regional stocks, but such exchange is presumed to be limited.

By examining calcified growth zones in vertebral centra, age and growth of leopard sharks from central California have been determined. Growth rate is generally slow (averaging less than one inch per year), with considerable individual variation. The maximum recorded and verified length is about six feet; however, most adults are smaller than that. The maximum age is presumed to be around 30 years; the oldest ages that have been determined by reading calcified rings on vertebrae, are 24 years for a 53-inch male, and 20 years for a 51-inch female. The

SMB-26784

largest female aged so far (a 55-inch specimen) was estimated at 19 years. Size at birth is about eight to 10 inches in total length.

The live-bearing female leopard shark produces from seven to 36 offspring in an annual reproductive cycle. Males mature at seven years, and females at 10 years, when fish reach lengths between 40 and 42 inches total length. The gestation period is estimated at 10-12 months. Birth apparently takes place in the spring from March through July. The only known eye-witness account of leopard sharks giving birth in the wild is that of a fisherman who observed pupping activity at Catalina Island in southern California in the 1940's. Dozens of large females, with backs and dorsal fins breaking the surface of the water over a shallow mudflat in Catalina Harbor, were observed releasing their pups in the three to four-foot deep water; some of the pups were seen milling around in water only about a foot deep.

This shark is an opportunistic benthic feeder. Invertebrates taken include crabs, ghost shrimp, clam siphons and sometimes whole clam bodies, polychaete worms, fat innkeeper worms, and octopi. Fishes in the diet include herring, anchovy, topsmelt, croakers, surfperches, gobies, rockfishes, midshipman, flatfishes, and small elasmobranchs such as smoothhounds, guitarfish, and bat ray. Leopard sharks seasonally consume the eggs of herring, topsmelt, jacksmelt, and midshipman.

Predators of the leopard shark are not known, but young or smaller individuals may be preyed upon by larger sharks such as the sevengill and sixgill sharks, which are known to enter bays. The phenomenon of young sharks being preyed on by larger sharks is not uncommon.

These strong swimming, nomadic sharks often occur in schools, sometimes with smooth-hounds, which also belong to the houndshark family. Numbers of animals may suddenly appear in an area, then move on. Although generally timid and wary of divers, there is one record of an attack on a skin diver in 1955 in California. Pectoral fin nipping of smaller individuals by larger ones has been observed in fish held in captivity. Evidence attests to the hardiness of these fish, both in their ability to thrive in captivity, and in their capacity to recover from the trauma of hooking injuries.

Migrations of this species have been studied in central California. Results of the San Francisco Bay tagging project revealed that at least 10 percent of the resident population moves out of the bay into the ocean during fall and winter. A fish tagged in San Francisco Bay was recaptured in Elkhorn Slough and vice versa, indicating some exchange between these stocks.

Status of Population

The size of the California leopard shark population has not been estimated, and the only information on relative changes in stock abundance is that which can be inferred from catch statistics. There is evidence, however, that fluctuation in catches may not be a reliable indicator of changes in stock abundance, as environmental conditions may also affect patterns of availability or vulnerability of leopard sharks to capture. Increased commercial and recreational catches have been observed in the San Francisco area in heavy delta outflow years, increases that tagging results indicate do not appear related to immigration of sharks from other areas.

Susan E. Smith
National Marine Fisheries Service

References

Kusher, D.I., S.E. Smith, and G.M. Cailliet. In press. Validated age and growth of the leopard shark, *Triakis semifasciata*, with comments on reproduction. Environmental Biology of Fishes.

Russo, R.A. 1975. Observations on the food habits of leopard sharks (*Triakis semifasciata*) and brown smoothhounds (*Mustelus henlei*). Calif. Fish Game 61:95-103.

Smith, S.E. 1984. Timing of vertebral band deposition in tetracycline-injected leopard sharks. Trans. Am. Fish. Soc. 113:308-313.

Smith, S.E. and N. Abramson. 1990. Leopard shark *Triakis semifasciata* distribution, mortality rate, yield, and stock replenishment estimates based on a tagging study in San Francisco Bay. Fish. Bull., U.S. 88(2):371-381.

THRESHER SHARK

History of the Fishery

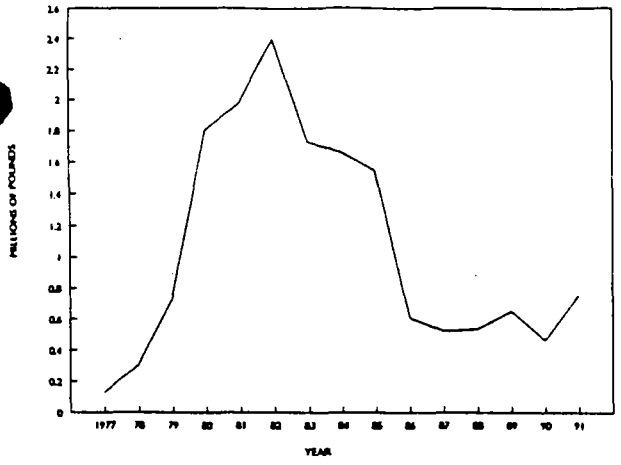
For a short span of 10 years beginning in 1977, the thresher shark (*Alopias vulpinus*), also known as the common thresher, was the subject of an important commercial fishery. During its peak year, 1982, over 2.3 million pounds of dressed meat were processed for California fresh fish markets. This fishery began and expanded rapidly, driven by a new public health consciousness and consumer acceptance of shark meat as a dietary alternative. It ended almost as suddenly due to overfishing, necessitating the implementation of increasingly strict regulations.

During the early years of commercial harvesting, threshers were pursued in waters off southern California and the Channel Islands. But each year after 1982 brought a new expansion to the north, first to Morro Bay, then to Monterey and San Francisco. During the later years, experimental fishing was conducted off the Columbia River mouth off Oregon and Washington.

The thresher shark is still pursued to a far lesser extent by local fishermen from ports between San Diego and Morro Bay, but now primarily as an incidental catch in the more profitable drift gill net fishery for swordfish. The coastwide fishery for the once abundant thresher is now a thing of the past. It may be many years before stocks can once again begin to support the demands of commercial exploitation.

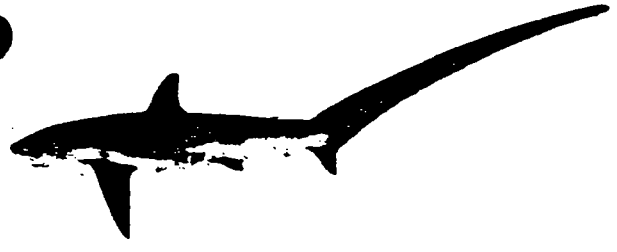
The commercial thresher shark and subsequent swordfish fisheries brought with them the introduction of the large mesh (14 to 20 inches), surface or drift gill net. These are nets measuring up to 6,000 feet in length and spanning to a depth of 60 to 100 feet. When fished, the drift gill net hangs vertically in the water column stretched between a buoyant corkline and a lead-core line. During fishing operations the boat remains attached to one end of the net in order to keep the net stretched to its full length. These nets have proven to be highly efficient in capturing pelagic shark species.

SMB-26785



California commercial landings of common thresher shark, 1977-1991.

Over the last several years some important steps have been taken to further reduce harvests of the thresher shark. Out of concern for declining stocks, Oregon canceled experimentation with the development of a coastal thresher shark fishery. Simultaneously, Washington canceled its experimental fishery, although the reasons given had more to do with the incidental take of marine mammals and sea turtles, than with concerns that the thresher shark stock might be declining. In California, seasonal restrictions on the use of drift gill nets have now eliminated the directed fishery for these sharks.



Common thresher shark, *Alopias vulpinus*.

Status of Biological Knowledge

The thresher shark is distributed throughout the coastal regions of the warm and temperate oceans of the world. It appears to be abundant only within a distance of about 50 miles from land. This coastal habit, along with its worldwide distribution, implies that there may be many isolated subpopulations or stocks. The hypothesis that a local stock exists in the eastern Pacific is supported by evidence gathered from the west coast fishery. During the short duration of this fishery, some age segments of threshers were depleted. These have not been replaced by inmigration from the outside. Other evidence includes differences in size at reproductive maturity from different geographic areas within the world population distribution. Similarly, there are differences in the number of young carried by pregnant females. For example, studies conducted in the Indian Ocean found that 8.5-foot females were mature and bore only two pups. Off California females do not mature prior to reaching 14 feet and typically bear four pups.

If such a local stock does exist, then observational evidence suggests that its distribution ranges seasonally from approximately mid-Baja California, Mexico, to Vancouver Island, British Columbia, Canada.

It has been estimated that thresher sharks may live for more than 30 years, although estimates of age for individuals are still somewhat crude. Females may attain a total length of about 20 feet. Males are smaller, growing to a maximum length of about 16 feet. Off the U.S. west coast, female threshers mature at a total length of approximately 14 feet, males at about 11 feet. Since the tail of the thresher makes up about half its total length, these lengths may seem deceptively large. The female will attain this length in about seven years; the male will reach his mature size in about five years.

As with all shark species, reproductive rates are very low. This is uncharacteristic of most fishes and is similar to reproduction in mammals. The thresher shark gives live birth to fully developed pups. Mating takes place during the midsummer. The gestation period lasts nine months. Annually during the spring months, the female may give birth to an average of four pups, each having already attained a length of four to five feet. Reproduction is ovoviviparous, meaning there is no placental attachment to nourish the developing embryos. Instead, they obtain their nourishment by eating other eggs within the uterus. This arrangement is entirely unique to some shark species.

The shallow nearshore waters off southern California provide a suitable nursery area for thresher sharks where they spend the first couple of years of life. During most years concentrations of young threshers may be found within two or three miles off the beaches from Santa Barbara County through Santa Monica Bay. During unusually warm-water years these young fish may be found as far north as Monterey Bay.

Despite their large size, thresher sharks have relatively small teeth and a small mouth. Their diet consists mostly of bait fishes, the principal one being the northern anchovy. Unlike the other pelagic shark species off California, the thresher does not appear to be an opportunistic feeder. During warm-water years, when pelagic red crabs are present in great quantities, it has been observed that threshers taken from a net that also contains blue sharks or shortfin makos will have only anchovies in the stomach, while the other sharks may be gorged on the far more abundant pelagic red crabs.

Probably few predators exist for the thresher shark due to its large size even at birth. Aside from man there is only one known. A large mako shark approximately seven feet in length was found to have two thresher pups in its stomach.

It is apparent from the records of the drift gill net fisheries from California, Oregon, and Washington, and from the California inshore set gill net fisheries, that a migration of thresher sharks moves north and south annually along the west coast. Large adult threshers pass through southern California waters in the early spring of the year. They appear to remain in these offshore waters from one to two months. This coincides with the time of pupping, after which the newborn pups move into shallow nearshore waters. The adults then continue to follow the warming

SMB-26786

water and perhaps schools of bait northward. By late summer these large adults have arrived off Oregon and Washington.

During early summer subadult members of the stock arrive off southern California. As summer progresses these subadult threshers also move up the coast but do not appear to continue much farther north than about San Francisco.

By fall this migration has reversed. Subadults once again arrive in waters around the Channel Islands. It is not known what happens to the large adults which are not seen again until the following spring. Perhaps they do not return to waters off southern California until winter, when fishing activity has normally ceased. Very young individuals remain in local, nearshore shallow waters off southern California until they reach two or three years of age. At that time, they too presumably begin the annual migration.

Status of the Population

Between 1977 and 1982 the subadult (4- to 6-year olds) portion of the thresher shark population made up the bulk of the commercial shark fishery. During those years this segment of middle-size fish was effectively removed from the population, so that after the mid-1980's these subadult fish were almost undetectable in our daily sampling of the catch. The impact of this hole in the age structure of the coastal thresher stock will probably be felt for many years.

There can be little doubt that the thresher shark population of the west coast has been reduced substantially from what it was in the mid-1970's. During the early 1980's we believed that the reported Pacific wide distribution would act as buffer against overharvest and would, in effect, provide time to study the critical biological attributes of this species. Hindsight has shown that to be a poor and costly assumption. The repeated failures of other shark fisheries elsewhere in the world underscores the need for a fresh, more conservative approach to shark management. If there is a positive note, it is that the thresher shark may have provided west coast fisheries managers with a valuable lesson while there are still many other shark species in a relatively unexploited state.

Finally, while the thresher shark's low reproductive capacity places limits on its capacity to recover, there are recent reports from researchers sampling wholesale markets, that some midsize sharks are beginning to reappear in their samples. This is a positive sign that the very restrictive fishing regulations of recent years may be having a desirable effect.

Dennis W. Bedford
California Department of Fish and Game

References

Bedford, D.W. 1987. Shark management: a case history - the California pelagic shark and swordfish fishery. Pages 161-171 *in* S. Cook (ed.) Sharks - an inquiry into biology, behavior, fisheries, and use. Oregon State Univ. Extension Serv.

Cailliet, G.M. and D.W. Bedford. 1983. The biology of three pelagic sharks from California waters, and their emerging fisheries: a review. Calif. Coop. Oceanic Fish. Invest. Rep. 24:57-69.

Cailliet, G.M., L. Martin, J. Harvey, D. Kusher, and B. Weldon. 1983. Preliminary studies on the age and growth of blue (*Prionace glauca*), common thresher (*Alopias vulpinus*), and shortfin mako (*Isurus oxyrinchus*) sharks from southern California waters. Pages 179-188 *in* E.D. Prince and L.M. Pulos (eds.) Proceedings, international workshop on age determination of ocean pelagic fishes. NOAA Tech. Rep. NMFS 8.

Compagno, L.J.V. 1984. FAO species catalogue: sharks of the world, vol. 4. U.N. Development Programme, Rome.

Gubanov, Y.P. 1978. The reproduction of some species of pelagic sharks from the equatorial zone of the Indian Ocean. J. Ichthyol. 15:37-43.

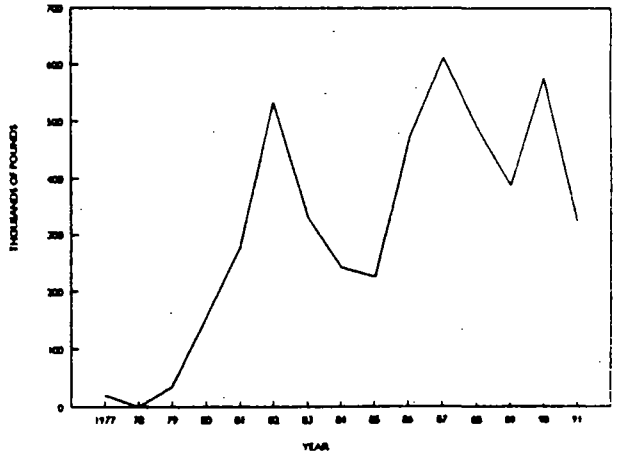
Strasburg, D.W. 1958. Distribution, abundance, and habits of pelagic sharks in the central Pacific Ocean. Fish. Bull. 138(58):335-361.

SHORTFIN MAKO

History of the Fishery

Since the late 1970's the shortfin mako (*Isurus oxyrinchus*), also known as the bonito shark, has been taken incidentally in the commercial drift gill net fisheries for thresher shark and swordfish. Not until 1987 was a fishery begun which specifically sought mako.

There are good reasons why the mako is only now becoming the primary target of a commercial fishery. Although readily marketable, the makos off southern California average only 34 pounds dressed. The thresher, which generated a major fishery during the late 1970's, had an average dressed weight of about 150 pounds. As long as threshers were plentiful, fishermen paid little attention to the mako. This situation might have changed during the mid-1980's when the thresher population began to show signs of a serious decline. But the drift gill net fleet which pursued the thresher also took a more valuable species - swordfish. These fish had a commercial value of $4 per pound, compared to $1 per pound for most sharks, and averaged nearly 200 pounds dressed. It is not surprising, then, that the drift gill net fleet has given little regard to the mako.



California commercial landings of shortfin mako (bonito) shark 1977-1991.

SMB-26787

It took the application of an entirely different fishing gear to create commercial interest in the mako. During 1988, the California Fish and Game Commission established an experimental shark fishery for makos and blue sharks using drift longlines. These longlines consist of three- to four-mile lengths of stainless steel cable to which leaders and baited hooks are attached. The cable is buoyed at intervals of approximately 250 to 300 feet so that the entire length of the longline remains in the near-surface zone. Ten vessels were given permission to use the gear in hopes that a market could be developed for the blue shark. After three years, little progress has been made towards achieving this objective, but it has been demonstrated beyond doubt that longlines are a potent gear for capturing makos. During the first year of operation, 240,000 pounds of mako were delivered by 10 vessels. Landings equaled the entire incidental catch by the 250-vessel drift gill net fleet.

At some point during the mid-1980's, the mako captured the attention of the southern California sport fishing public. It is curious that little attention had been given makos prior to that time since makos have been esteemed as game fish for many years along the U.S. east coast. But between 1986 and 1989, estimates of the number of California angler trips for makos grew ten fold from 41,000 to over 410,000 annually. Commercial passenger fishing vessels (party boats) now run shark fishing trips on a regular basis from nearly all southern California ports. The number of mako tournaments now takes second position only to marlin tournaments as southern California's most prestigious saltwater fishing events.

Shortfin mako shark, *Isurus oxyrinchus*.

Status of Biological Knowledge

The shortfin mako is distributed throughout the warm and mid-temperate oceans of the world. In the eastern Pacific, it ranges from Chile to the Columbia River, although during most years it is seldom seen north of Point Conception. It is considered an oceanic species and does not tend to venture into the green nearshore waters off our coastline. Evidence from tracking using sonic depth transducers indicates that while off southern California the mako remains in the warm offshore surface waters.

Very little is known about the existence of subpopulations or stocks from differing parts of the world's oceans, although given the shortfin mako's warm-water distribution, geographically isolated stocks must surely exist. Evidence from size availability, tag-recapture, and catch data suggests that southern California waters and waters off Baja California, Mexico, define the limits of an important nursery area for some segment of the Pacific shortfin mako population. High recapture rates for tagged juveniles reveal that newly born makos remain in these waters for about two years after birth. Mature and subadult individuals are rare off California. The commercial and sport catch consist almost entirely of newborn to two-year-old fish.

There is an ongoing disagreement surrounding the proper aging of shortfin makos, particularly in the large size classes. Young makos appear to grow fairly rapidly. A two-year-old fish may reach nearly five feet in total length. After two years, however, growth rate is less well defined. The maximum size reported was about 13 feet. It is possible that this fish was as old as 40 years.

Males mature at six feet, while females do not mature until they reach approximately nine feet. Females either mature at a much later age than males, or the sexes grow at greatly differing rates. The truth probably lies somewhere in between. Accordingly, males may mature as early as four years, but females, even by the most generous estimates of growth, do not mature prior to seven or eight years.

A pregnant female may have up to 18 pups. Like the thresher, shortfin makos are ovoviviparous. The embryos have no umbilical attachment to the mother and receive all their intrauterine nourishment by eating other eggs. At birth, the pups are approximately 2.5 feet in length. Given what is known of the growth rate of young pups, this birth size is consistent with a gestation period of less than a single year. Much basic information is still to be learned about this important species.

The shortfin mako is a top carnivore in the ocean food chain. It is known to prey upon many species of fish. With its powerful streamlined frame and great speed, adults are known to prey on tunas. Other items in the adults' diet probably include several marine mammals. But the mako, like many of its oceanic relatives, is an opportunistic feeder. It may eat whatever is abundant in its surroundings.

Status of Population

The shortfin mako population, like other truly oceanic shark populations in the Pacific, is believed to be healthy and relatively unexploited. This evaluation, however, is based largely on a lack of information concerning exploitation rather than a positive affirmation of the health of the population.

Adult makos do not frequent California's coastal waters and so are not subject to local fisheries. The real threat to the mako population off California and elsewhere in the eastern Pacific lies in the potential for overdevelopment of fisheries within the coastal nursery. This threat is particularly insidious, as the effect of overfishing may not manifest itself for a number of years until the missing juveniles would themselves have become the spawning stock. A sudden population collapse might follow. One can only hope that the lessons learned from the thresher and other shark fisheries around the world will inspire a more conservative approach to future fisheries development on the shortfin mako and other shark species.

Dennis W. Bedford
California Department of Fish and Game

SMB-26788

References

Cailliet, G.M. and D.W. Bedford. 1983. The biology of three pelagic sharks from California waters, and their emerging fisheries: a review. Calif. Coop. Oceanic Fish. Invest. Rep. 24:57-69.

Cailliet, G.M., L. Martin, J. Harvey, D. Kusher, and B. Weldon. 1983. Preliminary studies on the age and growth of blue (*Prionace glauca*), common thresher (*Alopias vulpinus*), and shortfin mako (*Isurus oxyrinchus*) sharks from southern California waters. Pages 179-188 *in* E.D. Prince and L.M. Pulos (eds.) Proceedings, international workshop on age determination of ocean pelagic fishes. NOAA Tech. Rep. NMFS 8.

Compagno, L.J.V. 1984. FAO species catalogue: sharks of the world, vol. 4. U.N. Development Programme, Rome.

Pratt, H.L. and J.G. Casey. 1983. Age and growth of the shortfin mako, *Isurus oxyrinchus*, using four methods. Can. J. Fish. Aquat. Sci. 40:1944-1957.

Stevens, J.D. 1983. Observation on reproduction in the shortfin mako *Isurus oxyrinchus*. Copeia 1983:126-130.

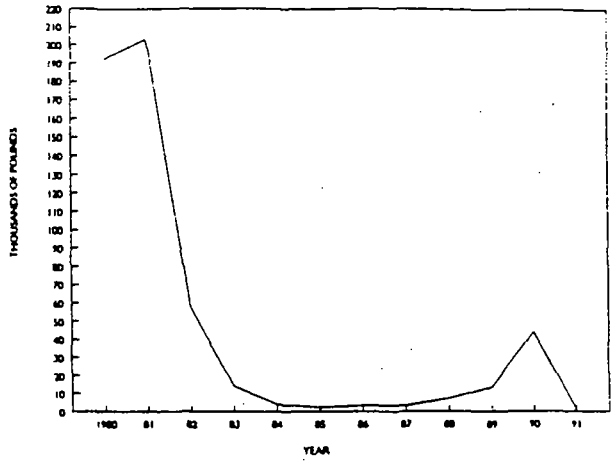
BLUE SHARK

History of the Fishery

Until recently blue sharks (*Prionace glauca*) were not a major target of California's recreational or commercial fisheries. Urea stored in their blood system quickly turns to ammonia when the shark dies, thus rendering the meat unpalatable. Development of a quality meat product has been the limiting factor in creating commercial interest. Only two serious attempts at developing a quality food product in California have occurred. The first took place in 1979 and 1980 when one vessel fished blue sharks experimentally with longline gear. Product quality was judged to be good enough to establish blue shark as a viable alternate fishery, and 150,000 pounds dressed meat were sold at about $0.25 per pound. Although market interest developed in several western states, a steady demand could not be assured and the fishery was discontinued.

The second attempt at developing a food product began in 1988 with an experimental longline fishery directed at shortfin mako (*Isurus oxyrinchus*) and blue shark. Participants in the fishery were required to develop a market for human consumption with the bycatch of blue sharks which were not released alive. In 1989 and 1990, a total of 54,000 pounds of blue shark was sold for making jerky and "fish and chips." It was clear from these attempts however that a quality food product and related market had not been achieved. Participants in the fishery substantially reduced the incidental mortality of blue sharks by developing a hook removal tool which allowed up to 88 percent of the blue shark catch to be released unharmed. As a result, the requirement to develop a wholesale market for blue sharks was dropped in 1991.

The recreational catch of blue sharks has grown tremendously in recent years. Estimated annual catch increased 10-fold between 1981 and 1988 with over 400,000 angler-trips on private boats which had "sharks" (including mako sharks) as the primary or secondary target species. Most southern California sport fishing areas offer shark fishing trips aboard charter boats from two to seven nights per week. Catches average 10 to 40 blue sharks per trip, although this varies throughout year.



Commercial landings of blue shark, 1980-91.

The greatest source of fishing mortality for southern California blue sharks over the past two decades probably occurred as a result of their incidental capture during the developing years of the drift gill net fishery for swordfish and thresher sharks. Annual estimated bycatch in the late 1970's and early 1980's was between 15,000 and 20,000 blue sharks. Changes in season length, fleet size, time-area closures and the use of large mesh nets substantially reduced blue shark mortality, although there are no reported estimates of current mortality in this fishery.

Blue shark, *Prionace glauca*.

Status of Biological Knowledge

The blue shark is circumglobal in tropical and temperate waters. It is epipelagic and generally considered abundant in the coastal and offshore waters of the western United States and Mexico. In the north Pacific, seasonal migrations occur between 20° and 50° N latitude. The northward movement extends into the Gulf of Alaska as waters warm in the summer months, reversing southward during winter. A seasonal segregation by sex may be influenced by water temperature. Mature females tend to start their northward journey as warmer water moves northward while juveniles of both sexes follow close behind. Large males start later and tend to stay further offshore.

Blue sharks are viviparous. As such, developing embryos are nourished initially from a yolk sac. Once the yolk sac is exhausted, developing young obtain nourishment and oxygen from the maternal blood stream through a placenta. Blue sharks

SMB-26789

are released fully formed and independent at birth. Gestation is nine to 12 months. Brood size varies considerably depending on the females size and condition, with over 100 young in a single brood reported, although 20 to 40 young are more typical. Off California, mating occurs in late spring to early winter. The Southern California Bight (SCB) is a major birthing area and is generally considered a nursery area for immature blue sharks, where they are often seen cruising slowly with their dorsal fin and dorsal tail lobe sticking out of the water. Females mature at five to six years and males mature a year earlier. Maximum age is estimated to be at least 20 years.

Blue sharks feed opportunistically on small pelagic fishes including jack mackerel, northern anchovy, Pacific herring, market squid, and red crab. Juveniles make shoreward movements at night to feed in shallow water especially in the SCB, where numerous islands and submerged banks provide ample prey. They also feed on marine mammal carrion but are not known to attack healthy individuals.

Status of Population

The size of California's blue shark stock is unknown. Local abundance undergoes major seasonal fluctuations with juveniles to three year-olds most abundant in the coastal waters from early spring to early winter. Mature adults are uncommon in coastal waters.

Fishery-dependent data needed for determining abundance, mortality, etc. are lacking because blue sharks are usually discarded at sea and the catch often goes undocumented. Local abundance depends on recruitment of juveniles and immigration of individuals from Mexico and offshore into California waters. Although there are no abundance estimates (local or Pacific-wide), some fishermen and field biologists speculate that there are fewer blue sharks than there were 10 years ago. The combined mortality from recreational anglers, commercial set net and drift net fisheries, Mexican fisheries and foreign high-seas fisheries undoubtedly has the potential to impact the population and the local blue shark stock to an unknown extent.

David B. Holts
National Marine Fisheries Service

References

Harvey, J.T., 1989. Food habits, seasonal abundance, size, and sex of the blue shark, *Prionace glauca*, in Monterey Bay, California. Calif. Fish and Game. 75(1):33-44.

National Marine Fisheries Service. 1991. Marine Recreational Fishing Statistical Survey. Pacific Coast. (in Press) Current Fishery statistics number XXXX. NOAA, NMFS.

Tricas, T.C., 1979. Relationships of the blue shark, *Prionace glauca*, and its prey species near Santa Catalina Island, California. Fishery Bull. 77(1):175-182.

West Coast Fishery Development Foundation. 1981. A report on the development of the Pacific blue shark as a commercial fishery. NMFS, S-K Contract No: 80-ABH-00052. 255p.

COW SHARKS

History of the Fishery

Two species of cow sharks (family Hexanchidae) occur along the California coast: the sixgill shark (*Hexanchus griseus*) and sevengill shark (*Notorynchus cepedianus*). Sevengill sharks were among the most common species taken during shark fisheries of the 1930's and 1940's. Even after this fishery collapsed, these sharks were taken in considerable numbers during fishing competitions in San Francisco Bay in the 1950's and 1960's. The popularity of *Jaws* movies in the mid-1970's brought renewed interest in shark fishing. Several operators in the San Francisco Bay area targeted their charters on sevengill sharks, and as recently as the mid-1980's these sharks were still the object of a popular sport fishery in San Francisco Bay. Although caught primarily by recreational fishermen, sevengills are caught incidentally in commercial fisheries for other species.

The sixgill shark is also an incidental catch, especially in trawl and gill net fisheries. It frequently appears in fish markets and at dining establishments, but exact data on the extent of this fishery is lacking. Both species are typically either discarded or sold as "shark, unidentified," making it difficult to quantify landings.

Status of Biological Knowledge

The sevengill shark has a world-wide distribution in most temperate seas, the only notable exception being its absence from the temperate waters of the North Atlantic. In the eastern North Pacific, sevengill sharks range from southeast Alaska to the Gulf of California, with their distribution becoming sporadic south of San Francisco Bay.

It is a fairly common coastal species which frequently enters bays and, although rarely occurring below depths of 300 feet, is found occasionally to depths of over 600 feet.

Sevengill sharks are ovoviviparous. Males mature at about five feet and grow to about eight feet. Females mature at around seven and a half feet and may grow to at least ten feet. The young are born during the spring at between 14 and 18 inches after a year's gestation period. The litters are large, with 80 to 100 young being born per pregnancy. Humboldt Bay and San Francisco Bay are areas that sevengills use as breeding grounds. The young remain within the vicinity of the nursery grounds for the first few years of life, before ranging further afield upon entering adolescence.

The sevengill shark is an active predator that feeds at or near the top of the food chain. The main prey items include other sharks, batoids, teleosts, and marine mammals. In most areas where it occurs, the sevengill shark is displaced only by the white shark and killer whale as the top nearshore marine predator.

The sixgill shark is one of the widest ranging of all shark species, with a circumglobal distribution from northern and temperate areas to the tropics. It occasionally occurs close inshore, but is most common below a depth of 300 feet and has been recorded at depths of over 7,500 feet. In the eastern North Pacific, this species occurs from the Aleutian Islands at least to southern Baja California.

SMB-26790

The sixgill shark matures at about 10 feet for males and 13 feet for females. Adult males typically remain in deeper water, where mating and courtship take place. Females move onto the continental shelf during the spring to drop their litter. This is one of the most fecund species of sharks with a litter size between 50 and 100 young. The size at birth is between 24 and 29 inches. Newborn and juvenile sixgills usually remain on the shelf and uppermost slopes until they reach adolescence, at which time they move further down the slope and into deeper water. It is the newborns and juveniles that typically seem to stray close inshore and occasionally even occur in bays and harbors.

The sixgill shark is a large, active, powerful predator that feeds on a wide variety of prey species, including other sharks, rays, chimaeras, and bony fishes, as well as squids and crabs.

Status of Populations

The main concentrations of sevengill shark populations in California appear to be in Humboldt and San Francisco Bays, both of which serve as nursery grounds for newborns and juveniles. Damage to either of these areas could have an adverse effect on the population. Outside these bays there is little reliable information regarding the status of sevengill shark populations.

There is no information on the population status of the sixgill shark.

David A. Ebert
Ocean Resource Consulting Associates

References

Ebert, D.A. 1986. Biological aspects of the sixgill shark, *Hexanchus griseus*. Copeia, 1986(1):131-135.

_____. 1986. Aspects on the biology of hexanchid sharks along the California coast. *In*: Indo-Pacific fish biology: Proceedings of the second international conference on Indo-Pacific fishes (T.Uyeno, R. Arai, T. Taniuchi, and K. Matsuura, eds.), p. 437-449. Ichthyol. Soc. Jpn, Tokyo.

_____. 1989. Life history of the sevengill shark, *Notorynchus cepedianus* Peron, in two northern California bays. Calif. Fish Game, 75(2):102-112.

OTHER MACKEREL SHARKS

History of the Fishery

The mackerel sharks (Order Lamniformes) are a small, but diverse group containing seven families, five of which occur along the California coast. In addition to mako and thresher sharks, there are three additional mackerel shark species that are caught or have been fished along the coast: the basking shark (*Cetorhinus maximus*), white shark (*Carcharodon carcharias*), and salmon shark (*Lamna ditropis*).

The basking shark has been the object of occasional localized harpoon fisheries off the California coast and elsewhere. The fishery has been sporadic due to periodic declines in the stocks. As with most shark species the basking shark is slow growing, long-lived and probably produces relatively few young. The California basking shark fishery began in the 1930's and peaked during the 1940's and 1950's. The meat is utilized fresh or dried for human consumption, the fins may be used for soup, and the oil-rich liver for tanning leather and as a base for paints and cosmetics.

There has never been any directed fishery for white shark off California. However, they are often taken incidentally in commercial catches and by sport fishermen and, when caught, they bring a fairly high price, mainly due to their reputation as a man-eater. The jaws of a white shark can be sold for up to $5,000 a set. It has been estimated by one researcher that between 10 and 20 white sharks are caught per year along the California coast. Unfortunately, more accurate data are unavailable.

Salmon sharks are not very abundant off California, but are an occasional incidental catch in other fisheries, and are readily sold when caught. The flesh is good, and the fins are sought for shark fin soup. Salmon sharks are often considered an annoyance by fishermen because they destroy fishing gear used in more commercially important fisheries such as those for salmon.

Status of Biological Knowledge

A cold to warm temperate species, the basking shark's range in the eastern Pacific Ocean is from southeast Alaska to Chile, from the surfline and into enclosed bays, to well offshore. These sharks are sometimes common in coastal waters, usually when the water temperature is below 57° F.

Basking sharks are presumed to be ovoviviparous, but whether they have intrauterine cannibalism like other lamnoids is uncertain. Gravid females have never been observed in this species. Males mature at about 13 to 16 feet, and females at about 26 to 29 feet. The smallest recorded free-living basking shark measured 5.6 feet, but size at birth is unknown. Maturity has been estimated at six to seven years, although the aging technique has never been verified for this species and may underestimate the age by one-half.

The basking shark is one of three gigantic filter-feeding species of shark and feeds almost exclusively on small planktonic organisms that it traps in its gill rakers. The prey items include small copepods, barnacles, crustaceans, and fish eggs and larvae. Approximately one-half ton of food material may be present in the stomach of an individual shark. It has been estimated that an adult basking shark cruising at a constant speed of two knots passes approximately 2,000 tons of water over its gills per hour.

Basking sharks are highly migratory, appearing and then disappearing seasonally at specific localities. These sharks are especially abundant between October and April off the California coast but move northward to Washington and British Columbia during late spring and summer. Basking sharks are very social animals and are often observed in small groups of three to 10, but at times up to 500 or more individuals.

The white shark has a world-wide distribution from cold temperate to tropical waters, though it is most common in temperate to warm temperate waters between 54° and 68° F. In the eastern North Pacific the white shark occurs from the Gulf of Alaska to the Gulf of California. It is fairly common off central California and around the offshore islands of southern California.

SMB-26791

The white shark occurs along the nearshore waters of the California coast, including bays and estuaries, but sometimes may be oceanic since individuals are common around the offshore islands. There seems to be some spatial segregation by size, as young white sharks under eight feet and older ones over 16 feet are common off southern California, while intermediate sized animals are more common in northern California waters.

White sharks are thought to be ovoviviparous with intrauterine cannibalism. Litters of three, seven, and nine have been reported, but other details such as the mother's or embryos' size are not known. Male white sharks mature at about 12.8 feet and grow to at least 18 feet. Female maturity is less certain since no pregnant females have been captured and accurately measured, but it appears that 15 to 16 feet is a close approximation. The size at birth is probably between three and four feet. The Channel Islands off southern California seem to be an area where large females and small white sharks are occasionally captured, leading to speculation that females may give birth there.

The largest reliably measured white shark from California waters measured about 20 feet; however, there is an unconfirmed record of one individual that measured 29.5 feet. The growth rate of white sharks has been estimated to be around a foot per year, and they may live to a maximum age of 30 years or more.

The white shark is perhaps the most formidable of large marine predators. It has a broad spectrum of prey species that includes bony fishes, other sharks, rays, and marine mammals. Sharks over 10 feet long tend to feed on marine mammals while those less than six feet feed more on bony and cartilaginous fishes. White sharks tend to congregate around seal rookeries, especially when these mammals are breeding. Subadult and young nonbreeding adult seals appear to be more susceptible to predation.

The salmon shark range in the eastern Pacific Ocean is from the Bering Sea to southern California and possibly to Baja California. It is a coastal and oceanic shark of subarctic and temperate waters, most often found in temperatures of less than 64° F and depths less than 500 feet. The salmon shark is common in continental offshore waters to close inshore, but also ranges far from land in deep oceanic waters.

Salmon sharks are ovoviviparous with uterine cannibalism. They mature at about six feet for males and at about eight feet for females. Salmon sharks give birth to between two and four young per litter. Estimated age at maturity is five years for males and nine or 10 years for females and maximum age is probably between 20 and 30 years.

The salmon shark feeds mostly on bony fishes. They may follow their main prey, salmon, as they migrate around the North Pacific Ocean basin.

Status of Populations

The basking shark has not been commercially fished for over 20 years and no recent stock assessment has been made.

The population status of white sharks along the California coast is not known.

The salmon shark is an uncommon species in California waters and its abundance is not known.

David A. Ebert
Ocean Resource Consulting Associates

References

Ainley, D.G., R.H. Henderson, H.R. Huber, R.J. Boekelheide, S.G. Allen, & T.L. McElroy. 1985. Dynamics of white shark/pinniped interactions in the Gulf of the Farallones. Southern Calif. Acad. Sci. Mem. 9: 109-122.

Cailliet, G.M., L.J. Natanson, B.A. Welden, & D.A. Ebert. 1985. Preliminary studies on the age and growth of the white shark, *Carcharodon carcharias*, using vertebral bands. Southern Calif. Acad. Sci. Mem. 9: 49-60.

Parker, H.W. & F.C. Stott. 1965. Age, Size, and vertebral calcification in the basking shark, *Cetorhinus maximus*. Zool. Meded., 40(34): 305-319.

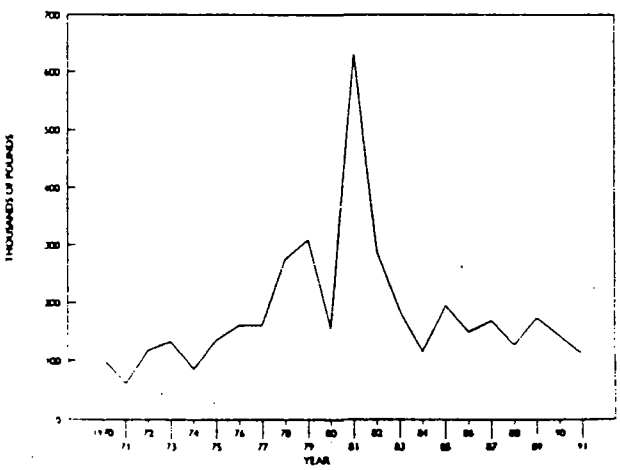
Paust, B.C. & R. Smith. 1986. Salmon shark manual. The development of a commercial salmon shark, *Lamna ditropis*, fishery in the North Pacific. Uni. Alaska, Alaska Sea Grant Rept. 86-01, May 1986: 1-430.

SKATES AND RAYS

History of the Fishery

Skates and rays are not specifically sought by commercial fishermen, but are taken incidentally, primarily by bottom trawlers offshore in central and northern California waters. A few nearshore species, most commonly the bat ray (*Myliobatis californica*) and shovelnose guitar fish (*Rhinobatos productus*) are the target of small sport fisheries.

Only the wings of skates caught in the commercial fishery are marketed. The bodies are either discarded at sea when the skates are landed, or occasionally sold as bait for the rock crab fishery. Skate wings are sold, fresh and frozen, predominantly in the oriental fresh fish markets in southern California. Wings are also dried or salted and dehydrated for the oriental trade. The economic value of the skate fishery relative to California's total fishery is extremely small. From 1958 to 1969 the ex-vessel price for skate wings ranged from $.01 to $.02 per pound. The ex-vessel price increased from $.12 per pound in the 1970's to $.25 per pound in 1991.



Commercial landings of skate, 1970-91.

SMB-26792

Historically, skates have been processed for fish meal, but most such enterprises experienced economic failure. Seafood restaurants and retail markets have been suspected at times of punching out rounds of skate wing to serve as cheap substitutes for scallops.

Central California (Monterey and San Francisco) had the majority of the skate catch from 1948 through 1989, accounting for 41 to 100 percent of the total landings. The northern California areas (Eureka, Crescent City, Fort Bragg) have played an increasing role since about 1975. Areas south of Monterey are relatively insignificant in terms of total landings. From 1916 to 1990 skate landings, which ranged from 36,247 pounds (1916) to 631,240 pounds (1981), comprised two to 90 percent of the total elasmobranch catch (11.8 percent average). Like the shark fishery, which had peaks from 1937 to 1948, and more recently from 1976 to 1990, the skate catch has fluctuated widely during the last half century.

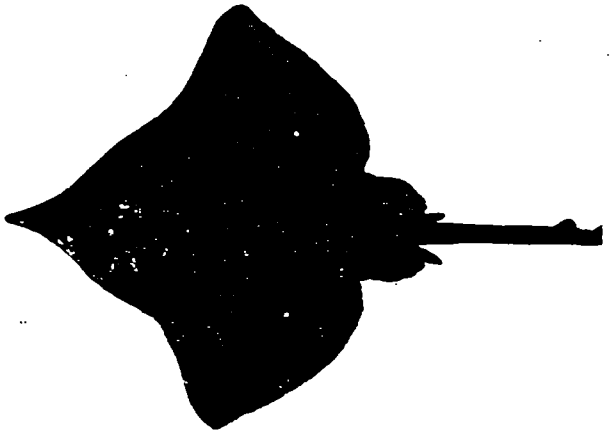
Status of Biological Knowledge

Skates and rays (batoids) can be distinguished from the sharks by having pectoral fins which extend above and in front of the gills, attaching to the head and forming an expanded and flattened disk with its gill slits located completely on the underside. They can be thought of as sharks flattened to accommodate a life spent on the sea floor. Twenty species of rays and skates have provisionally been recorded from California waters.

Rays and skates occur in all marine habitats, from protected bays and estuaries to open seas, ranging from the surface to 9,528 feet deep. While some species are common, others are known from only a few specimens. So far as is known, batoids follow the typical elasmobranch reproductive strategy in which sexual maturity is attained relatively late in life, brood size is relatively small, and fecundity is generally low. These characteristics make populations of these species susceptible to overfishing.

All batoids have internal fertilization, but have two different modes of development. The skates are oviparous. Following fertilization, the yolk is enclosed in a tough, permeable eggcase, which is deposited on the sea floor. The embryo develops within the eggcase, feeding on nourishment stored in the form of an attached yolk mass. After hatching, eggcases (known as "mermaid's purses") are frequently washed ashore to be found by beachcombers. All other batoids are live bearing, or viviparous. The embryo is protected by, and develops within, a portion of the female's oviduct which functions as a uterus. The gestation period for skates and rays varies widely; depending on the species it may range from two to 18 months.

Batoids feed on a variety of worms, mollusks, crustaceans, other invertebrates, and fishes. Some lie buried on the bottom to wait for prey, while others actively forage. As a group they have a wide variety of feeding strategies, ranging from straining plankton (manta), to electric shock (electric ray), to excavation and suction (bat ray). In turn, batoids are preyed upon by marine mammals, sharks and other large fishes. Their predator avoidance adaptations include cryptic (camouflage) coloration and burying themselves in sand or mud. In some species, rows of sharp spines on the back and/or tail also serve as protection. Only a few of the batoid species are dangerous to humans: electric rays are capable of producing a powerful shock, and stingrays can inflict serious wounds on unwary waders and fishermen.



Big skate, *Raja binoculata*.

THE SKATES

The skates are the largest group of batoid fishes. Nine species in two genera are presently known to occur in California waters. California's three commercially important skates are the California skate (*Raja inornata*), big skate (*Raja binoculata*) and longnose skate (*Raja rhina*).

The skates have a greatly flattened, usually rhomboidal shaped disk. Most species have enlarged thorns or sharp spines (denticles) on disk and tail. Adult males have rows of enlarged, hooked thorns along the front edge (malar thorns) and lateral edge (alar thorns) of the disk. The tail is slender, with two small dorsal fins located near the tip. The caudal fin is small or absent, and there are no stinging spines. Skates have paired electric organs along the sides of their tails which generate weak, low-voltage electric currents believed to be used in intra-specific communication, possibly for mate recognition or to demonstrate aggression.

The California skate ranges from the Strait of Juan De Fuca to off central Baja California. It is common inshore in shallow bays at depths of 60 feet or less, but also occurs in deeper water to a depth of 2,200 feet. Females and males both reach sexual maturity at a total length of about 30 inches. They feed on shrimp and other invertebrates.

The big skate ranges from the Bering Sea to off central Baja California, but is rare south of point Conception. It occurs at depths from 10 to about 2,600 feet, being most common at moderate depths. It is the only known California skate with more than one embryo per egg case. The big skate grows to a length of up to eight feet, but usually does not exceed six feet and about 200 pounds. Females mature at 12 to 13 years and a length of 51 to 55 inches; males mature at seven to eight years and a length of 39 to 43 inches. It feeds on crustaceans and fishes.

SMB-26793

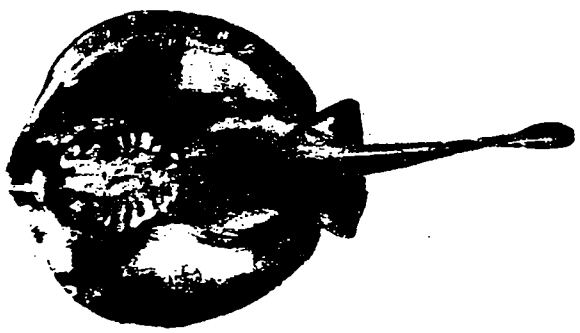
The longnose skate ranges from the Bering Sea to off central Baja California, and is usually found on the bottom at depths from 80 to 2,250 feet. It attains a maximum length of about 4.5 feet. Females mature at eight years and a length of 28 inches; males mature at five years and a length of 24 inches.

THE GUITARFISHES

The guitarfishes derive their name from their similarity to the musical instrument; head tapered or round, flattened, and somewhat broader than their sturdy, shark-like tail. They are usually found on the bottom and close inshore. All are viviparous, the embryos being nourished by nutrients stored in their yolksac. Guitarfishes have small, blunt teeth used for crushing, and feed on invertebrates such as worms, crustaceans, and mollusks, as well as small fishes, and are generally harmless to man. Three species are known from California waters. The shovelnose guitarfish has a sharply pointed snout and a tapered, somewhat shovel-shaped disk. It ranges from San Francisco to the Gulf of California, but is rare north of Monterey Bay. It is found in shallow coastal waters, bays, sloughs and estuaries over sandy or muddy bottoms to a depth of about 50 feet. Mating occurs during the summer months and the females give birth to live young the following spring or summer. Newborn are six inches long, with up to 28 per litter. Females reach a length of 5.5 feet and a weight of about 40 pounds; males are smaller.

THE ELECTRIC RAYS

Electric rays are found worldwide in all tropical and warm-temperate seas. They have a greatly expanded sub-circular disk which is fleshy toward the margins, and specialized to accommodate the two kidney-shaped electric organs. These are modified muscles capable of producing a powerful electrical shock. Only one species is known from California waters.



Round stingray, *Urolophus halleri.*

The Pacific electric ray (*Torpedo californica*) ranges from northern British Columbia to central Baja California, at depths from 10 to 1,400 feet. Commonly found over sandy bottoms, it also occurs in rocky areas and kelp beds. Females reach a length of over 4.5 feet, while males may reach three feet. It feeds exclusively on fish, including anchovies, herring, kelp bass, mackerel and halibut. One four foot female ray was observed to consume a two-foot silver salmon. Unlike most predatory fish, however, it does not initially seize its prey with its mouth, but first immobilizes it with electric discharges. It then manipulates the prey toward its mouth, using its remarkably dexterous disk, before swallowing it.

Sometimes aggressive when approached or provoked by divers, it may swim toward them with pectoral fins curled downward in a challenging manner. While its electric shock may be quite powerful, reaching up to 60 volts in larger individuals, it does not extend a great distance from the ray's body. Its shock apparently is not fatal to humans, but often snaps the backbone of prey fish.

THE MYLIOBATIDIFORM RAYS

The myliobatidiform rays are a large and rather diverse group, most of which have a greatly flattened disk and whiplike tail with one or more serrated stinging spines that are readily replaced when they become old or worn. This group includes both the smallest and largest batoids. Most are bottom-dwellers, occurring in shallow inshore waters, bays, estuaries and sloughs, but some are also found in deeper waters. At least one species of stingray and all mantas and mobulas are epipelagic.

They bear live young and are unique among the elasmobranchs in their method of nourishing the developing embryo on a nutritive fluid called uterine milk, secreted from hairlike processes called trophonemata which line the oviduct wall. They feed on soft benthic invertebrates, mollusks, crustaceans, and benthic, midwater and schooling nektonic fishes.

Rays are usually popular when displayed in public aquaria; eagle rays and bat rays are especially suited for shallow petting tanks. Used by cultures throughout the world for food, myliobatidiform rays are of little interest to California commercial fishermen, who mostly consider them to be a nuisance. Because most species have a stinging spine, care should be taken when handling them, especially the stingrays. Seven species of myliobatidiform rays are known from California waters.

The round stingray (*Urolophus halleri*), our most common stingray, has a nearly round disk and short, stout tail with well-developed caudal fin and stinging spine. It ranges from northern California to Panama, but is most abundant south of Point Conception. A benthic species with restricted habitat requirements, this ray is limited to a relatively shallow coastal zone at depths from three to 100 feet, occurring primarily in water less than 50 feet deep. It can be found off beaches and in protected bays, sloughs, channels and inlets, where it requires bottoms of loose sand or mud.

The round stingray's stinging spine is located far enough back on its tail to afford a powerful stinging reflex. When large numbers of round stingrays congregate off beaches, injuries to bathers can result. This danger can usually be avoided, however, by shuffling one's feet or pushing a stick along the bottom. Injuries from the spine may also result when rays are removed

SMB-26794

from nets or hooks. While the wounds do not appear to be fatal, they can be severely painful, and can cause vomiting, diarrhea, sweating, cramps and difficult breathing.

The bat ray is a common seasonal inhabitant of shallow inshore waters from Oregon to the Gulf of California. It occurs in muddy or sandy bays and sloughs as well as rocky areas and in kelp beds from near the surface to depths of 150 feet.

Gestation is estimated to take from nine to 12 months, with two to 12 young per litter. Size range at birth is 8.7 to 13.8 inches disk width (wing tip to wing tip). Onset of sexual maturity in males occurs at an age of two to three years and a disk width of 17.7 to 24.5 inches; maturity in females occurs at five to seven years and disk width of 35 to 40 inches.

Female bat rays reach a greater size than males, attaining a maximum disk width of 70.9 inches and weight of 210 pounds. The largest reported male is 40 inches wide at a weight of 37 pounds. Bat rays grow slowly, reach sexual maturity relatively late, have few young, and seem to be fairly long lived. A 59.8 inch disk width female was estimated to be 24 years old.

Bat ray feeding on oyster beds is a major reason for the fencing seen around commercial beds. Centra, tooth plates and sting fragments have been identified from coastal shellmounds, suggesting that bat rays were a regular diet item of early California Indians.

Status of Populations

Skate populations in California do not appear to be adversely affected by the current level of fishing. Taken incidentally in several commercial fisheries, they remain an underutilized resource. Nonetheless, research should accompany any significant expansion of the fishery. Skates and rays, like other elasmobranchs, have relatively slow growth rates, late age at maturity, and bear relatively few young compared to the bony fishes. Skate populations are susceptible to overfishing, as indicated by the decrease in annual batoid landings over the last five years in the Japanese fishery.

Little is known about the impact of sport fisheries on skates and rays. Data from 48 shark derbies in Elkhorn Slough, from 1950 to 1990 show, however, that shovelnose guitarfish, which in the 1950's and 1960's were the second, and in some years the most abundantly caught elasmobranch, have virtually disappeared from the catch. In the 1990's there has been a two thirds decrease in the catch per unit effort for bat rays compared to the 1950's catch rates. Reasons for the catch decline and change in species composition include numerous possibilities, only one of which is overfishing.

George D. Zorzi
California Academy of Sciences

Linda K. Martin
Monterey Bay Aquarium

References

Ferguson, A., and G. Cailliet. 1990. Sharks and rays of the Pacific coast. Monterey Bay Aquarium Foundation, Monterey, Calif. 1-64.

Roedel, P.M., and W.E. Ripley. 1950. California sharks and rays. Calif Dept. Fish and Game. Fish Bull. 75:1-88.

SHARKS, SKATES AND RAYS: DISCUSSION

Over the past two decades a tremendous amount of fishing pressure has focused on elasmobranchs. Reported catches world-wide exceed 600,000 tons annually. Just 15 years ago sharks, skates and rays were considered one of California's most underutilized resources. But commercial and recreational fisheries targeting California's elasmobranch resources have experienced dramatic growth during this short period, and the growth has made a significant impact on portions of that resource.

The value of these fisheries grew in response to public acceptance of shark as a wholesome and enjoyable alternative to traditional meat products. Led by landings of the common thresher shark in the early 1980's, California's elasmobranch fisheries peaked in 1981 and 1982 at over four million pounds. Landings continued high into the late-1980's, led by the Pacific angel and shortfin mako shark fisheries. The value of shark meat (ex-vessel price) averaged a dollar, or more, per pound for most species throughout this period. Common uses of shark products other than for human consumption include fins, skin, teeth, squalene, liver oil and medical products. The fins, while taken extensively on the east coast for oriental markets, have not developed into a sizeable market in California.

The importance of shark fishing to recreational anglers has also grown rapidly in recent years. Shark fishing trips for shortfin mako and blue sharks on charter vessels are available nightly throughout southern California. Shark derbies have become increasingly popular and angler effort directed at sharks and skates is estimated at a half a million trips annually.

Sharks, skates and rays have existed and adapted to their environment for over 400 million years. Generally, the pelagic species evolved into apex predators while inshore and bottom-dwelling species either approximated apex status or, like the pelagic species, had few natural predators. Elasmobranch reproductive strategy is simple but efficient. They produce a few well developed, strong individuals whose survival is assured because of their advanced development. All elasmobranchs have a slow growth rate, mature relatively late (30-50% of their life span), have a long gestation period or lay large, slowly maturing egg cases. Brood sizes are generally small. Annual production averages two to eight for ovoviviparous species, 20 to 40 for viviparous and perhaps a hundred or more egg cases in the oviparous species.

While this reproductive strategy has served them well in the past, it makes them quite vulnerable to modern day commercial and recreational fishing pressure. Clearly in a population where each mature female produces only a small number of young in each breeding cycle, recruitment is highly dependent on the number of mature females in that population. As Holden pointed out in the mid-1970's, success in establishing a sustained fishery on such a resource is dependent on maintaining a large population of mature individuals. This has not been the case in most fisheries targeting California's sharks. While many of these pelagic species may be found Pacific- or even world-wide, local stocks have experienced a high degree of exploitation. The Southern California Bight (SCB) is, at least in part, a nursery area for several species including the common

SMB-26795

thresher, shortfin mako and blue sharks. Nearly all sharks taken within this area are immature. Removing a large segment of juveniles from the population may create a reduced adult population in later years when those exploited juveniles would have become adults and begun reproducing themselves. The ability of local stocks to recover from over-exploitation depends not only on reducing fishing effort, but also on the size of the virgin stock, natural mortality, and migration rates. Also important to certain skates, rays and shallow water sharks is preserving breeding habitat and water quality.

We have learned much about biology and stock structure of many of California's elasmobranch species but there are still no stock size estimates available. Species distributions are poorly understood or known only from fishery dependent data. Many species have contiguous distributions into Mexican and adjacent state waters where they are also subject to fisheries. We have seen much variability in the apparent abundance of shortfin mako, blue, pelagic and bigeye threshers; still others like the Pacific angel and common thresher show a steady decline in apparent abundance. There is no direct evidence that skates and rays have experienced abundance declines, but if a major fishery were to develop or a loss of nursery habitat were to occur through coastal development, pollution, or increased recreational use, they, too, might suffer.

Specific Management Recommendations

Management of California's elasmobranch resources should be a high priority task for fishery managers in the 1990's. This stewardship will not be an easy task. Regulations enacted by special interest groups to benefit only one segment of the resource, combined with the lack of biological information, can only slow progress toward achieving rational management for sustained harvests. Coast-wide and stock-wide data gathering agreements are necessary for stock assessments. Only through decisive action by fishery managers and through public education can these resources be maintained at healthy levels.

Specific recommendations include:

1) Develop a coast-wide fishery management regime that recognizes and address the low reproductive capacity of California's elasmobranchs. A major objective is to develop a coast-wide management plan to prevent over-fishing and wastage, while maintaining healthy stocks. This is especially important for the common thresher, shortfin mako, blue, leopard and Pacific angel sharks. A conservative approach is recommended where actual species-specific fishery and biological data are lacking.

2) Continue to monitor current fisheries through skipper logs, landing receipts and port samplers with increased emphasis on coverage rates and data quality. On-board observers should be employed when appropriate.

3) Initiate a special monitoring or reporting system for shark derbies and on commercial passenger vessel trips targeting mako and blue sharks.

4) Begin efforts immediately to conduct a cooperative California-Mexico assessment of transboundary shark populations, including the collection of data from Mexico's Pacific shark fisheries.

5) Develop educational programs to elevate the public's perception of sharks and to promote a conservation attitude towards them.

6) Expand existing CDFG tagging programs to provide critically lacking life history information. This should include taking advantage of tagging opportunities provided by shark derbies, and aboard party boats, private anglers and commercial shark vessels.

David B. Holts
National Marine Fisheries Service

ANADROMOUS FISHES

SALMON

History of the Fishery

Two species of salmon are regularly taken in the California ocean sport and commercial salmon fisheries. Chinook salmon (*Oncorhynchus tshawytscha*) make up the bulk of the catch and coho salmon (*O. kisutch*) most of the remainder. Small numbers of pink salmon (*O. gorbuscha*) are taken, mostly in odd-numbered years. Chum salmon (*O. keta*) and sockeye salmon (*O. nerka*) are rarely seen in California.

Salmon have supported a variety of important California fisheries, some of which were significant before European settlers made their first appearance in the state. The Native American population of the lower Klamath River has been estimated at 5,000 at that time, and salmon was their most important food. The fish were harvested by a variety of methods and were dried for use throughout the year. Salmon were of such significance to these early fishers that ceremonies honoring their existence and importance were created.

By 1850, commercial salmon fisheries existed in the lower Sacramento and San Joaquin rivers, in Suisun Bay, and in San Pablo Bay. Gill nets were the most effective river gear and the type that remained legal longest. The inland commercial salmon fishery gradually spread to include other rivers north of San Francisco, but the Sacramento-San Joaquin fishery remained the largest and lasted longest. The Mad River fishery was closed by legislation in 1919, the Eel in 1922, the Smith and Klamath in 1933. The legal fishing area in the Sacramento-San Joaquin system was reduced, and finally that fishery was closed in 1957.

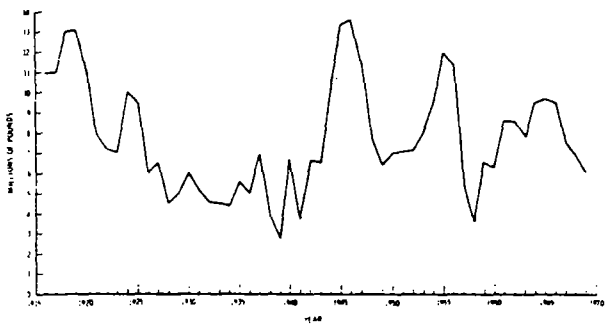
Early development of the salmon fishery was stimulated by the canning industry. The first salmon cannery on the Pacific coast started operations on the Sacramento River in 1864. By 1876, there were two canneries in operation in the area, and in another five years there were 20. The industry collapsed after two peak years in 1881 and 1882, and by 1885 there were only six canneries operating on the Sacramento-San Joaquin river system. The industry gradually faded away; the last cannery closed in 1919.

SMB-26796

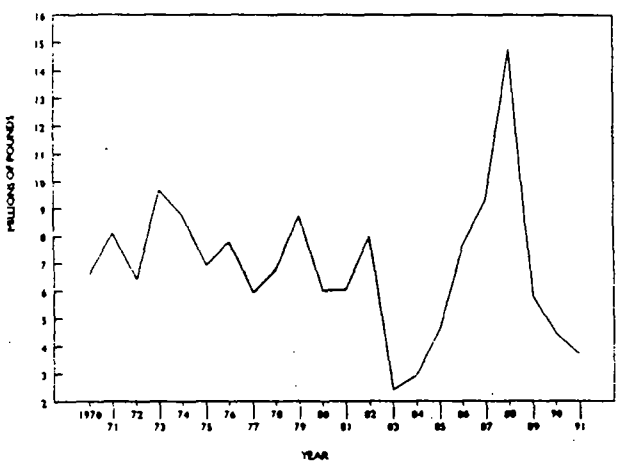
The ocean troll fishery started in the 1880's in Monterey Bay, and the first trollers used small sailboats. About 1908, some Sacramento River fishermen began taking their powered gill net boats to Monterey Bay to troll for salmon. These boats were a great improvement over sailboats, but were small by present standards. Trolling had spread north to Point Reyes by 1914 and, in another two years, boats were operating off Eureka and Crescent City.

A typical troller of the 1920's or 1930's fished up to nine lines which might each carry five or more hooks and up to 30 pounds of lead to keep them at the proper depth. Pulling weights, fish, and lines onto a moving boat by hand was a back-breaking job. Around that time, power gurdies were devised to pull the lines, and, by the late 1940's, most of the professional trollers were using them.

Additions to the salmon troll fleet during the 1960's and 1970's included many summer fishers who had other jobs during the remainder of the year. Some of them were serious about commercial fishing and had adequate ocean-going boats, but many were using sport-type boats that could conveniently be towed on a trailer.



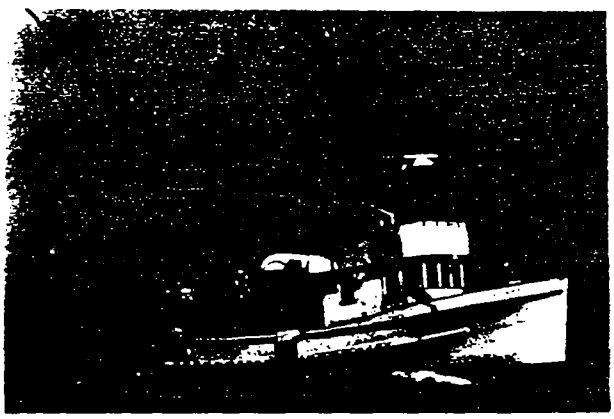
California commercial landings of salmon, 1916-1969.



California commercial landings of salmon, 1970-1991.

The modern, full-time salmon troller still uses the basic fishing techniques developed in the 1920's and 1930's, including powered gurdies and four to six main trolling lines. Now, however, the vessels are equipped with a myriad of electronic devices that greatly aid in finding and staying on the fish. Radio communications are possible among several vessels simultaneously, and distance between vessels for effective communications is virtually unlimited. Highly sensitive sonar equipment aids the troller in finding the salmon or bait-fish schools and in pinpointing the depth at which to position lures. Precise vessel positioning is made possible through the use of digitized loran and satellite signal receivers. It is no problem today to replicate a troll path or "tack" within a few feet of a previous or suggested path. Collectively, the instruments have probably more than doubled the efficiency of the modern troller compared to those of 60 years ago.

From its start through the early 1970's, the ocean troll fishery was regulated by seasons and minimum size limits. In the 1970's, ocean fisheries management was extended from three to 200 miles off the United States and was conveyed to the U.S. Secretary of Commerce. Thereafter, the California salmon fisheries were increasingly regulated under quotas. Barbless hooks were required in ocean salmon fisheries north of Point Conception, to reduce hooking mortality of sublegal or out-of-season salmon. The 1970's also marked the resumption, by court order, of commercial salmon fishing in the Klamath River by Native American fishers, who use gill nets. Quotas were used by the Department of Interior to regulate the catch.



Typical commercial salmon troller.

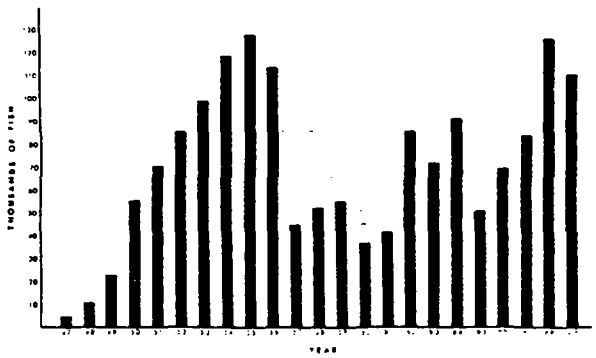
In 1980, a moratorium was placed on the issuance of permits to new participants in the ocean commercial salmon fishery. This was done to increase profits of individual fishers and to reduce overall fishery impacts on the resource. In 1983, a limited-entry program, which capped the fishery at about 4,600 commercial salmon vessels, was implemented. By 1991, the fleet had declined 30 percent to about 3,200 vessels.

Salmon catch statistics, of a sort, are available in some years starting as early as 1874. Over the years, there have been wide fluctuations in the commercial catch. Changes in weather and ocean conditions have contributed. However, dams, water diversion, and habitat degradation are primarily responsible for the recent downward trend.

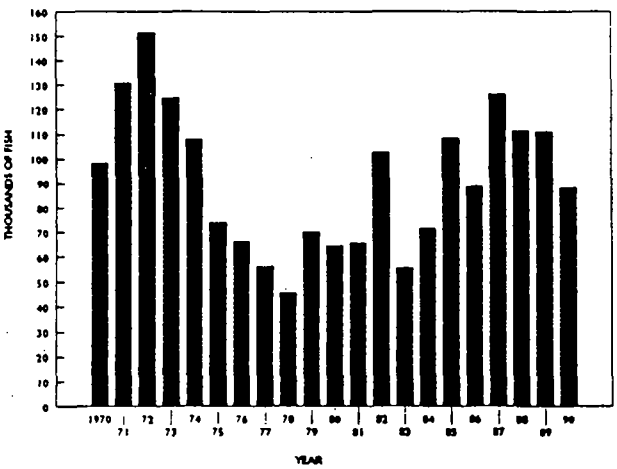
Ocean sportfishing for salmon has been important only since World War II. The sport fishery has taken about 14 percent of the salmon landed since 1950. Commercial passenger fish-

SMB-26797

ing vessels (CPFV's) have taken about 65 percent of this catch. Most of the salmon CPFV's operate out of San Francisco Bay ports; nevertheless, vessels operating in the Monterey and more southern areas catch significant numbers of salmon in some years. Numerous private boats fish for salmon out of many ports from Monterey northward, but relatively few small private boats fish out of San Francisco Bay, because of the long trip, strong tides, and rough water encountered going through the Golden Gate. The total marine sport effort on salmon has been about 200,000 angler-days per year throughout the 1980's.



California commercial passenger-carrying fishing vessel (CPFV) landings of salmon, 1947-1969.



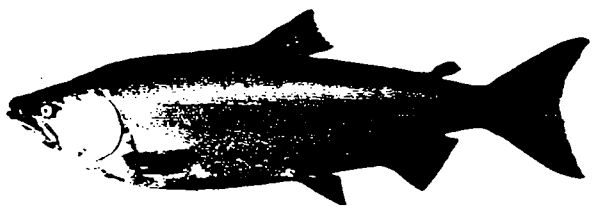
California commercial passenger-carrying fishing vessel (CPFV) landings of salmon, 1970-1990.

Mooching, or drifting, for salmon using a baited hook lowered to the depth of feeding fish began increasing in popularity in the late 1980's. Previously, trolling a baited hook or lure behind the boat was by far the most common method used by sport salmon anglers. Many anglers prefer mooching to trolling as lighter gear can be used, and at times it appears to be more effective. Mooching has been successful commercially, particularly in the San Francisco and Bodega Bay areas. The technique is generally used when salmon are feeding on forage fish such as anchovies or herring in nearshore, fairly shallow areas.

Many salmon anglers are attracted to streams from Santa Cruz County north. Historically, almost half of the effort was in the Sacramento-San Joaquin River System. Most of this activity occurs from the city of Sacramento upstream. The main stem of the Sacramento River is the most important valley stream, followed by the Feather and American rivers. Of the coastal streams, the Klamath System receives by far the most effort, followed by the Smith and Eel. Much of the fishing in coastal river systems occurs in estuaries. The Klamath and Smith river mouths draw large numbers of anglers from great distances and concentrate them in a small area. The term "madhouse" is appropriate during the peak of a good run. Chinook salmon make up the bulk of the catch in both of these rivers, and in the Eel. Many smaller coastal rivers have runs of coho salmon that enter during brief periods after the first heavy fall rains and move upstream into areas where they are unavailable to anglers.

Status of Biological Knowledge

All Pacific salmon are anadromous, and all die after spawning. Both chinook and coho salmon have similar spawning requirements and similar spawning habits. Successful spawning requires water temperatures less than 56°F, clear water, suitable gravel riffles, and a stream velocity sufficient to permit excavation of nests, or redds, and to cover up the deposited, fertilized eggs. The female digs the nest, lays the eggs, and covers them after they are fertilized by the male. After a period of time, depending primarily on water temperature (usually 50 to 60 days in California), the juveniles hatch and wriggle up out of the gravel. The length of stream residency by juveniles varies according to species and race.



Chinook salmon, *Oncorhynchus tshawytscha*.

CHINOOK SALMON

Chinook salmon spawn in suitable rivers from the Sacramento-San Joaquin system northward. Chinooks are the largest of the salmon species. The State record for a sport-caught chinook in fresh water is 88 pounds. The largest chinook on record is a 127-pounder taken from a trap in Alaska. California chinook mature at two to five years of age, varying somewhat between rivers and races or runs of chinook within individual rivers. Ocean fisheries can have a significant impact on the average age of spawning chinook. This is because ocean fishing gear selects for larger, older fish and because minimum size limits allow for the harvest of chinook in the sport fishery starting at age 2 (20-inch minimum) and in the commercial fishery at age 3 (26-inch minimum). Ocean harvest rate and average age of spawner are inversely related. It has not been documented that the selectivity of the ocean fisheries for older maturing fish has adversely affected the genetics of the populations, but it has probably reduced the utilization of spawning

SMB-26798

habitats that are best suited for larger, older fish. Larger fish, for example, are probably better able to utilize the larger gravel found in the main stems of most river systems. High rates of ocean harvest in recent decades have led to the virtual disappearance of five-year-olds in chinook salmon runs throughout the State.

The small percentage of chinook that mature at age two are predominately males and are commonly referred to as "grilse," or "jacks." The older age classes of chinook are composed of about equal proportions of males and females.

Populations of chinook salmon in some rivers include more than one race, or run, each spawning at a different time and often in a different area. There are four distinct runs in California, named [illegible] they enter fresh water: fall, late-fall, winter, and spring. The Sacramento River system is used by all four runs, while smaller coastal rivers have only fall runs. On the coast, the Klamath, Eel, Mad and Smith rivers have fall and late fall runs. Spring chinook are present in several streams within the Klamath River basin and occasionally appear in the Eel and Smith rivers. Spring chinook formed the major run in the San Joaquin River before completion of Friant Dam in 1942 and subsequent elimination of the run. Completion of Shasta Dam in 1945 eliminated the large runs of spring chinook in the upper Sacramento drainage. Spring chinook were believed to be comparable in abundance to fall chinook in the Klamath River before completion of barrier dams in upper river areas in the late 1800's. In a river where all four runs of chinook spawn, adults migrate upstream and juveniles migrate downstream during all months of the year. In general, the timing of chinook spawning varies somewhat from river to river, and even within river systems, often being influenced by stream flow and water temperature.

Fall run. Fall-run chinook salmon are the most numerous salmon in California today. They arrive in spawning areas between September and December, depending upon the river system, but peak arrival time is usually during October and November. Under current ocean harvest rates, the fall chinook runs are dominated by three-year-old fish followed by jacks and four-year-olds. Five-year-old fish are rare. Spawning occurs in the main stem of rivers, as well as in tributaries, from early October through December. In general, there is a large outmigration of fry and fingerlings from the spawning areas between January and March. An additional outmigration from the spawning areas, consisting primarily of smolts, occurs from April through June. The juveniles enter salt water as smolts between April and July.

Late fall run. In California, late fall-run salmon are found primarily in the Sacramento River system, but have been reported from the Eel and Klamath rivers as well. They arrive in upper river spawning areas between October and mid-April. The runs of late-fall chinook tend to consist of equal numbers of three- and four-year-old fish. Spawning occurs from January through mid-April, primarily in the main stem of the Sacramento River. Some of the juveniles start migrating seaward as fry during May, but the bulk of the juveniles leave the upper river between October and February. Late fall smolts enter the ocean between November and April.

Winter run. Winter-run salmon are unique to the Sacramento River system. Adults arrive in the upper Sacramento River spawning area from mid-December through early August, with a peak in March. Spawning occurs primarily in the main stem of the upper Sacramento River below Shasta Dam between late-April and mid-August. May and June are peak spawning months. The juveniles migrate seaward from early July though the following March, but the bulk of the juveniles move seaward in September. Winter-run smolts enter the ocean between December and May. The adults mature and spawn as three-year-olds, unlike the other races which include many four-year-old fish. Because of winter chinook's unique life history, ocean fisheries which are structured to harvest the more abundant fall chinook runs during spring and summer months presumably have a relatively minor impact on winter chinook.

Spring run. Spring-run salmon arrive in the spawning areas between March and June, with the peak time of arrival usually occurring in May or June, depending upon flows. They rest in the deep, cooler pools during the summer and then move onto the gravel riffles and spawn between late August and early October. There are generally two overlapping juvenile outmigration periods, one between November and June when a portion of the production moves seaward as fry and fingerlings, and the other between October and December when the outmigrants are primarily yearlings. Most of the juveniles enter the ocean as smolts from March through June, and the remainder enter the ocean as yearlings from October through December. Spring chinook runs tend to be dominated by three-year-old fish followed by four-year-olds and jacks.

Ocean distribution. The development and widespread use of the coded wire tag since the mid-1970's have provided extensive data on the ocean distributions of Pacific coast salmon stocks. Tagging studies in California, particularly on Central Valley and Klamath River fall chinook salmon stocks, have provided better definition of the coastal areas used by these stocks, as well as the mix of stocks in a particular ocean area. Central Valley fall chinook are found to range widely, entering fisheries in significant numbers as far north as Westport, Washington. Klamath River fall chinook are found more narrowly distributed between Point Arena in central California and Cape Blanco in southern Oregon. Ocean conditions have also been found to affect the ocean distribution patterns of these and other Pacific coast salmon stocks.

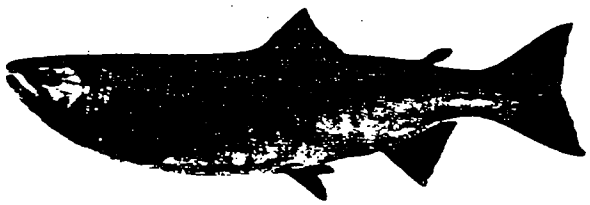
The coded wire tag has been limited to those stocks readily available for tagging, mainly hatchery fish. The 1980's saw the development and refinement of a genetically-based system to differentiate chinook salmon stocks in ocean fishery landings. The technique has verified tag data for hatchery stocks, and has provided indications of ocean distribution for the naturally produced stocks for which tag studies have not been feasible. It has also allowed estimation of the way many different stocks mix in ocean areas, as well as the rate at which they contribute to the fisheries.

COHO SALMON

Coho salmon are smaller than chinook salmon; the average size of a mature coho is seven to twelve pounds. The

SMB-26799

California record for a freshwater sport-caught coho salmon is 22 pounds. The world record is a 33-pound sport-caught coho landed in British Columbia



Coho salmon, *Oncorhynchus kisutch*.

In California, coho spawn in suitable streams from northern Monterey Bay northward, but they rarely enter the Sacramento-San Joaquin River system. Coho enter many small coastal streams that are not utilized by chinook, but they also spawn in some larger river systems where chinook occur. Compared to chinook salmon, there are relatively few coho in California today. Most California streams utilized by coho salmon are short in length, but some coho do make relatively long migrations, particularly into the Eel River system.

Within California river systems, coho salmon populations include only one race, or run, which is generally consistent as to spawning area used and time of spawning. Most spawning occurs between October and February. The juveniles usually spend a little more than a year in fresh water before migrating to the ocean; a few spend two years. Most coho mature at the end of their third year of life. Coho salmon older than three years are relatively rare. A few males, or grilse, mature at age two.

Genetic analysis of California coho populations has indicated a wide degree of mixing of the stocks in the past, probably reflecting past stocking and transplantation practices involving hatchery fish.

Coded wire tagging of California hatchery coho stocks has indicated nearly all are harvested in ocean fisheries as three-year olds. Some are caught as far north as the central Washington coast, but most are caught within 100 miles of the stream from which they entered the ocean.

Status of Spawning Populations

There have been declines in all of California's salmon populations since the 1950's and 1960's. In the Sacramento River system, the numbers of fall-run chinook salmon have decreased from 513,000 in 1953 to 124,000 in 1991, and the late fall-run from 37,000 in 1967 to 8,000 in 1991, a loss of about 75 percent in each instance. Winter-run salmon have declined by 99 percent, and the race is now listed as endangered by California and as threatened by the U.S. Government. In the San Joaquin River, the spring run was eliminated with the completion of Friant Dam in 1942, and the fall run has experienced wide fluctuations since the early 1950's and numbered about 1,000 fish in 1991. Spring-run chinook in the upper Sacramento River and the Trinity and Salmon rivers in the Klamath basin have been at very low levels in recent years. The runs are so low that the race may soon qualify for listing under the California Endangered Species Act.

Reasons for the decline in California's salmon populations vary somewhat from river to river, but there are two major causes: (1) destruction or loss of habitat, and (2) water diversion.

In the Central Valley, a multitude of factors has contributed to the decline. These include several hundred unscreened irrigation diversions in the Sacramento Valley, 1,800 unscreened diversions in the Delta and about 150 unscreened diversions in the San Joaquin Valley; poor or lost gravel deposition in salmon spawning and rearing areas; pollution; aberrant river flow fluctuations caused by alternating water-release schedules from dams to meet downstream water-quality standards and water diversion contracts; elevated water temperatures stemming from power generation operations and reduction in cold water storage as reservoirs are emptied to meet agricultural contracts; and impediments to migration such as dams or diversions. The massive and increasing export of water from the southern Sacramento-San Joaquin Delta has probably been the greatest cause of decline in Central Valley salmon.

Red Bluff Diversion Dam on the upper Sacramento River continues to be a major impediment to adult upstream migration, a major point of diversion and loss of downstream migrating juveniles, and a haven for predatory squawfish. Lifting of the gates at this facility has been implemented in the spring to protect winter-run chinook, but may be needed year round in the very near future as the runs of the other races of chinook in the upper Sacramento continue to decline. Alternative methods of delivering water from the river at Red Bluff are currently being considered.

Declines in coastal river chinook and coho salmon populations have been caused by many of the same factors. But, in addition, these areas have been affected by past and, in some instances, present timber harvest practices. These practices have reduced stream shading, resulting in high temperatures, and have accelerated erosion and filling of pools. Logjams have formed impediments or blockages to adult migrations.

Runs of hatchery chinook salmon have been stable or increasing, except in the San Joaquin, stemming from expanded rearing facilities and improved rearing and disease control techniques. Trucking operations in the Central Valley have greatly increased hatchery fish survival by reducing instream losses of fish at diversions and to predators. Improved disease prevention and treatment techniques have substantially increased the chances of a hatchery fish surviving to proper release size. Rearing of juvenile salmon to larger sizes has also benefitted production.

The trucking of hatchery fish in the Central Valley has increased the rate of straying of returning adults, possibly to the detriment of the naturally produced fish. Hatchery fish have been important to maintaining ocean and in-river fisheries, and have incorrectly been perceived as a viable alternative to maintenance of natural spawning populations. Unfortunately, a successful hatchery program can mask the decline in the natural run due to straying of the returning adults, and this appears to be the case for chinook in many areas of the Central Valley and the Klamath River basin.

Hatchery adults spawning in the wild can compete with naturally produced fish for adult spawning and juvenile fish rearing areas. Interaction of hatchery and naturally produced

SMB-26800

salmon is most acute in the close vicinity of the rearing facilities. Battle Creek below Coleman Hatchery and Bogus Creek adjacent to Iron Gate Hatchery typically are overloaded with spawning fish each fall due to straying of hatchery adults.

L.B. Boydstun
Richard J. Hallock (Retired)
Terry J. Mills
California Department of Fish and Game

References

Bartley, D., B. Bentley, and G.A.E. Gall. In press. Population genetic structure of coho salmon (*Oncorhynchus kisutch*) in California. Calif. Fish and Game.

California Advisory Committee on Salmon and Steelhead Trout. 1988. Restoring the balance. 1988 annual report. Calif. Dept. Fish and Game, Sacramento. 84 p.

Campbell, E.A. and P.B. Moyle. 1990. Historical and recent population sizes of spring-run chinook salmon in California. Pages 155-216. *In* Proceedings, 1990 Northeast Pacific Chinook and Coho Salmon Workshop. Humboldt Chapter, American Fisheries Society.

Fry D.H., Jr. 1961. King salmon spawning stocks of the California Central Valley, 1940-1959. Calif. Fish and Game, 47(1):55-71.

Gall, G.A.E., B. Bentley, C. Panattoni, E. Childs, C. Qi, S. Fox, M. Mangel, J. Brodziak, and R. Gomulkiewicz. 1989. Chinook mixed fishery project, 1986-89. Prepared under contract for the Calif. Dept. Fish and Game, Sacramento. 192 p.

Hankin, D.G., and M.C. Healey. 1986. Dependence of exploitation rate for maximum yield and stock collapse on age and sex structure of chinook salmon (*Oncorhynchus tshawytscha*) stocks. Canadian J. Fish. Aquat. Sci., 43(9):1746-1759.

King, D. 1986. The economic issues associated with commercial salmon fishing and limited entry in California. Prepared under contract for the California Commercial Fishing Review Board, Sacramento. 106 p. plus appendix.

Kope, R.G. 1987. Separable virtual population analysis of Pacific salmon with application to marked chinook salmon, *Oncorhynchus tshawytscha*, from California's Central Valley. Canadian J. Fish. Aquat. Sci., 44(6):1213-1220.

Lufkin, A. 1991. California's Salmon and Steelhead: The Struggle to Restore an Imperiled Resource. University of California Press: Berkeley and Los Angeles. 305 p.

Moyle, P.B., J.E. Williams, and E.D. Wikramanayake. In revision. Fish species of special concern in California. Prepared under contract for the Calif. Dept. Fish and Game, Sacramento.

Nehlsen, W., J.E. Williams, and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries, 16(2):4-21.

Pacific Fishery Management Council. 1984. Final framework amendment for managing the ocean salmon fisheries off the coasts of Washington, Oregon, and California commencing in 1985. Pacific. Fish. Mgmt. Council, Portland. Eight sections plus appendices.

_____. 1992. Review of 1991 ocean salmon fisheries. Pacific. Fish. Mgmt. Council, Portland. Four sections plus appendices.

_____. 1992. Preseason report I, stock abundance analysis for 1992 ocean salmon fisheries. Pacific Fish. Mgmt. Council. Portland. Three sections plus appendices.

SALMON: DISCUSSION

Maintaining salmon runs in California depends more on preserving an adequate freshwater environment than on regulating ocean and inriver fisheries. A poor law or regulation can be changed long before the damage it causes becomes permanent, but a stream that is blocked near its mouth by an impassable dam will produce no more salmon. A stream kept dry through the spawning season by diversion is no better, but may prove salvageable if water can eventually be provided. Diverting all the water from a stream during the downstream migration period of juveniles will prevent any of them from reaching the ocean, even if adequate fish screens keep them from entering the irrigation canals. Reducing stream flows or shade may result in a stream becoming too warm for salmon. Siltation from logging or road construction can smother salmon eggs or divert water away from them. Although habitat destruction of these and certain other forms can be quite obvious, sometimes the causes of serious damage can be considerably less obvious.

Challenges to Inland Salmon Management

In 1960, the salmon runs of the San Joaquin Valley consisted of about 50,000 fish and seemed to be doing well. The next year they were down to 2,500, about a 95 percent drop. A careful investigation revealed that salmon habitually refused or were unable to go up the San Joaquin River past a polluted area below Stockton until flows there were sufficient to raise the dissolved oxygen content to five parts or more per million. Although the situation in this area is quite complex, the basic problem is relatively simply understood: heavy pumping at the Bureau of Reclamation's Tracy plant and the State Water Project's Byron Facility withdraws much of the San Joaquin River flow and reduces, stops, or even reverses the flow past Stockton.

In a dry spring most of the San Joaquin water flows to the state and Federal pumping plants near Tracy and Byron, and the young salmon move with it. Fish screens at the two plants prevent complete disaster, but there are losses directly attributable to the screens and probably others due to the dislocation and interruption of the migration. Of particular concern is the loss of juvenile salmon in Clifton Court Forebay. Clifton Court is an enclosed body of water which feeds the massive pumps of the State Water Project. The forebay is refilled on a regular basis and the schedule is influenced by tidal sequences in the Delta. Experimental studies have revealed that losses of juvenile chinook salmon passing through the forebay have ranged from 65 to more than 90 percent. Most of the losses are attributable to predation by striped bass and other piscivorous fishes.

In 1989, the California Fish and Game Commission listed the winter-run chinook salmon as an "Endangered Species" under the California Endangered Species Act (CESA). In 1990, the Federal government followed by listing the winter-run as threatened pursuant to the Federal Endangered Species Act (ESA). Species management under provisions of the ESA requires that existing and proposed Federal actions and permit-

ted activities be conducted in a manner that will not jeopardize the continued existence of the animal or result in the destruction or adverse modification of habitat essential to the continuation of the species. Federal agencies must consult with the National Marine Fisheries Service when they propose to authorize, fund, or carry out an action which could potentially adversely affect the winter-run chinook salmon. Likewise, State-sponsored activities that might affect winter-run must be reviewed under the provisions of CESA.

Operation of the Federal Central Valley Project (CVP) and the State Water Project (SWP), both of which strongly influence the survival of winter-run chinook salmon, are presently under review and various operational and structural alternatives are being evaluated. These include: reduction in water exports from the Sacramento-San Joaquin Delta during peak migrations of winter-run fry and smolts; installation of a multi-level water temperature control device at Shasta Dam; closure of the Delta Cross Channel during peak winter-run outmigration; extending the period of unimpeded passage for adults and juveniles at Red Bluff Diversion Dam (*i.e.*, raising the gates); implementation and installation of alternative operational procedures and diversion structures for delivering water to the Tehama-Colusa Canal (replacing the existing gravity-feed method which requires closure of Red Bluff Diversion Dam); and temporary cessation of water diversion from Montezuma Slough during peak period of juvenile salmon outmigration.

Hatcheries have become increasingly important for producing fish to be caught in ocean and in-river fisheries. Near the coast, both chinook and coho are reared in four State facilities (Iron Gate, Trinity River, Mad River, and Warm Springs). In the Central Valley, chinook is the sole emphasis in the one Federal (Coleman) and four State hatcheries (Feather River, Nimbus, Mokelumne River and Merced River). All chinook hatcheries rear fall run fish, while the Trinity and Feather River hatcheries also rear spring chinook. Chinook generally are reared for release in spring at an average size of 90 per pound or to 10 per pound for fall release, although summer releases at intermediate sizes are also common. Coho are generally released in the spring as yearlings at an average size of about 12 per pound. Most of the chinook produced in the State facilities in the Central Valley are trucked and released at sites in the Sacramento-San Joaquin Delta. Trucking is done to bypass the numerous water diversions and predatory animals the young salmon have to avoid in reaching the ocean. This practice has significantly increased their survival. In recent years, hatchery-produced chinook have probably contributed half of the overall adult returns to Central Valley and the Klamath River basin streams. Hatchery-produced coho have comprised most of the coho in the Klamath River, although the returns have been small in comparison to chinook. The Mad and Russian River runs have each received significant contributions of hatchery-produced chinook and coho.

Disease prevention and control is a major concern of hatchery managers and is one of the important arguments against reliance on hatchery production for the conservation of salmon populations. Disease outbreaks can result in the total loss of a cohort of fish in a hatchery setting, while in the wild the cohort has access to alternative rearing habitats.

Hatcheries commonly produce a surplus of adult returns for their egg-take needs. Commercial and sport fishers then want less restrictive fishing regulations in order to harvest the hatchery surplus. This is detrimental to the naturally spawning fish, which cannot sustain nearly so high a rate of harvest. Responsible hatchery management means not only producing a healthy and robust fish, but also educating the sport and commercial fishers on the importance of managing the fisheries for natural production while accepting a surplus of hatchery adults.

Challenges to Ocean Management

The following statement is excerpted from the Pacific Fishery Management Council's Framework Plan for salmon: "When the Pacific Fishery Management Council was formed in 1976, it recognized that the salmon resources of Washington, Oregon, Idaho, and California required immediate attention because of conservation and allocation problems."

These management concerns continue to exist and currently shape ocean salmon management as it applies to the California fisheries. Relative to conservation, fishing regulations have been enacted that limit harvest via quotas or time/area closures so that adequate numbers of fish can return to river spawning areas. Greater restrictions have been enacted following droughts (such as in the early 1980's) or because of poor ocean survival conditions (such as the severe 1983 El Niño), while less restrictive fishing regimes have been enacted in times of abundance (such as in the mid-1980's in central California). These conservation measures, however, have been overshadowed, in terms of controversy, by the need to allocate the salmon resource in recent years among and between ocean and inriver user groups. For instance, higher allocation of chinook salmon to Klamath River users (Native American and inriver recreational anglers) in the mid-1980's led to restrictive ocean fishing regulations off northern California and southern Oregon, even though salmon were in very high abundance.

As ocean salmon fishing regulations have become more restrictive, the fishers, especially the commercial harvesters, have declined in number, some ceasing to fish at all while others have shifted to other fisheries. This has affected catch levels and regulation of the other fisheries, most notably rockfish and sablefish.

Ocean salmon managers must continually be prepared to respond to changes in the fisheries. The advent of "mooching" in central California, as opposed to the traditional trolling method of catch, may lead to different resource impacts. Likewise, the ocean environment continues to change, physically as well as biologically. Relative to the salmon resource, coastal water quality needs to be monitored and protected. There also appear to be increasing conflicts between ocean fishers (both recreational and commercial) and marine mammals, harbor seals and sea lions in particular. Federal legislation aimed at protecting these animals has been very effective in increasing their numbers and has led to increased depredation on sport and commercially hooked salmon. Most of the problems have been in the marine area, particularly in the Monterey-San Francisco region, but problems have also occurred in some lower river

SMB-26802

areas, such as the Klamath River estuary where Native American and sport fishers annually seek to harvest salmon.

Anglers show off their chinook salmon catch.

Specific Management Recommendations

The major threat to California's salmon resource is further degradation and elimination of its freshwater and estuarine habitats. Restoration of inland spawning and rearing habitats and renegotiation of inland water management policies, particularly in the Central Valley, must be pursued if salmon production levels are ever to return to their former levels. Prudent regulation of the fisheries will be required to equitably distribute the available fish between the various ocean and inriver users and to meet spawning escapement needs. To these ends, the California Department of Fish and Game should:

1) Continue its efforts to improve, restore, and enhance freshwater and estuarine habitats for salmon. Specific focus should be on:

a. Screening of water diversions;

b. abatement of pollution sources, chemical and thermal;

c. reductions in siltation and gravel compaction levels;

d. elimination of gravel removal operations in important spawning and rearing areas;

e. reduction of vegetation encroachment into major spawning areas;

f. maintenance of suitable stream flows and temperatures; and

g. control of diseases, particularly bacterial kidney disease in hatcheries.

2) Support studies to differentiate races of salmon, particularly in the Central Valley, where winter-run chinook are close to extirpation and spring-run chinook are severely depressed.

3) Develop and implement plans to reverse the status of depleted salmon stocks, winter-run and spring-run in particular.

4) Investigate the feasibility of constructing a salmon (and steelhead) hatchery within the San Joaquin basin.

5) Continue to work with the Klamath Fishery Management Council in developing a long-term harvest sharing agreement between and among ocean and inriver users.

6) Support studies to compare hooking mortality rates following release for sublegal salmon caught by trolling and mooching.

7) Operate hatcheries and rearing facilities at full capacity striving to minimize effects on natural production.

L.B. Boydstun
Richard J. Hallock (Retired)
Terry J. Mills
California Department of Fish and Game

STEELHEAD

History of the Fishery

Steelhead (*Oncorhynchus mykiss*) and Pacific salmon were an important part of Native American culture prior to the arrival of European settlers. Native Americans utilized this resource for subsistence, trade, and ceremonial purposes. Salmon and steelhead were harvested year-round by central coast and Central Valley tribes, and primarily during late summer and fall months by north coast tribes. Nets, spears, traps, and weirs were utilized to capture the fish. Today, Native Americans employ gill nets to capture salmon and are limited to the Klamath River system. The large-mesh gill nets used in this fishery are targeting salmon, and so the smaller-sized steelhead are not taken in large numbers.

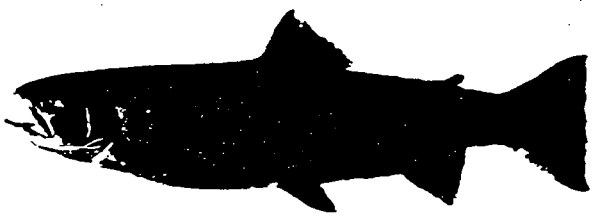
There is no commercial steelhead fishery in California today. Commercial salmon trollers cannot legally possess steelhead, and very few are taken incidently in the commercial salmon catch.

There is a well-established steelhead sport fishery in California. The majority of angler effort is expended in river systems and coastal streams of the north coast, the central coast north of San Francisco Bay, and the Sacramento River system. There are a few rivers and streams of the central coast south of San Francisco that still support a steelhead sport fishery, but these have become limited in recent years due to a decline in populations. The steelhead fishery of southern California (south of San Luis Obispo) is almost nonexistent, due to severe declines and extirpation of many of the runs. There are a few historical accounts of a steelhead fishery in the San Joaquin River system; at present, though, it does not support a steelhead sport fishery.

Steelhead sport fishing is important not only for the recreation that it provides, but also for its economic benefits. A

SMB-26803

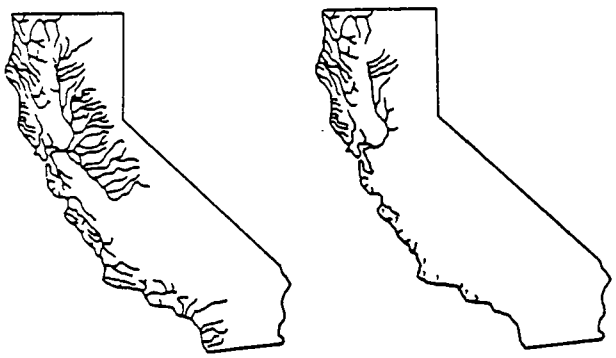
1985 economic analysis of the anadromous sport fishery of the Sacramento-San Joaquin river system estimated that sales revenue generated from steelhead sport fishing in the Sacramento River and tributaries was over 7.2 million dollars. When nonfishing activities were included, Sacramento River steelhead generated over 9 million dollars annually.



Steelhead, *Oncorhynchus mykiss*.

Status of Biological Knowledge

Steelhead are anadromous rainbow trout, a salmonid native to western North America and the Pacific coast of Asia. In North America, steelhead are found in Pacific Ocean drainages from southern California to Alaska. In Asia, they are found on the east and west coast of the Kamchatka Peninsula, with scattered populations on the mainland. In California, spawning populations are found from Malibu Creek, in Los Angeles County, to the Oregon border and in the Sacramento River system. The present distribution of steelhead in California has been greatly reduced from historic levels.



Historical ranges (left) and present (right) of steelhead in California.

Steelhead are similar to some Pacific salmon in their ecological requirements. They spend most of their lives in the ocean, where they grow to a large size, and then return to fresh water to spawn. Unlike salmon, steelhead do not necessarily die after spawning. Post-spawning survival rates, however, are generally quite low.

Two principal races of steelhead are defined by the migration timing of adults and the degree of maturation of the gonads of the adults upon entry into freshwater. Summer steelhead (also called "spring-run" steelhead) enter fresh water in spring and early summer with only slightly developed gonads, ascend to headwater tributaries, and hold over during summer in deep pools. They spawn in late fall and early winter. Winter steelhead have well-developed gonads when they begin their spawning migration in late fall and winter, and are usually ready to spawn within a few weeks or months of the time they enter fresh water.

Prior to the intensive water development of this century, summer steelhead were much more common in California than they are today. They may have been the more prevalent of the two races in the Sacramento system (and probably the San Joaquin system) until the construction of large dams on many of the major spawning tributaries blocked access to the headwaters. Today, summer steelhead are found only in north coast drainages, mostly in tributaries of the Eel, Klamath, and Trinity river systems. Winter steelhead are also present in north coast drainages, as well as the Sacramento River system, and central and south coast drainages.

Steelhead generally spawn in small tributaries where cool, well-oxygenated water is available year-round. Like salmon, the female digs a nest, or "redd," deposits eggs while an attendant male fertilizes them, then covers the eggs with gravel. Fry emergence from the gravel is dependent upon water temperature, but usually occurs within 60 days.

The life history of steelhead differs from that of Pacific salmon principally in two aspects: juveniles have a longer freshwater rearing requirement (usually from one to three years); and the amount of time spent in fresh and salt water is much more variable both for adults and juveniles. In the classic study of steelhead biology by Shapovalov and Taft on Scott and Waddell Creeks in Santa Cruz County, it was found that the majority of adults returning to the stream to spawn had spent two years in fresh water and one or two years in the ocean. However, steelhead showing other life history patterns were not uncommon: scale analysis of adults indicated that they spent from one to four years in fresh water and from one to three years in the ocean.

Unlike salmon, steelhead do not necessarily migrate at any set age. Some individuals will remain in a stream, mature, and even spawn without ever going to sea, others will migrate to sea at less than a year old, and some will return to freshwater after spending less than a year in the ocean. The well-known Klamath River "half-pounders" are sexually immature steelhead that return to fresh water after spending only a few months at sea. These fish do not spawn, but return to the ocean and eventually ascend the river in a second upstream migration as a larger, mature steelhead.

The variability in life history patterns is a survival mechanism that may have evolved in response to seasonal variations in rainfall patterns. This is evident in southern California, where steelhead exist at the southernmost limit of their range. The major river systems in this area are subject to extreme variations in rainfall which can result in high volume, flash flood runoff or droughts lasting several years. It is common for the lower reaches of many of these rivers to dry up completely during the summer. Juvenile steelhead rearing in the perennial headwaters of these rivers would, at times, have no access to the ocean for several years. The flexibility to survive in freshwater

SMB-26804

until the next storm opened a migration corridor to the ocean has allowed steelhead to exist in this marginal environment.

Status of Population

Because of the difficulty in assessing steelhead populations, we have few good estimates of adult numbers and a statewide population estimate is not available. Carcass surveys, a dependable method to estimate salmon spawning populations, are not very useful for assessing steelhead spawning populations, because steelhead do not necessarily die after spawning. Counts made at weirs and fishways can be difficult, because adult steelhead tend to migrate on high, turbid winter flows. Despite the lack of accurate numbers, other reliable indicators show that steelhead, like most other anadromous salmonid stocks in California, are declining.

Southern steelhead stocks (those occurring south of San Francisco Bay) are the most jeopardized of all of California's steelhead populations. The southernmost range of steelhead formerly extended to northern Baja California and they were present in streams and rivers of Los Angeles, Orange, and San Diego counties. At present, Malibu Creek in Los Angeles County is the southernmost stream containing a spawning population, although there may be isolated population remnants present in other streams further south.

Steelhead numbers have declined drastically in nearly all southern California streams. The 1943-1944 run in the Santa Ynez River, one of the largest of the southern California rivers, was estimated to be from 13,000 to 25,000 adults. Other streams that historically supported large steelhead runs include the Ventura, Santa Clara, and Carmel rivers. Today, these streams support very few steelhead, if any at all. About 20 adult steelhead were observed in the Ventura River estuary in 1991, none have been seen in the Santa Clara River system for several years, and very few adult steelhead have returned to the Carmel River during the past five years.

These populations are clearly on the verge of extinction. Major impacts are from urbanization and other watershed disturbances, blocked access to headwater spawning and rearing areas, and partial and total dewatering of streams by water diversions and groundwater pumping.

Steelhead numbers in the Sacramento River system have been steadily declining since the 1960's and 1970's. Mean annual run for the total system (calculated from tag recovery, creel censuses, and direct observation) has declined from 30,300 adults in the 1960's to about 13,000 adults in the 1980's. Steelhead counts at the Red Bluff Diversion Dam on the Sacramento River near Red Bluff have declined from an average annual count of 13,300 adults in the 1960's to 2,500 adults in the 1980's. Hatchery counts at Coleman National Fish Hatchery and Nimbus Hatchery also show a declining trend.

Approximately 95 percent of the adults returning to spawn in the Sacramento system are of hatchery origin. The decline of natural reproducing populations of wild stocks has been more precipitous than that of the hatchery-produced stocks. Wild stocks in the Sacramento system are mostly confined to upper Sacramento River tributaries such as Clear, Battle, Deer, and Mill creeks and the Yuba River. Annual counts made at Clough Dam on Mill Creek from 1953 to 1963 ranged from 417 to 2,269 adults. In 1964, 1,006 adult steelhead were counted at Vina Dam on Deer Creek. There has been no recent evidence of steelhead spawning in Deer and Mill creeks. There are indications that steelhead were present in tributaries of the San Joaquin River, although this system has not supported a viable population for at least 50 years.

Major impacts to natural and hatchery-maintained stocks in the Sacramento River system are due mostly to water development resulting in inadequate instream flows caused by excessive water diversions for irrigation, rapid flow fluctuations due to water conveyance needs, high summer water temperatures in streams immediately below reservoirs, diversion dams which block access, and entrainment of juveniles into unscreened or poorly screened diversions. The operations of the federal Central Valley Project and the State Water Project, particularly the pumps in the south delta, have had a major detrimental effect on steelhead. These massive irrigation and municipal water supply projects are the hub from which water is distributed in California, and they have exacted a heavy toll on California's aquatic resources. Reverse flows, entrainment of fish into the pumps, and increased predation at water facilities are the major problems caused by the operations of these projects.

The greatest abundance of steelhead in California occurs in north coast streams and rivers. The largest run of steelhead in California waters is in the Klamath-Trinity river system. The Eel River also supports a sizeable run. Unfortunately, we do not have estimates of the size of the current run for these systems. Because many of the spawning and rearing tributaries are largely undeveloped and still fairly remote, the north coast runs are in better condition than other areas of the state, although these populations are also declining.

Major factors impacting north coast steelhead stocks are watershed disturbances caused by logging on unstable and steep slopes, grazing, and road building. Poaching is a major problem, especially for summer steelhead, which must oversummer in pools, often in crowded conditions. This renders them susceptible to snagging and netting, especially if the pools are located in accessible areas.

Management

Admittedly, the Department of Fish and Game is behind the times in steelhead management and research. From the 1930's through the 1950's, the Department was in the forefront, producing such classic studies as Shapovalov and Taft's steelhead life history study on Waddell Creek, and Hallock's evaluations of stocking of hatchery-reared steelhead in the Sacramento River. The Department's steelhead management and research efforts have been greatly reduced since this time. The need for information regarding salmon stocks has intensified over the past decade, and this has led to a redirection of the Department's anadromous research and management efforts.

The Department of Fish and Game has recently begun a Steelhead Management and Research Project. One of the primary tasks of this project will be to develop a statewide steelhead management plan that will identify goals, objectives,

SMB-26805

and restoration needs. In 1993, California will institute a catch report card requirement for all steelhead anglers. This requirement will provide much needed angler harvest information and also funds to be used for management, research, and specific restoration projects. Restoration of wild and native steelhead populations will be a major objective of the Steelhead Project.

Dennis McEwan
California Department of Fish and Game

References

Barnhart, R.A. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) - steelhead. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.60). U.S. Army Corps of Engineers, TR EL-82-4. 21 p.

Hallock, R.J., W.F. Van Woert, and L. Sapovalov. 1961. An evaluation of stocking rainbow trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River system. Calif. Dept. Fish and Game, Fish Bull.114. 74 p.

Lufkin, Alan. (ed.) 1991. California's salmon and steelhead: the struggle to restore an imperiled resource. Univ. Calif. Press. Berkeley. 305 p.

Meyer Resources, Inc. 1985. The Economic value of striped bass, *Morone saxatilis*, chinook salmon, *Oncorhynchus tshawytscha*, and steelhead trout, *Salmo gairdneri*, of the Sacramento and San Joaquin River Systems. Calif. Dept. Fish and Game, Anadromous Fisheries Branch Administrative Report No. 85-03, revised.

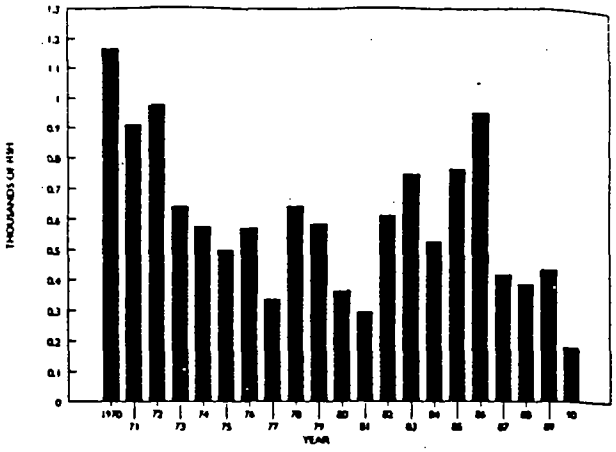
Shapovalov, L. and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Calif. Dept. Fish and Game, Fish Bull. No. 98. 373 p.

WHITE STURGEON

History of the Fishery

Historically, the white sturgeon (*Acipenser transmontanus*) resource has been very important to Californians. Sturgeon scutes and skull plates are found in native American middens in the San Francisco Bay, Sacramento - San Joaquin Delta, and Elkhorn Slough areas, indicating that these large fish were important sources of tribal nutrition. An early commercial fishery developed for white sturgeon between the 1860's and 1901, stimulated by a growing acceptance of smoked sturgeon and caviar on the East Coast of North America. The California harvest was concentrated in the San Francisco Bay and Delta. Fishing gear included gillnets, longlines, and multiple unbaited hooks for snagging sturgeon. The commercial catch peaked at 1.65 million pounds in 1887, declined to 0.3 million pounds in 1895, and to 0.2 million pounds in 1901 when the commercial fishery was closed. Small commercial catches in a reopened fishery from 1909 to 1917 indicated that white sturgeon populations were still low, and commercial fishing ceased in 1917.

Sport fishing for white sturgeon was legalized in 1954, with a 40 inch total length minimum size and a one fish per day



California commercial passenger-carrying fishing vessel (CPFV) landings of sturgeon, 1970-1990.

per person limit. In 1956, snagging for sturgeon was outlawed, and the legal size minimum was raised to 50 inches through 1963. The small sport fishing catch increased dramatically in 1964 when the minimum size reverted to 40 inches and grass shrimp were discovered to be effective bait. By 1967, 2,258 sturgeon were landed by partyboat anglers. Possibly due to reduced stocks of other estuarine and coastal marine species such as striped bass, angling for white sturgeon has become very popular. Although exact sport catch data are not available, the California Department of Fish and Game estimates that harvest rate during the 1980's was 40 percent greater than it was during the previous two decades. In 1990, a 72 inch *maximum* size limit became law and the minimum size was increased by two inches per year until a new minimum size of 48 inches is reached (1993).

White sturgeon, *Acipenser transmontanus*.

Status of Biological Knowledge

White sturgeon are generally found in estuaries, and their range extends along the Pacific Coast of North America from Ensenada, Mexico, to the Gulf of Alaska. However, spawning populations have been found only in large rivers from the Sacramento-San Joaquin system north. Indeed, most California white sturgeon are found in the Suisun Bay-San Pablo Bay-San Francisco Bay estuarine system. Some white sturgeon move into the Delta and lower Sacramento River during fall and early winter. Some of these fish move up the Sacramento River to the Colusa area or into the Feather River for spawning. A smaller number move up the San Joaquin River. The Klamath River supports the other California sub-population of white sturgeon. A few fish have shown extensive movements along the Pacific coast. Some tagged fish from San Pablo Bay have been caught in Oregon and Washington.

SMB-26806

California white sturgeon grow very rapidly. Young sturgeon can reach 7.5-12 inches fork length in one year. This rapid growth slows somewhat and they reach 40 inches after six to twelve years. Subsequently, they grow one to 2.5 inches per year. Ages and growth rates of field-caught fish have been determined from the number and spacing of annular rings, visible in sections of first pectoral fin rays. Laboratory experiments have shown that young-of-the-year white sturgeon growth is affected by water temperature and dissolved oxygen concentration. They grow significantly faster at 68°F than at 59° F, but an increase to 77° F does not significantly increase growth rate. When dissolved oxygen concentrations drop to 56 percent of air saturation at any of these three temperatures, juvenile fish show a significant decrease in growth rate, presumably due to reduced food consumption. The white sturgeon's rapid growth rate has attracted the interest of some California aquaculturists, who grow sturgeon in freshwater tanks which have consistently moderate temperatures and high dissolved oxygen concentrations.

The largest sturgeon were caught before 1900 when size records were vague. However, the largest of these fish was probably more than 13 feet long and weighed more than 1,300 pounds, making white sturgeon the largest freshwater-inhabiting fish in North America! This fish may have been 100 years old. The largest white sturgeon captured in California waters during the past 40 years (a 9.2 foot, 460 pound, 47 year-old female) was inadvertently caught in a Sacramento River fish trap in 1955. In a U.C. Davis study of white sturgeon during the 1980's, many fish were caught, measured, examined for sex and stage of maturity, and released. Median male size was 3.6 feet and median female size was 4.6 feet in San Francisco Bay.

Compared with most freshwater or anadromous fishes, white sturgeon are quite old when they become sexually mature, but they evidence impressive fecundity at this large size. In the U.C. Davis study during the 1980's, sexually mature males were 3.6-6.0 feet long (10-15 years old), whereas mature females were generally 4.6-6.6 feet (12-20 years old) in San Francisco Bay. However, high natural variability in the size at sexual maturity was noted, especially among female white sturgeon. For example, the smallest pre-spawning female white sturgeon weighed only 25 pounds, whereas a 120 pound female was caught which, from gonadal analysis, was determined to have not yet spawned in her life! Preliminary studies indicate that white sturgeon females probably do not spawn every year. Several years may lapse between successive spawnings in an individual female. In the study on San Francisco Bay fish, approximately 50 percent of the males captured were approaching spawning condition for that year, compared with only about 15 percent of the captured females. Fecundity scales with female size. Smaller females (under five feet) contain about 100,000 eggs, whereas the 9.2-foot record female contained 4.7 million eggs!

Spawning occurs in the Sacramento River between mid-March and early June when water temperatures are 50-75° C Little is known about spawning behavior. White sturgeon spawn their eggs onto deep gravel riffles or rocky holes in the upper Sacramento and Feather Rivers. The fertilized eggs are very adhesive and hatch after one or two weeks on the bottom Larvae stay close to the bottom and are washed into the upper reaches of the Sacramento-San Joaquin estuary. Young juvenile sturgeon become increasingly tolerant of brackish water as they grow and develop.

White sturgeon feed on a wide variety of bottom-dwelling, estuarine animals. Sturgeon feed by suction with their ventral, protrusible mouths. Dense aggregations of taste buds on their four barbels presumably assist in identification of food on the bottom. When their mouths are blocked by food, white sturgeon can ventilate their gills by flushing water in via the dorsal part of the gill slit and out via the ventral part. Young sturgeon (eight inches) feed primarily on small crustaceans such as amphipods and opossum shrimp. As they develop, they take a wider variety of benthic invertebrates, including various species of clams, crabs, and shrimp. Larger sturgeons' diets include fish such as herring, striped bass, anchovy, smelt, starry flounder, salmon, and trout. White sturgeon in San Francisco Bay gorge themselves on herring roe, when it is available during the winter.

Little is known about predators on white sturgeon. Smaller fish are undoubtedly taken by various fish and bird predators, although the five lines of bony scutes along their bodies probably make them less desirable prey than other estuarine species. Anglers undoubtedly mount the largest predatory effort on the adult fish.

Status of Population

The nineteenth century history of white sturgeon fishing in California waters shows this species' vulnerability to overfishing. Delayed sexual maturity and infrequent spawning by the females exacerbates this vulnerability compared to most bony fishes. California Department of Fish and Game gillnet surveys during the 1980's in San Pablo Bay showed that angler harvest was high, and new size limits (including initiation of a first-ever maximum size limit in 1990) reflect the Department's management concerns. Their analysis of the supply-demand relationship indicates that the "white sturgeon cannot sustain the current 10 percent annual harvest rate."

Besides mortality associated with fishing, white sturgeon populations are influenced very much by recruitment of young fish. California Department of Fish and Game surveys of young and adult fish spanning the 1975-1986 period show that recruitment of young fish is directly proportional to freshwater outflow through the Sacramento-San Joaquin estuary. Thus, recruitment is highest in years with high rainfall and runoff, although the mechanism driving this phenomenon is not yet known.

Joseph J. Cech, Jr.
University of California

References

Chapman, F.A. 1989. Sexual maturation and reproductive parameters of wild and domestic stocks of white sturgeon, *Acipenser transmontanus*. Ph.D. Diss. Univ. Calif., Davis.

Gobalet, K.W. 1990. Fish remains from nine archaeological sites in Richmond and San Pablo, Contra Costa County, California. Calif. Fish and Game 76:234-243.

SMB-26807

Kohlhorst, D.W., L.W. Botsford, J.S. Brennan, and G.M. Cailliet. 1991. Aspects of the structure and dynamics of an exploited central California population of white sturgeon (*Acipenser transmontanus*). pp. 277-293 *In*: Williot, P. (ed.) Acipenser. Cemagref Publ.

Kohlhorst, D.W., L.W. Miller, and J.J. Orsi. 1980. Age and growth of white sturgeon collected in the Sacramento-San Joaquin estuary, California: 1965-1970 and 1973-1976, Calif. Fish and Game 66:83-95.

STRIPED BASS

History of the Fishery

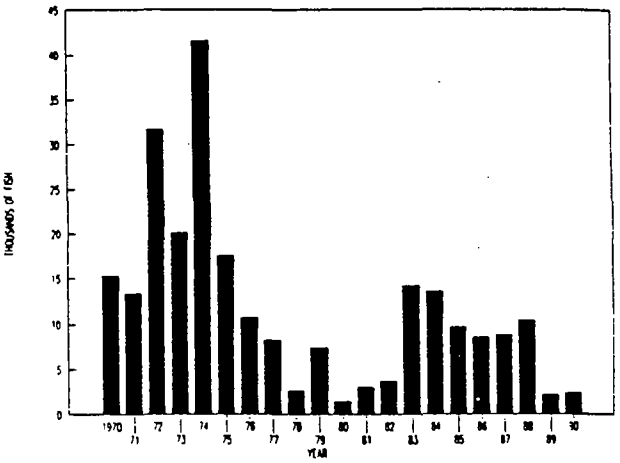
In 1879, 132 young striped bass (*Morone saxatilis*) from the Navesink River, New Jersey were released into the Sacramento-San Joaquin Estuary at Carquinez Strait. A second plant of 300 fish from the Shrewsbury River, New Jersey followed in 1882. Shortly after these introductions, striped bass experienced a population explosion in the estuary. Commercial harvesting started in the early 1880's and, by the turn of the century, exceeded one million pounds annually. The greatest recorded commercial catch, over two million pounds, occurred in 1903. Subsequently, annual catches declined due to increased restrictions on the fishery.

In 1935 the commercial fishery for striped bass was closed, although the stock was not depleted. The closure stemmed largely from a social conflict between sport and commercial fishing interests which culminated in the closure of the commercial gill net fisheries for chinook salmon and American shad in 1957. Thousands of striped bass which could not be legally marketed were killed annually in nets fished for these two species. Closure of the salmon and shad fisheries reduced fishing mortality for striped bass, but the magnitude of the reduction cannot be estimated because the precise extent of the incidental harvest is unknown. Some illegal netting continues today.

The striped bass sport fishery has become the most important fishery in the Sacramento-San Joaquin Estuary and one of the most important fisheries on the Pacific coast. From 1969 to 1989 there has been a general decline in catch associated with a decline in striped bass abundance. Over this period, the annual catch varied from about 403,000 fish in 1975 to 68,000 fish in 1989. During the early 1960's the annual catch of striped bass was even larger, probably around 750,000 fish. In 1985 an economist estimated the annual value of the striped bass fishery to exceed 45 million dollars.

Striped bass angling occurs year-round, but fishing localities vary seasonally in accordance with the striped bass migratory pattern. Tag recoveries indicate that many adults inhabit salt water—San Pablo Bay, San Francisco Bay, and the Pacific Ocean—in the summer. The proportion entering the ocean varies from year to year. These fish begin returning to the delta in the fall.

The distribution of fishing effort and catch has changed substantially over the years. Before the late 1950's there was little fishing in San Francisco Bay and the Pacific Ocean. Most of the catch came from San Pablo and Suisun bays, the delta, and rivers upstream. From the late 1950's to early 1980's, however, postspawning striped bass generally migrated farther downstream and stayed there longer. Thus, fishing improved in San Francisco Bay and the Pacific Ocean and declined in the delta. Also, the use of the Sacramento River as a spawning area appeared to have increased, improving fishing there in the spring. Now the migrations have shifted upstream again with Suisun Bay and the delta providing the bulk of the catch in the 1980's. While significant environmental changes have occurred, data are insufficient to develop conclusions regarding causes of these changes in striped bass migrations.



California commercial passenger-carrying fishing vessel (CPFV) landings of striped bass, 1970-1990.

Based on tag returns from 1969-1979, private boat anglers accounted for an average of about 65 percent, shore anglers for 21 percent, and commercial passenger fishing vessels for 14 percent of the annual striped bass catch. During creel checks over this same period, predominantly in the bay area, the average length of censused fish ranged from about 23 inches in 1979 to 28 inches in 1977. Average catch per hour ranged from about 0.1 to 0.3 fish.

Striped bass are generally caught by bait fishing or trolling, although under some conditions fly fishing or casting plugs or jigs is effective. Common dead baits include threadfin shad, anchovies, cut sardines, staghorn sculpins (bullheads), gobies (mudsuckers), shrimp, blood worms, and pile worms. Drift fishing with live anchovies or shiner perch is popular in San Francisco Bay and the Pacific ocean, and live golden shiner minnows sometimes are used in the Delta. Trolling methods are specialized. Many types of plugs, jigs, and spoons are used in trolling, frequently in double combinations.

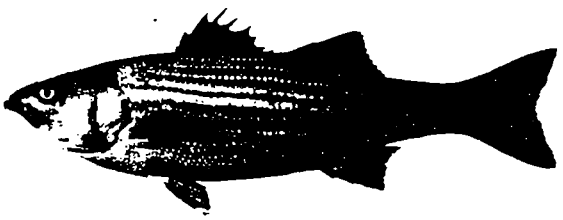
Present fishing regulations include an 18-inch minimum length and a daily bag limit of two fish. From 1956 to 1981, the minimum length was 16 inches and the bag limit was three fish. Prior to 1956, regulations were more liberal. A 12-inch minimum length and five-fish bag limit generally was in effect.

Exploitation rates have been estimated almost annually since 1958. They have varied from nine percent (1989) to 28 percent (1963) except for an unusually high 37 percent in 1958. Exploitation in the Sacramento-San Joaquin Estuary is lower

SMB-26808

than for Atlantic coast stocks which are fished commercially and have been exploited at rates as high as 50 to 70 percent of the population annually.

While the primary California population of striped bass is located in the Sacramento-San Joaquin Estuary, striped bass also have been introduced into many other areas including the lower Colorado River, several reservoirs, and the Pacific Ocean in southern California. Conditions are generally not suitable for striped bass spawning in the reservoirs or in marine waters off southern California, and so those fisheries usually depend on maintenance stocking from hatcheries. However, at least two reservoir populations, Millerton and New Hogan, do reproduce successfully. A striped bass fishery also has developed in reservoirs which are part of the State Water Project (SWP) and the federal Central Valley Project (CVP), such as San Luis Reservoir, O'Neill Forebay, and Pyramid and Silverwood lakes. These reservoirs are unintentionally stocked by young bass contained in water diverted from the Sacramento-San Joaquin Delta, and their fisheries have tended to decline in response to the decline of the Sacramento-San Joaquin population.



Striped bass, *Morone saxatilis*.

Status of Biological Knowledge

Adult Striped Bass Abundance. The decline of the striped bass fishery in the Sacramento-San Joaquin Estuary between the early 1960's and the present is a direct result of a substantial decline in the striped bass population. The California Department of Fish and Game (CDFG) has measured adult (larger than 16 inches, about 3 years old) striped bass abundance with mark-recapture (tagging) population estimates since 1969.

According to the estimates, the striped bass population ranged from about 1.4 to 1.8 million adults between 1969, when the estimates began, and 1976. Subsequently, abundance has declined to less than one million adults. A combination of much greater catches by the fishery and tag returns suggest that the striped bass population had about three million adults in the early 1960's. The reduction in the adult stock is principally due to reduced recruitment of young fish.

Spawning and Early Nursery Period. Striped bass begin spawning in the spring when the water temperature reaches 60° F. Most spawning occurs between 61° and 69° F, and the spawning period usually extends from April to mid-June. They spawn in fresh water where there is moderate to swift current. The section of the San Joaquin River between the Antioch bridge and the mouth of the Middle River, together with the other channels in the area, is one very important spawning ground. Another is the Sacramento River from Sacramento to Colusa. About one-half to two-thirds of the eggs are spawned in the Sacramento River and the remainder in the San Joaquin River system. Female striped bass usually spawn for the first time in their fifth year when they are 22 to 25 inches long. Many males mature when two years old and only about 11 inches long. Most males are mature at age three.

Stripers are very prolific. A five-pound, five-year-old female may spawn as many as 250,000 eggs in one season, and a 12- pound, eight-year-old fish is capable of producing over a million eggs. Some striped bass live for more than 20 years; these fish may exceed 50 pounds in weight and spawn several million eggs. Because of this great reproductive potential, striped bass were able to establish a large population within a few years after their introduction in California.

Striped bass typically spawn in schools at night during periods of warm weather when water temperatures rise. On June 9, 1967, CDFG biologists observed several thousand striped bass at the surface along the bank of the Sacramento River above Knights Landing. Small groups of from three to six bass were observed splashing and churning in the main current of the river in the act of spawning. At times, five or more groups of bass were observed spawning at one time. Usually a large female, was accompanied by several smaller males.

During the spawning act, eggs and milt are released into the water. The milt contains microscopic sperm cells which penetrate the eggs and cause them to begin to develop. While the eggs are still in the female they are only about 0.04 inch in diameter, but upon their release they absorb water and increase to about 0.13 inch in diameter. At this time they are so transparent that they are virtually invisible.

Striped bass eggs are only slightly heavier than water; so a moderate current will suspend them while they develop. Without any water movement they sink to the bottom and die. The larval bass hatch in about two days, although the length of time depends upon the temperature. Development is faster when the water is warmer.

The newly hatched bass continue their development while being carried along in the water. At first, the larval bass subsist on their yolk, but in about a week they start feeding on tiny crustaceans which are just visible to the naked eye. After several weeks, they begin feeding on opossum shrimp. At this time they generally inhabit the delta and Suisun Bay. By late July or August the young bass are about two inches long.

Young Striped Bass Abundance. Reduced juvenile production is the principal cause of the adult striped bass population decline. Since 1959, the CDFG has sampled young-of-the-year striped bass each summer (except 1966). An extensive survey is conducted every second week from late June to late July or early August throughout the nursery habitat. The fish are measured and, when their mean fork length reaches 1.5 inches, a young-of-the-year index is calculated on the basis of catch per net tow and the volume of water in the areas where the fish are caught.

Young-of-the-year striped bass abundance has suffered an erratic but persistent decline from high index levels sometimes exceeding 100 in the mid-1960's to the all time low of only 4.3

SMB-26809

in 1990. From 1959 to 1976, average abundance of young striped bass was more than three times subsequent levels.

Substantial effort has gone into evaluating factors controlling young striped bass production. Initially (1959-1970), annual fluctuations in young bass abundance could be explained by a simple model based on delta freshwater outflow which indicated that young bass production was much greater in years with high spring-early summer flows than in years with low flows. The mechanism causing the most abundant year classes to occur under high flow conditions was unknown. However, one potential explanation was that when flows were high, a lower percentage of the flow to the delta was diverted by the combination of major water projects (CVP and SWP) and local Delta agriculture. Hence, under those conditions, fewer young bass would be entrained in diverted water and removed from the estuary. Other potential explanations for the greater abundance in high flow years included: 1) expansion of the nursery area resulting in greater habitat availability and less competition, 2) higher food production, 3) dilution of toxicity, and 4) reduction in predation losses due to more turbid conditions.

In the early 1970's, production of young bass began to fall below the levels expected based on the initial models, and this decline was most acute in the delta portion of their nursery. During this period the SWP and CVP substantially increased their water export from the delta, resulting in greater diversion rates being associated with any particular flow. Minimum estimates of losses, which do not include fish smaller than 0.8 inches, in these water exports were approximately 10-30 million young striped bass annually. Maximum loss estimates approached or exceeded 100 million young bass in some years. Contrasting these losses with estimates of abundance at the 1.5 inch stage of about 15-30 million fish indicates that significant population impacts could be expected. Potential effects were taken into account by developing a new model which considered the delta and Suisun Bay separately and included both outflow and diversion terms in the delta portion of the model. This model yielded reasonable predictions of young bass abundance from 1959 to 1976 and provided additional evidence that losses of young fish to diversions were an important factor regulating striped bass abundance.

However, since 1977, the abundance of young striped bass has been considerably lower than predicted by the 1959-1976 model. Biologists evaluating this decline initially focused on four potential explanations: 1) the smaller adult bass population produced fewer eggs; 2) production of food for young striped bass has been reduced due to changes in abundance and species composition of the zooplankton which have occurred from unintentional introduction of exotic zooplankton by ship ballast discharges and possibly partly from unexplained changes in the phytoplankton; 3) large numbers of striped bass eggs and young were removed from the estuary with water diverted for agriculture, power plant cooling, and other uses; and 4) point and nonpoint discharges of toxicants may cause mortality of adults, reduce their ability to reproduce, or reduce the survival of their eggs and young.

An important distinction between these explanations is that increased losses of young fish to starvation, diversion, and toxicity would cause the survival rate to decrease, whereas the reduced egg supply concept does not require a decrease in survival rate—fewer eggs alone would yield fewer fish.

Statistical testing provided no evidence that survival rates differed significantly before and after 1977, although survival varied annually during both periods. Furthermore, the egg supply and young striped bass abundance have declined similarly since 1977. Averages compared for 1969-1976 with 1977-1990 indicate young striped bass abundance has declined 67 percent while the egg supply has declined 60 percent. Thus, in the opinion of CDFG biologists, the decline in the spawning stock and egg production is the proximate cause of the decline in young striped bass abundance. The root of the problem, however, relates to the cause of the initial decline in the spawning stock. A recent evaluation showed that the stock decline lagged the high water exports and associated losses of young fish in the early 1970's by the five- to eight-year interval appropriate for those losses to have substantially reduced egg production starting in the late 1970's.

Fishery Restoration. The CDFG is committed to stabilizing, restoring, and then improving the striped bass fishery of the Sacramento-San Joaquin Estuary, with the objective of restoring a self-sustaining striped bass population of more than three million adult fish. Specific actions have included the development of a restoration and management plan which defines the following problems detrimental to striped bass: delta water diversions, reduced delta outflows, lower San Joaquin River flows, water pollution, dredging and spoil disposal, bay-fill projects, illegal take, diseases and parasites, an annual spring-summer die-off, by-catch in the commercial bay shrimp fishery, and accidental introductions of exotic aquatic organisms through the discharge of ship ballast waters.

Other actions by the CDFG include: 1) testifying about water management impacts on striped bass at State Water Resources Control Board (SWRCB) hearings which will set new water quality, flow, and water diversion standards for the Sacramento-San Joaquin Estuary; 2) negotiating for mitigation from the Pacific Gas and Electric Company for losses caused by power plant operations and for mitigation from the California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR); 3) increasing study effort to improve understanding of processes controlling striped bass abundance with study funding coming from several sources including the DWR, USBR, SWRCB, Federal Aid to Sport Fish Restoration funds, and sales of striped bass stamps required of all striped bass anglers; and 4) annual stocking of several million striped bass which have been raised in the CDFG's own hatchery or purchased from private aquaculturists as the result of negotiated mitigation requirements or with striped bass stamp funds.

The extent to which the wild striped bass population of the Sacramento-San Joaquin Estuary is eventually restored depends ultimately on the degree to which five critical things happen: 1) how well the CDFG does its job of describing and justifying what needs to be done; 2) how well water development agencies, water-user groups, and other parties all work together to solve problems; 3) how well local, State, and Federal regulatory agencies establish controls and regulations to benefit

SMB-26810

aquatic life; 4) how well the public, including angler and environmental groups, communicates its interests to all parties; and 5) how well the Legislature is able to develop legislation and other aids to promote fishery restoration.

Donald E. Stevens
California Department of Fish and Game

References

California Department of Fish and Game. 1987. Factors affecting striped bass abundance in the Sacramento-San Joaquin River system. Interagency Ecological Study Program, Tech. Rep. 20. 147 p.

California Department of Fish and Game. 1989. Striped bass restoration and management plan for the Sacramento-San Joaquin Estuary Phase I. 39 p.

Meyer Resources. 1985. The economic value of striped bass, *Morone saxatilis*, chinook salmon, *Oncorhynchus tshawytscha*, and steelhead trout, *Salmo gairdneri*, of the Sacramento and San Joaquin River systems. Calif. Dept. Fish and Game, Anadromous Fish. Branch, Admin. Rep. 85-03. 44 p.

Stevens, D.E. 1977. Striped bass (*Morone saxatilis*) monitoring techniques in the Sacramento-San Joaquin Estuary. Pages 91-109 *in* W. Van Winkle, (ed.). Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press, New York, NY.

Stevens, D.E., D. W. Kohlhorst, L.W. Miller, and D.W. Kelley 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary, California. Trans. Amer. Fish. Soc. 114:12-30.

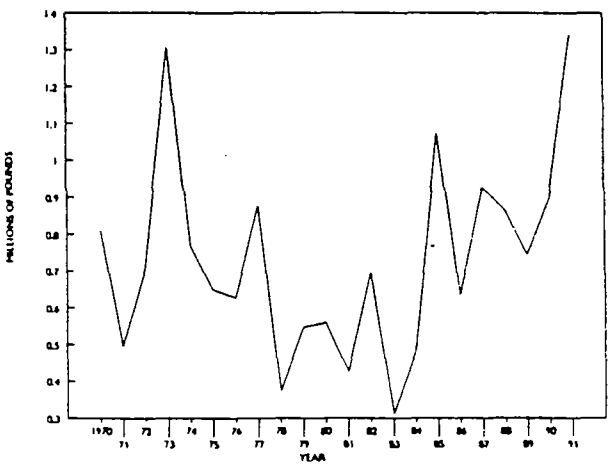
SMELT

TRUE SMELTS

General

True smelts (Osmeridae) are a family of small fishes highly prized for their delicate flavor. The 12 species in the family are characteristic of cold coastal, estuarine, and fresh waters of the northern hemisphere where they support both commercial and sport fisheries. They are also important forage fish for marine mammals and birds, as well as for predatory fishes such as salmon and cod. Seven of the 12 species occur in California: whitebait smelt, *Allosmerus elongatus*, found from San Francisco Bay northward; surf smelt, *Hypomesus pretiosus*, commonly known as day smelt, found along most of California's coast but spawning only from Santa Cruz northward; delta smelt, *Hypomesus transpacificus*, found only in the upper portions of the Sacramento-San Joaquin estuary; wagasaki, *Hypomesus nipponensis*, a Japanese freshwater species introduced into California reservoirs; night smelt, *Spirinchus starksi*, found from Pt. Arguello, northward; longfin smelt, *Spirinchus thaleichthys*, an estuarine species found mainly in the Sacramento- San Joaquin estuary and Humboldt Bay; and eulachon, *Thaleichthys pacificus*, an anadromous species found mainly in the Klamath River.

The six native smelts have all supported commercial fisheries in the past but probably only surf and night smelts contribute significantly to fisheries today. The combined fisheries are quite large and fairly stable, with a catch of about 0.5 to 1.3 million pounds per year (1970-1991). In 1989, for example, almost 750,000 pounds of smelt were landed, with a value of over $180,000. In addition, there is a large, but largely unreported, sport fishery for surf smelt and night smelt, as well as a bait fishery. In contrast, populations of delta smelt, longfin smelt, and eulachon have dropped to point in California where they may merit designation as endangered or threatened species.



California commercial landings of all smelt, 1970-1991.

Unfortunately, most catch records for smelt have lumped species together, so tell little about the relative importance of each species in the fisheries. The records of the California Department of Fish and Game for 1916-1969 are for "smelt" and "whitebait smelt." Their "smelt" includes not only surf smelt but jacksmelt, topsmelt, and grunion, all three of which are not smelt at all but silversides (atherinids). After 1969, the silverside catch was removed from the "smelt" statistics and supposedly all smelt except whitebait and night smelt were lumped into the category "true smelt." The whitebait smelt category is supposed to include both whitebait smelt and, until 1977, night smelt. However, it is unlikely that whitebait smelt are, in fact, harvested in any numbers. Furthermore, "whitebait smelt" is usually the only smelt category available to fish processors who fill out the required CDFG "pink slips" on which catch is recorded. Therefore, it is quite likely that "whitebait smelt" in the fisheries statistics includes all species of smelt harvested (but mainly surf and night smelt). The distinction between "whitebait" and "true" smelt in the statistics seems to be meaningless, and so only the total smelt catch since 1969 is presented here.

WHITEBAIT SMELT

History of the Fishery

Although about half the commercial smelt catch is called whitebait smelt, the species itself is apparently uncommon

throughout its range or only locally abundant and so it probably infrequently taken in the fishery.

Status of Biological Knowledge

One indication of the uncommonness of whitebait smelt is that comparatively little is known about its biology. Like other smelt, they live in large schools and are voracious feeders on zooplankton. They tend to favor productive inshore areas and bays, where they are presumably prey of many other fishes as well as seabirds and mammals. They live one to three years and reach lengths of seven inches. Spawning takes place in sandy, subtidal areas.

Status of Population

This species seems to be locally abundant and rarely enters the fishery. However, we have no idea if it has been more abundant in the past or if its populations are stable or not. Smelt catches shall be periodically examined for the presence of this species.

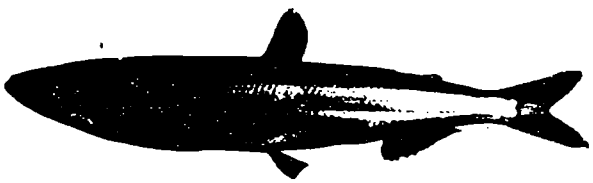
SURF SMELT

History of the Fishery

The fact that surf smelt spawn on selected beaches at predictable times of the day and year has made them a favorite sport fish. The standard A-frame dip net used to catch the smelt is a based on one used by Native Americans in the aboriginal fishery. It consists of a three- to four-foot long triangle of netting with poles on two sides and bag at the apex, into which fish can be flipped by tilting the net upwards. Beach seines ("jump nets") up to 20 feet long (with mesh sizes of at least 7/8 inch) are also legal in the sport fishery, as are cast nets. In 1991, the sport catch limit for smelt was 25 pounds per day, a regulation that has been in place for many years. The commercial fishery uses similar techniques to the sport fishery but also catches smelt in purse seines on occasion. This species is probably the dominant species in the commercial smelt catch as well as in the sport catch. Unfortunately, there are no reliable records of the sport catch (it was estimated as 400,000 pounds, roughly four million fish, in 1958) and the commercial statistics are hopelessly mixed with those of other smelt species. It is likely, however, that the commercial and sport catches combined average about 400,000 to 600,000 pounds per year. Surf smelt (and night smelt) are sold fresh in the coastal markets or sold to public aquaria to feed fish and marine mammals.

Status of Biological Knowledge

Surf smelt are the most widely distributed smelt in California but are only common north of San Francisco Bay. They are schooling, plankton-feeding fish that can reach 10 inches in length, making them the largest smelt in California. Females typically grow the largest and live the longest (up to five years), while males rarely live longer than three years. Females are mature, however, in one to two years, producing 1,300-37,000 eggs. In California, most spawning occurs in June through September, in the surf zone of beaches, especially during periods of high tides. The spawning smelt congregate in the surf during the day, usually while the tide is falling. The biggest congregations occur when high tide is in the late afternoon. The fertilized eggs adhere to sand and pebbles. The most favored spawning beaches are those made up largely of coarse sand and pea-sized gravel, with some freshwater seepage. During periods of heavy spawning, some beaches are literally coated with eggs. The eggs hatch in two to three weeks. Little is known about their larval life or of the habits of juvenile and adults in the ocean environment. They presumably spend their lives in waters close to shore, however, as smelt are a common bycatch in the shrimp fishery.



Surf smelt, *Hypomesus pretiosus*.

Status of Population

While the fishery for surf smelt (and for night smelt) seems to be stable, the fishery is in fact poorly regulated and monitored. Given their short life cycle, excessive fishing could cause smelt populations to plummet in just two or three years. Heavy recreational use of the beaches may also compact gravels and crush recently spawned eggs. It is also possible that the developing eggs may depend on water percolating through the gravels from above, so alterations of inflowing streams or lagoons may affect the suitability of the spawning habitat for egg survival.

DELTA SMELT

History of the Fishery

In the nineteenth century, Delta smelt and longfin smelt were the object of a commercial fishery that supplied markets in San Francisco. Much of the market seems to have been for dried fish for the Chinese community and most of the fishermen were Chinese.

Status of Biological Knowledge

Delta smelt are unusual in that they are endemic to the Sacramento-San Joaquin estuary, with one of the most limited distributions of any fish species. The species was fairly abundant in the estuary until its population collapsed in the 1980's. Although a number of factors probably contributed to the decline of the smelt population, the single most important factor seems to have been an increase in the amount of fresh water

SMB-26812

being diverted from the upper estuary (the Delta) in the spring, when the smelt are spawning. This not only diverted larval smelt out of the estuary but reduced the amount of habitat available for larval rearing.

Delta smelt are small, rarely exceeding three inches in length and rarely living longer than one year. They feed primarily on copepods and live primarily upstream of the estuarine mixing zone, in salinities of less than 10 parts per thousand. In winter they gradually move upstream to spawning areas in the freshwater portions of the estuary, where they spawn mainly in March and April. Each female produces 1,400-2,800 eggs.

Status of Population

After the fishery was abandoned, delta smelt were largely ignored until it was realized that the species was becoming so scarce that it was a potential candidate for listing as an endangered species. It has been recommended for listing as a threatened species by the US Fish and Wildlife Service in 1991. The short life history and low fecundity make Delta smelt exceptionally vulnerable to changes in the estuary and contribute to its precarious status.

NIGHT SMELT

History of the Fishery

Night smelt are also taken in numbers, both in the commercial and sport fisheries, in much the same ways as surf smelt. Because of smaller size and nocturnal habits, they are presumably taken in lesser numbers than surf smelt, but the statistics are uncertain. Like surf smelt, night smelt are caught mainly with A-frame dip nets. Most are caught in area around Eureka, which accounts for about 70 percent of all commercial smelt landings. The smelt are either sold for consumption as fresh fish or shipped to oceanaria for consumption by fish, birds, and mammals.

Status of Biological Knowledge

Like surf smelt, night smelt are schooling, plankton-feeding fish that are important prey for other fishes as well as marine mammals and birds. They rarely exceed six inches in length or three years in age.

Spawning has been recorded from January through September on the same beaches as those used by surf smelt. Much of the spawning takes place earlier in the season than the spawning of surf smelt; so it is likely that most of the smelt catch before June is night smelt, with surf smelt the predominant species in the summer. However, both species have been observed using the same beaches on the same day, with night smelt spawning at night and surf smelt spawning during the day. Peaks of spawning occur between dusk and midnight on outgoing tides, although night smelt spawning seems much less tied to tidal height than is the spawning of surf smelt. A distinguishing feature of night smelt spawning aggregations is the prevalence of males close to shore (and in the shore fishery). The male to female ratio early in the season is eight-to-one, but by the end of the season it is nearly 100-to-one. The ratio is close to one to one in offshore catches of smelt. Females apparently spawn repeatedly during the season, dashing in to release their eggs among crowds of eager males. The fertilized eggs stick to the gravel and hatch in about two weeks.

LONGFIN SMELT

History of the Fishery

Longfin smelt were once harvested along with Delta smelt in the Chinese fishery but were subsequently ignored.

Status of Biological Knowledge

Longfin smelt are primarily an estuarine species and seem to have two main populations in California, one the Sacramento-San Joaquin estuary (including San Francisco Bay) and one in Humboldt Bay. The southern population was once recognized as a distinct species (Sacramento smelt) and may still deserve recognition as such. Little is known about the Humboldt Bay population, but it appears to be small.

The Sacramento-San Joaquin population is widely distributed in brackish parts of the estuary, where juveniles feed on copepods and adults feed on mysid shrimp. Longfin smelt live up to three years and reach lengths of six inches, but most spawning adults are around four inches. Spawning takes place in the freshwater portions of the estuary from February through April and the larvae apparently concentrate in the mixing zone. The abundance of longfin smelt, like that of striped bass, is strongly tied to the amount of freshwater outflow flowing through the estuary in the spring.

Status of Population

In recent years, numbers of longfin smelt have declined alarmingly and they have become rather scarce. Their decline is associated with that of other species with strong ties to freshwater outflows; so it is most likely caused by the increase in diversions of freshwater from the estuary during the same period.

EULACHON

History of the Fishery

Eulachon is also known as candlefish, because they are so oily that Native Americans once dried them to burn like candles. They are highly prized as a food fish, being considered one of the tastiest of the smelts. Until the mid 1970's or so, eulachon supported a fairly consistent river sport dipnet fishery, as well as a dipnet fishery by Native Americans. The commercial catch in California has apparently never been large (although statistics are lacking) but eulachon are important commercially in British Columbia.

Status of Biological Knowledge

In California, they are found along the coast as far south as Monterey Bay and seem to prefer the outer continental shelf.

SMB-26813

where they school at depths of 150-750 feet. They reach a length of up to four inches on a diet of zooplankton, and reach maturity in two to three years. They can be important food for predatory marine animals, including salmon and sturgeon, especially when they move into bays on their way to spawn in fresh water. The principal spawning run in California is in the Klamath River, but runs have also been recorded from the Mad River and Redwood Creek to the south. They spawn in gravelly riffles close to the stream mouths, rarely ascending more than six-seven miles. Most eulachon die after spawning, but a few apparently live to spawn a second time. Each female lays about 25,000 eggs which stick to the gravel and hatch in two to three weeks.

Status of Population

In recent years, eulachon numbers seem to have declined drastically; so they are now rare or absent from the Mad River and Redwood Creek and scarce in the Klamath River. However, the eulachon and its fishery have been largely ignored in the past, and so we do not known if the fish are at a low point in a natural population cycle or if they have been reduced by human related factors. The eulachon populations in California need investigation to see if the fishery for this fascinating fish can be restored.

Discussion

California smelt provide examples at two ends of the spectrum of California fisheries. At one end are the surf smelt and night smelt, which together support a fairly constant sport and commercial fishery. The fishery is one of the largest in California in terms of numbers and pounds of fish caught, although its value is relatively low. It is also one about which surprisingly little is known and could conceivably decline or collapse from a combination of overexploitation and alterations to the 19-20 principal spawning beaches, which are receiving increasingly heavy recreational use. At the other end of the fisheries spectrum are eulachon, longfin smelt, and Delta smelt, all species which once supported fisheries but that are now in such low numbers they may qualify for endangered species status. These three species require fresh water for spawning and their declines are probably all related to alterations of the spawning and rearing habitats. It is clear that we need to know much more about all of California's smelt, so that they can be managed for fisheries of the future and to maintain their important roles in coastal and estuarine food webs.

Peter B. Moyle
University of California

References

Fitch, J.E. and R.J. Lavenberg. 1971. Marine food and game fishes of California. Berkeley: Univ. Calif. Press. 177 pp.

Love, R.M. 1991. Probably more than you want to know about the fishes of the Pacific Coast. Santa Barbara: Really Big Press. 215 pp.

Moyle, P.B. 1976. Inland fishes of California. Berkeley: Univ. Calif. Press. 405 pp.

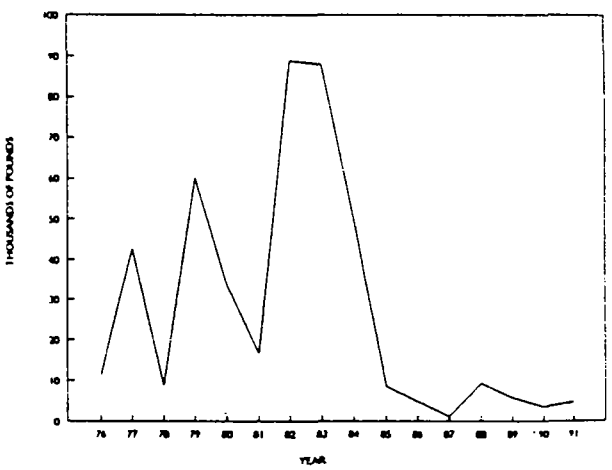
Moyle, P.B., B. Herbold, D.E. Stevens, and L. Miller. 1991. Life history and status of the Delta smelt in the Sacramento-San Joaquin estuary. Trans. Amer. Fish. Soc. (In press).

SILVERSIDES

There are three species of silversides (family Atherinidae) in California ocean waters, the grunion (*Leuresthes tenuis*), the topsmelt (*Atherinops affinis*), and the jacksmelt (*Atherinopsis californiensis*). Information on grunion is presented in a separate section. Even though "smelt" is included in the common names of these species, silversides differ in part from true smelts (family Osmeridae) in having two dorsal fins (one with spines), while the true smelts have one dorsal fin and an adipose fin near the tail.

History of the Fishery

Silversides are marketed fresh for consumption or bait. The commercial fishery for silversides has been conducted with gill nets, lampara nets, and round haul nets. Historically, set lines have been used in San Francisco Bay for jacksmelt, and during the 1920's beach nets, pulled ashore by horses, were used at Newport Beach. Commercial catches of jacksmelt have varied sharply over the past 70 years. The high year for this fishery was 1945, when over two million pounds were taken. During the 1980's, the catch varied between 88,770 pounds in 1982 to 4,902 pounds in 1986, with most of the catch being landed in the Los Angeles area. This is an occasional or incidental fishery, and fluctuations observed in catch records reflect demand, not true abundance. Principal commercial fishing areas are usually in harbors and bays such as San Pedro, Monterey, San Francisco, Tomales, and Humboldt. Commercial catches of topsmelt are not as large as those of jacksmelt because of the smaller size and more scattered distribution of topsmelt. There are no commercial or sport bag and possession limits on these two species.



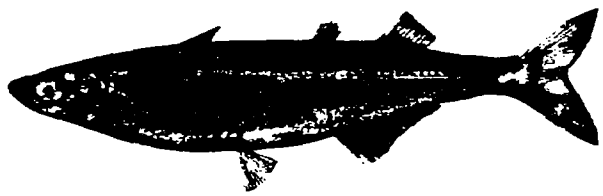
California commercial landings of jacksmelt and topsmelt, 1976-1991.

Jacksmelt and topsmelt make up a significant portion of the pier and shore catch throughout California, and private boat anglers fishing near shore catch them occasionally. During 1958 to 1961 these two species comprised about 10 percent of the total hook-and-line sport catch by numbers (272,000 jacksmelt and 43,000 topsmelt) in central and northern California. These are among the most abundant fishes available to pier and

SMB-26814

shore anglers and represent a very important recreational fishery, especially for children. When taken with light fishing gear, they are easy to catch and excellent fighters.

Jacksmelt are caught by a variety of sport fishing methods. A string of half-a-dozen bright red artificial flies or small hooks baited with shrimp or squid is the most successful terminal tackle used by pier anglers. Single baited hooks are also used from piers and by shore and skiff anglers. The larger jacksmelt is quite a game fish and will take a small spinner or lure cast out and retrieved with a series of quick jerks. Young jacksmelt and topsmelt are quickly attracted with bread crumb chum thrown into the water. A rapid feeding activity takes place, making it easier to catch fish attracted to the chum.



Topsmelt, *Atherinops affinis*.

Status of Biological Knowledge

Topsmelt range from the Straits of Juan de Fuca, British Columbia, to the Gulf of California. They attain a total length of 14.5 inches, but individuals in sport catches are usually six to eight inches in length. There are seven subspecies of topsmelt, three of which are in California. These numerous subspecies demonstrate varied behavior and reflect the different environments occupied by this species: kelp beds, harbor areas, and sandy beach areas. They usually form loose schools but will congregate when feeding.

Topsmelt grow about 2.5 to four inches the first year, gain another two inches the next year, and grow proportionally less each year until they reach maximum size of about 14 inches. The largest topsmelt that has been aged was seven or eight years old. Some topsmelt spawn by their second year but most reach maturity during their third year. The spawning period is from May to July. This species attaches its eggs in a mass on eelgrass and low growing algae in harbors and bays, and possibly on kelp. The egg mass from each female is intertwined to the substrate by fine string-like filaments attached to each egg.

The food of topsmelt consists primarily of plankton species including crustaceans. Intertidal inhabitants eat algae and fly larvae, as well as crustaceans. Bay forms have been observed working along muddy bottoms for food items. Topsmelt have the ability to withstand high salinity concentrations. They have been known to live in salt ponds with salinities as great as 1.5 times that of open ocean water.

Topsmelt are a very important species in bay and nearshore ecosystems in southern California. Collections of fishes by beach seine in bays are almost always numerically predominated by young topsmelt. Young-of-the-year topsmelt were found to contribute 85 percent of the total annual fish production in the shallow water areas of upper Newport Bay. Topsmelt have been shown to be the most ubiquitous and numerically abundant fish species in submarine meadows of surfgrass on the open coast. They are one of the five primary species brought to the breeding colonies of the least tern, an endangered seabird.

Jacksmelt form dense and larger schools than topsmelt and range over much of the inshore area of California. The geographic range is from Yaquina Bay, Oregon to Santa Maria Bay, Baja California. This species attains a length of 22 inches, with 17-inch fish commonly taken. Jacksmelt are relatively fast growing, reaching 4.5 to five inches in the first year and up to eight inches during the second year. The oldest aged jacksmelt, a 16-inch male, was 11 years old. The spawning season is during winter from October to April. Large masses of eggs, about the size of small BB's, are attached to eel grass and algae by means of long filaments. Pinkish egg masses have been observed along with herring eggs during winter months in Elkhorn Slough.

The larvae and young are distributed near the surface in harbors, along sandy beaches, and in the kelp canopy. Their food habits are not well known, but it can be assumed that fish as fast as jacksmelt, that readily take a moving lure, are predatory animals. Small fish as well as crustaceans make up part of their diet.

The species is not desired by some sport anglers because of the presence of relatively large sized worms in the flesh. These are an intermediate stage of a spiny-head worm that is thought to be a parasite in sharks and pelicans. It probably is harmless to man, and definitely is harmless when the flesh is cooked.

Status of Population

Stock sizes of these two species have not been determined. At present, there are no indications that topsmelt or jacksmelt are being overfished in California. However, as these species occur in inshore waters, they are apt to be affected by pollutants and loss of habitat through development.

Paul A. Gregory
California Department of Fish and Game

References

Carpelan, L.H. 1955. Tolerance of the San Francisco topsmelt, *Atherinops affinis affinis*, to conditions in salt-producing ponds bordering San Francisco Bay. Calif. Fish and Game, 41(4):279-284.

Clark, F.N. 1929. The life history of the California jacksmelt, *Atherinopsis californiensis*. Calif. Div. Fish and Game, Fish Bull. 16. 22 p.

Demartini, E.E. 1982. The spring-summer ichthyofauna of surfgrass, *Phyllospadix*, meadows near San Diego, California. Bull. South. Calif. Acad. Sci. 80(2):81-90.

Hubbs, C.L. 1918. The fish of the genus *Atherinops*, their variation, distribution, relationships and history. Amer. Mus. Nat. Hist. Bull., 38(13):409-440.

Quast, J.C. 1968. Observations on the food of kelp-bed fishes. Pages 109-142 in Utilization of kelp-bed resources in southern California. Calif. Dept. Fish and Game, Fish Bull. 139.

SMB-26815

Schultz, L.P. 1933. The age and growth of *Atherinops affinis oregonia* Jordan and Snyder and of other subspecies of baysmelt along the Pacific coast of the United States. Wash. Univ. Publ. Biol. 2(3):45-102.

GRUNION

History of the Fishery

The commercial use of grunion (*Leuresthes tenuis*) is very limited, this species forming a minor portion of the commercial "smelt" catch. Grunion are taken incidentally in bait nets and other round haul nets, and limited quantities are used as live bait. In recent years, no commercial landings have been reported. However, since grunion usually are taken with other small fish and are not separated out, catch records would not show any landings.

The grunion's principal value is as the object of a unique recreational fishery. These fish are famous for their spawning habits, which are so remarkable as to arouse an "I don't believe it" response from a person hearing about them for the first time. They are subjects of widespread popular interest, bringing thousands of people to beaches during night high tides in spring and summer months to catch the fish or just to observe them. Grunion hunting has become one of the famous sports of southern California. As the fish leave the water to deposit their eggs, they may be picked up while they are briefly stranded. Racing for fish spotted far down the beach and clutching for the small bits of slippery, wriggling energy provide an exhilarating time for young and old alike. The attraction provided by grunion can only be realized when one sees the numbers of people lining the more popular beaches in the Los Angeles area on the night of a predicted run. Often there seem to be more people than fish, but at other times everyone catches fish.

Status of Biological Knowledge

Grunion are members of the silversides family, Atherinidae, along with the jacksmelt and topsmelt. They normally occur from Point Conception, California, to Point Abreojos, Baja California. They are found more rarely from Monterey Bay on the north to San Juanico Bay, Baja California, on the south. They inhabit the nearshore waters from the surf to a depth of 60 feet. Marking experiments indicate that they are nonmigratory.

Grunion spawn at night on the beach, from two to six nights after the full and new moon, beginning a little after high tide and continuing for several hours. As a wave breaks on the beach, the grunion swim as far up the slope as possible. The female arches her body, keeping her head up, and excavates the semifluid sand with her tail. As her tail sinks, the female twists her body and digs tail first until she is buried up to her pectoral fins. After the female is in the nest, up to eight males attempt to mate with her by curving around the female and releasing their milt as she deposits her eggs about four inches below the surface. After spawning, the males immediately retreat toward the ocean. The milt flows down the female's body until it reaches the eggs and fertilizes them. The female twists free and returns to the sea with the next wave. The whole event can happen in 30 seconds, but some fish remain on the beach for several minutes.

Spawning may continue from March through August, with possibly an occasional extension into February and September. However, peak spawning is from late March through early June. Once mature, an individual may spawn during successive spawning periods at about 15-day intervals. Most females spawn about six times during the season. Counts of maturing ova to be laid at one spawning ranged from about 1,600 to about 3,600, with the larger females producing more eggs.

The eggs incubate a few inches deep in the sand above the level of subsequent waves. They are not immersed in sea water, but are kept moist by the residual water in the sand. While incubating, they are subject to predation by shore birds and sand-dwelling invertebrates. Under normal conditions, they do not have an opportunity to hatch until the next tide series high enough to reach them, in 10 or more days. Most of the eggs will hatch in 10 days if provided with the sea water and agitation of the rising surf, which probably triggers the release of a hatching enzyme that softens the covering of the egg. One can witness the spectacle of grunion eggs hatching. If you gather a cluster of eggs after a grunion run, keep them in a loosely covered container of damp sand in a cool spot. After 10 to 15 days, place some in a jar of sea water shaken briefly, and they will hatch before your eyes in a few minutes.

Grunion reach an average total length of five to six inches with a maximum of about seven inches. Average body lengths for males and females respectively are 4.5 and 5.0 inches at the end of one year, 5.5 and 5.8 inches at the end of two years, and 5.9 to 6.3 inches at the end of three years. Grunion mature and spawn at the end of the first year. After this, growth slows and their numbers decline rapidly. Only a few reach four years of age.

Grunion food habits are not known. They have no teeth, so they are presumed to feed on very small organisms. Man, larger fish, and other animals prey upon grunion. An isopod, two species of flies, sand worms, and a beetle have been found preying on the eggs. The reduction of spawning habitat due to beach erosion, harbor construction, and pollution is probably the most critical problem facing the grunion resource.

Status of Population

Despite local concentrations, the grunion is not an abundant species. In the 1920's the fishery was showing definite signs of depletion, and a regulation was passed in 1927 establishing a closed season of three months, April through June. The fishery improved, and in 1947 the closure was shortened to April through May. Grunion may be taken by sport fishers using their hands only. With these regulations, the resource seems to be maintaining itself at a fairly constant level. While the population size is not known, all research points to a rather restricted resource that is adequately harvested under existing law.

Paul A. Gregory
California Department of Fish and Game

SMB-26816

References

Clark, F.N. 1925. The life history of *Leuresthes tenuis*, an atherine fish with tide controlled spawning habits. Calif. Div. Fish and Game, Fish Bull. 10. 51 p.

Daugherty, A.E. 1962. California grunion. Pages 29-30 *in* California ocean fisheries resources to the year 1960. Calif. Dept. Fish and Game, Sacramento. 79 p.

Fritzsche, R.A., R.H. Chamberlain, and R.A. Fisher. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest), California grunion. Biol. Rep. U.S. Fish Wildl. Serv. 23 p.

Thompson, W.F. 1919. The spawning of the grunion (*Leuresthes tenuis*). Calif. Fish and Game Comm., Fish Bull. 3. 27 p.

Walker, B.W. 1952. A guide to the grunion. Calif. Fish and Game, 38(3):409-420.

SMELT: DISCUSSION

While the fishes in this group are quite similar in appearance, they belong to two different families, Osmeridae (the true smelt) and Atherinidae (the silversides). The smelt resources of California collectively provide an annual income of approximately $140,000 (1977-86) to the commercial fishers. They are also the object of several very important sport fisheries. The grunion fishery is quite unique since fishers may use only their hands to capture the fish. The smelt sport fishery in central and northern California is one of the few sport fisheries in the State in which it is permissible to use a net.

There is no apparent competition or interrelationship between the various species of smelt other than that the young of one species may fall prey incidentally to an adult of another species living in the same area. Fishes in this group undoubtedly form important links in the food chain of larger predatory fish, mammals, and birds.

Fishes composing this group occur in bays, estuaries, and inshore areas along the outer coast. Beach erosion, bay fill, and pollution may have deleterious effects on their spawning areas, general habitat, and populations.

Paul A. Gregory
California Department of Fish and Game

PELAGIC WETFISH

NORTHERN ANCHOVY

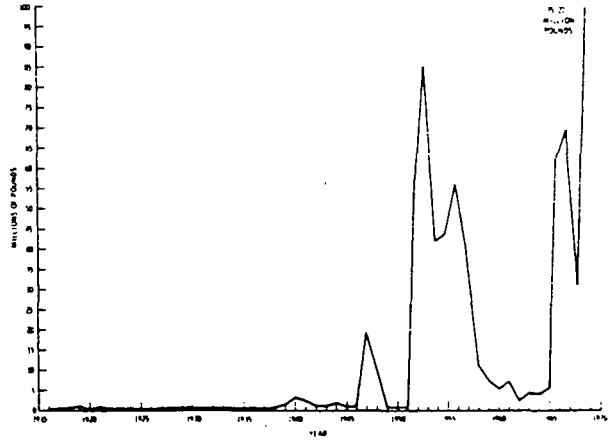
History of the Fishery

Northern anchovy (*Engraulis mordax*) are exploited by three separate fisheries in both California and Mexico. Anchovy landed by the reduction fishery are converted to meal, oil and soluble protein products that are sold mainly as protein supplements for poultry food but also as feed for farmed fish and other animals. Meal obtained from anchovy is about 65 percent protein compared to about 50-55 percent for meal from other fishes.

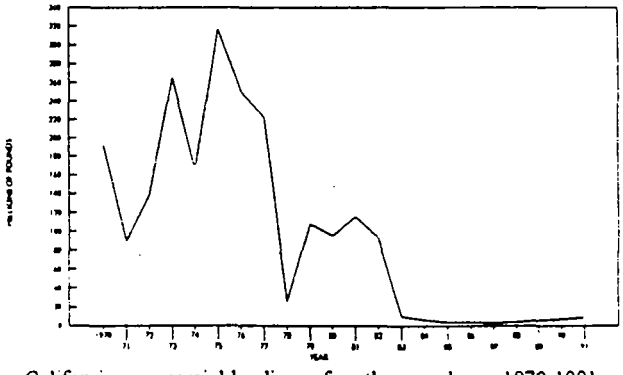
Anchovy harvested by the live bait fishery are not landed but kept alive for sale to anglers as bait. Transactions between buyers and sellers of live bait take place either at sea or at bait wells tied up at docks. Live-bait dealers generally supply bait to partyboats on a contract basis and receive a percentage of the fees paid by passengers. Bait is also sold by the "scoop" to anglers in private vessels.

Anchovy landed by the non-reduction (other than live bait) fishery are used as dead frozen bait, fresh fish for human consumption, canned fish for human consumption, animal food, and anchovy paste.

Reliable records of California landings of northern anchovy date from 1916. Landings were small until scarcity of Pacific sardine caused processors to begin canning anchovies in quantity during 1947, when landings increased to 9,464 tons. In order to lower the quantity of anchovies being reduced to fish meal, the California Fish and Game Commission required each processor to can a large proportion of the harvest (40-60 percent depending on can size). Anchovy landings declined with the temporary resurgence of sardine landings through 1951. Following the collapse of the sardine fishery in 1952, anchovy landings increased to 42,889 tons in 1953, but subsequently declined, largely due to low consumer demand for canned anchovy and increased sardine landings. Landings remained low through 1964. During the early years of the anchovy fisheries (1916-1964), anchovy were harvested almost exclusively by California fishermen. Mexico did not begin harvesting anchovy until 1962.



California commercial landings of northern anchovy, 1916-1969.

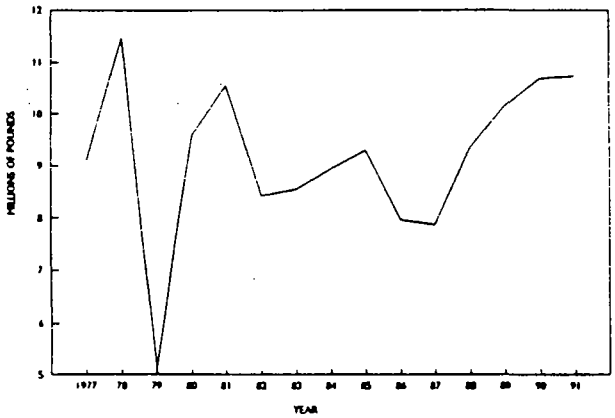


California commercial landings of northern anchovy, 1970-1991.

SMB-26817

Beginning in 1965, the California Fish and Game Commission managed anchovy on the basis of a reduction quota. This quota has been taken by a fleet of approximately forty small purse seine vessels known collectively as the "wetfish" fleet, which fishes for other species in addition to anchovy. Anchovy landed for reduction in California increased from 171 tons in 1965 to 27,330 tons in 1966, and ranged from 13,786 to 92,893 tons per year during 1966-1972, and from 80,855 to 155,966 tons per year during 1973-1977. In response to a decrease in the price of fish meal, landings declined to an annual average of 51,223 tons during 1979-1982. Reduction landings have been extremely low since 1983, largely as a result of low prices offered to fisherman.

The non-reduction fleet in recent years has consisted of about eighteen boats that are distributed along the California coast to serve the principal sport fishing markets, mostly in southern California.



California landings of northern anchovy for live bait, 1977-1991.

The live bait boats fish for a variety of species, but anchovies comprise approximately 85 percent of the catch. Historically, the anchovy live bait catch ranged from 4,000 to 8,000 tons per year and averaged 5,748 tons annually in recent years. Non-reduction (other than for live bait) landings averaged about 2,189 tons per year from 1965 to 1989 and, since 1985, have exceeded reduction landings in California because of a major decline in the reduction fishery.

Anchovy landed in Mexico are used primarily for reduction, although a small amount is used as bait. Mexico's harvesting and processing capacity increased significantly in the late 1970's when several large seiners were added to the fishing fleet and a large reduction plant was constructed in Ensenada. Mexican landings reached a high of 284,975 tons in 1981, fell to 196,078 tons in 1982, and have ranged from 87,024 to 136,594 tons per year since 1983. The fishery ceased operation in 1991.

The U.S. northern anchovy fisheries have been managed by the Pacific Fishery Management Council since 1978. Current regulations impose no numeric limit on live bait catch and provide a 7,711 ton quota for other non-reduction uses. The regulations also specify an optimum yield for the reduction fishery ranging from zero to 220,000 tons depending on the size of the spawning population.

Although the northern anchovy is harvested by fisheries in Mexican as well as U.S. waters, there is no bilateral management agreement with Mexico. In the absence of such an agreement, fishery managers in the U.S. assume that U.S. fisherman are entitled to 70 percent of the total optimum yield and quotas are set on this basis. The assumption is based on an estimate that 70 percent of the shared northern anchovy resource is, on average, found in U.S. waters. The Mexican fishery is managed independently and is not restricted by a quota.

Economics explain a great deal about the current dynamics of anchovy fisheries in California, because the fisheries are more limited by prices and markets than by biological constraints. The price paid to fisherman for anchovy landed as live bait has been about $618 per ton. On this basis, revenues in the live bait fishery during 1989 were about $3.1 million. Although prices and revenues for live bait tend to be surprisingly high, annual catches have been modest because of market limitations.

During 1980 to 1988, the price paid for anchovy landed for non-reduction purposes other than live bait averaged about $261 per ton. As with live bait, market limitations have resulted in modest annual catches despite relatively high prices paid to fishermen.

The average price for anchovy landed by the U.S. reduction fishery during 1974 to 1988 was about $55 per ton, but the price paid during 1988 was only $29 per ton. Low prices, as well as market problems, have prevented a significant U.S. reduction fishery in recent years.

Northern anchovy, *Engraulis mordax*.

Status of Biological Knowledge

Northern anchovy are distributed from the Queen Charlotte Islands, British Columbia to Magdalena Bay, Baja California. The population is divided into northern, central, and southern subpopulations or stocks. The central subpopulation ranges from approximately San Francisco, California to Punta Baja, Baja California, with the bulk being located in the Southern California Bight.

Northern anchovies are small, short-lived fish typically found in schools near the surface. They rarely exceed four years of age and seven inches total length, although individuals as old as seven years and nine inches have been recorded. There is a great deal of regional variation in age composition (number of fish in each age group) and size at age with older fish and larger fish found at relatively offshore and northerly locations. In warm years relatively old and large fish are found farther north than during cool years. These patterns are probably due to northern and offshore migration of large fish, regional differences in growth rate, and water temperatures. Northern anchovies in the central subpopulation are typically found in waters that range from 54° to 71° F.

SMB-26818

Information about changes in anchovy abundance during 1780 to 1970 is available from scales counted in sediment cores from the Santa Barbara basin. These data indicate significant anchovy populations existed throughout the time period and that biomass levels during the late 1960's were modest relative to those during most of the 19th and early 20th centuries.

The age at which northern anchovy become vulnerable to California fisheries depends on the location of the fishery and type of fishery. Fish become vulnerable to the inshore live bait fishery at an earlier age than they become vulnerable to the reduction fishery. However substantial numbers of zero and one year old fish are taken by both fisheries in most years.

Anchovy are all sexually mature at age two. The fraction of one-year-olds that is sexually mature in a given year depends on water temperature and has been observed to range from 47 to 100 percent. They spawn during every month of the year but spawning increases during late winter and early spring and peaks during February to April. Spawning has been observed over a temperature range of 54° to 71° F. Individual females spawn batches of eggs throughout the spawning season at intervals as short as seven to ten days. The eggs are found near the surface, and require two to four days to hatch, depending on water temperatures. Eggs and larvae are both found near the surface.

Northern anchovy are subject to intense predation throughout all life stages. Anchovy eggs and larvae fall prey to an assortment of invertebrate and vertebrate planktivores. As juveniles in nearshore areas, anchovies are vulnerable to a variety of predators, including birds and some recreationally and commercially important species of fish. As adults offshore, anchovies are fed upon by numerous marine fishes (some of which have recreational and commercial value), mammals, and birds, including the endangered California brown pelican. A link between brown pelican breeding success and anchovy abundance has been documented.

Northern anchovy eat plankton either by filter feeding or biting, depending on size of the food. Adult anchovy are known to filter anchovy eggs and it is possible that this type of cannibalism is an important factor in regulating population size.

Status of Population

Biomass of northern anchovy in the central subpopulation averaged 440,000 tons during 1964 to 1970, increased rapidly to 2,029,000 tons in 1974 and then declined to 543,000 tons in 1978. Since 1978, biomass levels have tended to decline slowly. Anchovy biomass during 1989 was 338,000 tons.

Maximum sustained yield of northern anchovy in the central subpopulation is estimated to be about 241,000 tons per year at a total biomass level of about 646,000 tons. However this harvest is a long-term average, and annual fluctuations are large.

Although total anchovy harvests and exploitation rates since 1983 have been below the theoretical levels for maximum sustained yield and historical levels, abundance continues to decline slowly. Annual harvests in the near future are expected to be lower because the Mexican reduction fishery has reportedly become unprofitable and has ceased operations. The size of the anchovy resource is now being determined mostly by natural influences.

Lawrence D. Jacobson
National Marine Fisheries Service

References

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. *In*: E. Vetter and B. Megrey (eds.). Mathematical analysis of fish stock dynamics: reviews, evaluations and current applications. Am. Fish. Soc. Symp. Series No. 6. Am. Fish. Soc., Bethhesda, MD.

Parrish, R.H., D.L. Mallicoate, and K.F. Mais. 1985. Regional variations in the growth and age composition of northern anchovy, *Engraulis mordax*. Fish. Bull. 83:483-495.

Parrish, R.H., D.L. Mallicoate, and R.A. Klingbeil. 1986. Age dependent fecundity, number of spawnings per year, sex ratio, and maturation stages in northern anchovy, *Engraulis mordax*. Fish. Bull. 84:503-521.

Thomson, C., T. Dickerson, G. Walls, and J. Morgan. 1991. Status of the California coastal pelagic fisheries in 1990. NMFS, Admin. Rept. LJ-91-22.

PACIFIC SARDINE

History of the Fishery

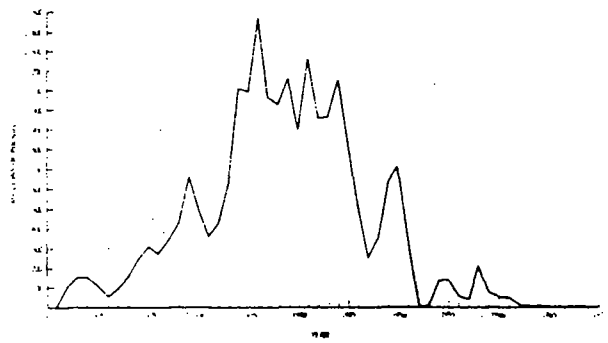
A sustained fishery for Pacific sardines (*Sardinops sagax*) first developed in response to the demand for food during World War I. Demand grew, and fishing effort and landings increased from 1916 to 1936, when the catch peaked at over 700,000 tons. The Pacific sardine supported the largest fishery in the western hemisphere during the 1930's and 1940's, with landings occurring in British Columbia, Washington, Oregon, and California. The fishery collapsed beginning in the late 1940's and declined, with short term reversals, to less than 1,000 tons per year in the late 1960's. There was a southward shift in the catch as the fishery decreased, with landings ceasing in the northwest in the 1947-1948 season and in San Francisco in 1951-1952. Through the 1945-1946 season, most California landings were at Monterey and San Francisco, but San Pedro accounted for most subsequent landings.

Sardines were used primarily for reduction to fish meal and oil and canned for human consumption, with small quantities taken for live bait. Although most fish landed north of California were reduced, California processors began as canners, and expanded to reduction as a lucrative supplement. Reduction was often more profitable, and for many years reduction tonnage exceeded tonnage canned. An extremely lucrative dead bait market for sardines developed in central California in the 1960's and was primarily responsible for continued fishing on the depleted resource.

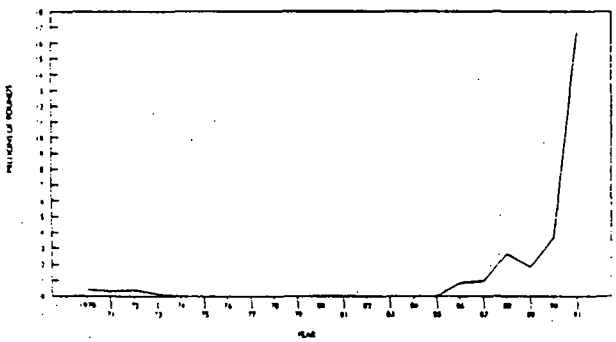
Prior to 1967, management of the sardine resource in California was mostly limited to: 1) control of tonnage of whole fish used for reduction, 2) case pack requirements (specified number of cases of canned fish per ton of whole fish), and 3) restriction of the fishing season. The first two controls were intended to lower the quantity of sardines used for reduction.

since this was regarded as a less desirable use and demand for reduction products was high. The latter control was designed to limit canning to periods when sardines were in prime condition and to improve the market for canned products. The total catch, however, was not regulated. From 1967 to 1973, California landings of sardines were limited to an incidental take of 15 percent sardines by weight mixed with other fish. Liberal provisions for use of incidental catch, and later a 250-ton dead bait quota, still supplied the demand for bait. In 1974, a moratorium on fishing sardines was established, which restricted landings to the 15 percent incidental limit and eliminated the use of sardines for dead bait. This legislation also established the state's intent to rehabilitate the resource. Through 1981, sardine landings were less than 50 tons per year.

Since the early 1980's, sardines have been taken incidentally in the southern California fishery for Pacific and jack mackerel. Most sardines from this source were canned for pet food, with a lesser amount canned for human consumption. A small directed fishery for sardines has been permitted annually since 1986. The quota (excluding bait fisheries) was limited to 1,000 tons per year from 1986 through 1990, and was increased to 8,150 tons in 1991. Sardines landed in the directed fisheries in southern and central California are primarily canned for human consumption and sold overseas, with minor amounts sold fresh for human consumption and animal food. Small quantities are harvested for dead bait and live bait. No reduction of sardines, except of waste produced from other processing operations, is currently taking place in California. Total annual landings of sardines have increased, from less than 100 tons in the 1970's and early 1980's, to 1,283 tons in 1986, and 8,543 tons in 1991.

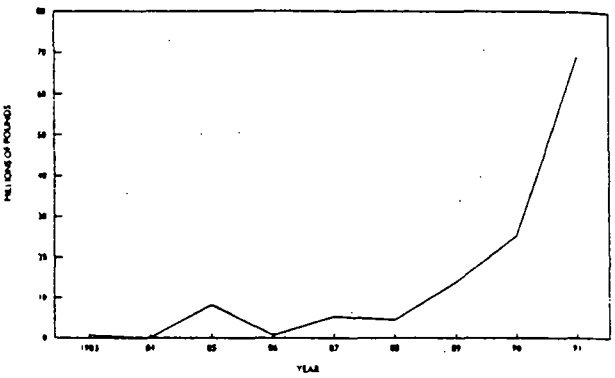


California commercial landings of Pacific sardine, 1916-1969.



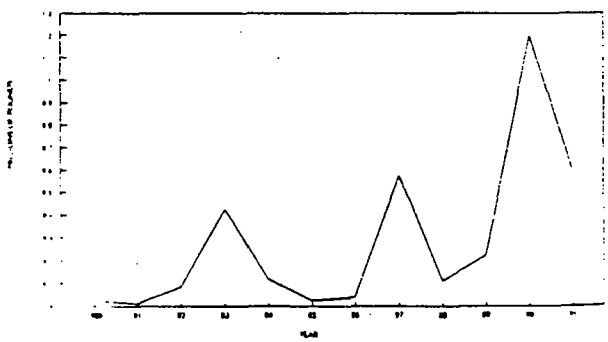
Commercial landings of Pacific sardine, 1970-1991.

Landings of sardines in Mexico have increased steadily during the 1980's, and were similar in magnitude to California landings through 1990. In 1991, however, sardine landings in Ensenada totaled 34,600 tons. Sardines landed in Mexico prior to 1991 were used for canning and reduction. In 1991, most sardines were used for reduction. The recent increase in sardine landings has been due in part to a decline in the availability of anchovies.



Commercial landings of Pacific sardine in Ensenada, Mexico, 1983-1991.

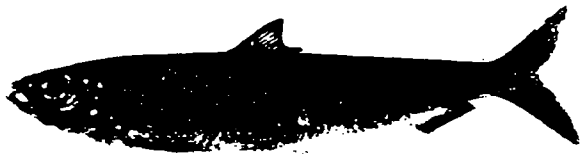
A fishery management plan for coastal pelagic species, including sardines, is being developed by the Pacific Fishery Management Council. Until the new management plan is adopted, the sardine fishery in California will continue to be managed by the state. Current state regulations provide for a 1,000-ton directed fishery when the spawning biomass is greater than 20,000 tons. This quota may be increased as warranted, provided any increase is consistent with the continued growth and rehabilitation of the resource. A quota of 250 tons (500 tons when the directed quota is 2,500 tons or greater) is reserved for dead bait. The live bait quota may be increased above a minimum level of 350 tons if such increase is consistent with the continued rehabilitation of the resource. At present, the live bait quota is 1,000 tons. Incidental take (in effect when directed or dead bait quotas are filled) is presently limited to 35 percent by weight. Current policy limits the total annual harvest of sardines to 10 percent of the spawning biomass. The sardine resource will be considered to be rehabilitated when the spawning biomass is at least one million tons, the population occupies much of its former range, and the age structure of the population resembles that of the population during previous periods of high abundance.



California landings of Pacific sardine for live bait, 1980-1991

SMB-26820

The price of sardines landed incidentally with mackerel decreased from about $190 per ton in the mid 1980's to about $150 per ton in 1991. The price for sardines landed in the directed fishery and canned for human consumption has ranged from $80 to $105 per ton. Only limited markets exist for canned products currently being produced. The traditional wetfish fleet and processing sector are in poor economic condition and have not successfully developed new products or markets. It remains to be seen whether markets will develop to utilize a fully-recovered population of Pacific sardines.



Pacific sardine, *Sardinops sagax*.

Status of Biological Knowledge

Sardines are small pelagic fish and members of the herring family. The genus *Sardinops* occupies the coastal areas of warm temperate zones of nearly all ocean basins. The genus is considered monotypic, and *Sardinops sagax* is the correct scientific name for sardine populations in the Alguhas, Benquela, California, Kuroshio, and Peru currents, and for populations off New Zealand and Australia. In the northeast Pacific Ocean, as in most other areas, the Pacific sardine occurs with anchovy, hake, and mackerel. It is generally accepted that the Pacific sardine population consists of three subpopulations or stocks: a Gulf of California subpopulation, a southern subpopulation off Baja California, and the principal northern subpopulation ranging from northern Baja California to Alaska. These stocks were distinguished on the basis of serological techniques. A fourth, far northern subpopulation was also postulated. Recent electrophoretic studies and examination of morphological variation showed no genetic variation among sardines from central and southern California, the Pacific coast of Baja California and the Gulf of California.

Historically, the northern subpopulation of sardines made extensive migrations, moving north as far as British Columbia in the summer months and returning south to southern California and northern Baja California in the fall. Northward movement was greater with increased age. The migration was complex, and the timing and extent of movement were affected to some degree by oceanographic conditions. At present, the population is relatively small, and is found primarily off central and southern California and Baja California. Contraction of range and spawning area has been associated with decreases in sardine population size around the world.

Estimates of sardine abundance from A.D. 280 to 1970 have been derived from the deposition of fish scales in sediment cores from the Santa Barbara Basin. Significant sardine populations existed throughout the time period and varied widely in size, typically over periods of roughly 60 years. Population declines and recoveries averaged about 36 and 30 years, respectively. Scale data indicate that sardine populations were much more variable than anchovy populations. Studies of deposits of otoliths have shown that, while the anchovy has been present for a million years or more, no trace of sardines has been found that is more than seven thousand years old. The tendency for tremendous variations in sardine biomass may be a characteristic of a species that has only recently occupied its habitat.

Pacific sardines reach about 16 inches and live as long as 13 years, but are usually less than 12 inches and eight years old. Most sardines in the historical and recent commercial catch were five years and younger. There is a good deal of regional variation in growth rate, with average size attained at a given age increasing from south to north. Sardine size and age at maturity may decline with a decrease in sardine biomass, although latitudinal and temperature effects may also play a part. At low biomass levels, sardines appear to be fully mature at age two, while at high biomass levels, only some of the two year olds are mature.

Sardines age three and older were nearly fully vulnerable to the historical fishery until 1953, but two and three year old fish became less available as the population declined and fewer southern fish moved northward. Recent catch data indicate sardines begin to become available to the fishery at age one, and are fully vulnerable by age three. Sardines probably become vulnerable to the live bait fishery, which is located close to shore, at a younger age.

Spawning occurs in loosely aggregated schools in the upper 165 feet of the water column, probably year-round, with peaks from April to August from Point Conception to Magdalena Bay, and from January to April in the Gulf of California. The main spawning area for the northern subpopulation is between Point Conception and San Diego, out to about 100 miles offshore, with evidence of spawning as far as 350 miles offshore. Historically, spawning also occurred off central California and may have been a fairly regular occurrence. Sporadic occurrences of spawning have been observed off Oregon and British Columbia.

Most spawning occurs between 55° and 63°F, with an apparent optimum between 59° and 61°F, and a minimum threshold temperature of 55°F. The spatial and temporal distribution of spawning is influenced by temperature; the center of sardine spawning has shifted northward and continued over a longer period of time during warm water conditions. Pacific sardines are serial spawners and spawn several times over a spawning season, although the number of spawnings is not known. Eggs and larvae are found near the surface. The eggs are spheroid, have a distinct, large perivitelline space, and require about three days to hatch at 59° F.

Recruitment of Pacific sardines is highly variable. Analyses of the stock-recruitment relationship have been inconclusive and controversial, with some studies showing a density-dependent relationship and others finding no relationship whatsoever. From 1932 to 1965, mean recruitment only slightly exceeded potential replacement of spawners at all levels of abundance, indicating little resilience to fishing. Recruitment occurs in strings, with several years of successful recruitment

SMB-26821

followed by similar periods of poor recruitment. The timing and duration of these strings has a large effect on population growth.

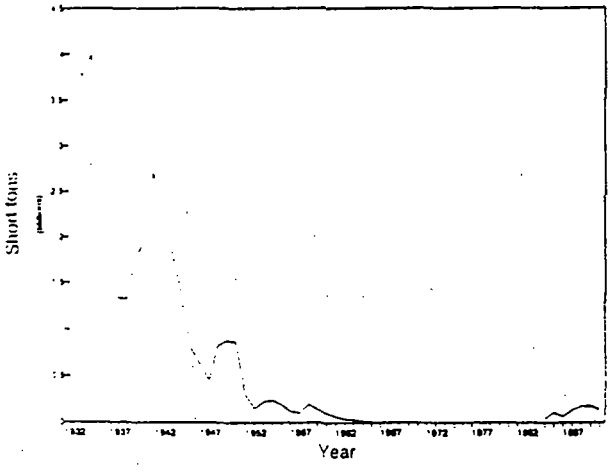
Sardines are filter feeders and prey on crustaceans, mostly copepods, and other plankton, including fish larvae and phytoplankton. Larval sardines feed extensively on the eggs, larvae, and juvenile stages of copepods, as well as other zooplankton and phytoplankton.

Through all life stages, sardines are eaten by a variety of predators. Eggs and larvae are consumed by an assortment of invertebrate and vertebrate planktivores. Although it has not been demonstrated in the field, anchovy predation on sardine eggs and larvae has been postulated as a possible mechanism for increased larval sardine mortality during the 1950's and 1960's. Juvenile and adult sardines are consumed by other fish, including yellowtail, barracuda, bonito, tunas, marlin, mackerel, hake, and sharks; sea birds, such as pelicans, gulls, and cormorants; and marine mammals, including sea lions, seals, porpoises, and whales. It is likely that sardines will become more important as prey for numerous species, including endangered species such as the California brown pelican, as the sardine resource continues to increase.

The Pacific sardine and other closely-related species undergo similar interannual changes in abundance in several other temperate coastal regions of the world. Scientists in several countries have conducted joint studies of recruitment and biomass of these coastal pelagic stocks under the Sardine-Anchovy Recruitment Program. Knowledge of the population dynamics and variability of these clupeoid fishes may eventually contribute to the detection of the oceanographic effects of global climate change.

Status of the Population

Spawning biomass of the Pacific sardine averaged 3,881,000 tons from 1932 to 1934, and fluctuated from 3,136,000 to 1,324,000 tons from 1935 to 1944. The population then declined steeply over the next two decades, with some short reversals following periods of particularly successful recruitment, to less than 100,000 tons in the early 1960's. During the 1970's, biomass levels were thought to be as low as 5,000 tons. Since the early 1980's, the sardine population has increased, and the spawning biomass in 1990 was estimated to be 130,000 tons.



Pacific sardine estimated biomass, 1932-1990.

Maximum sustained yield of Pacific sardine in the historical northern subpopulation was estimated to be 250,000 tons or about 22 percent per year, far less than the catch of sardines during the height of the fishery. Although combined landings in the U.S. and Mexico are still well below this level, landings have increased substantially in recent years. In the absence of a bilateral management agreement between the U.S. and Mexico, combined U.S. and Mexican catches of Pacific sardine may be high enough to retard the continued recovery.

Disagreement over whether the decrease in the sardine population was due to overfishing or to natural changes in the environment has persisted for many years. It is now apparent that both factors are important. Following the cessation of fishing and with the development of favorable environmental conditions, the sardine resource is recovering.

Patricia Wolf
California Department of Fish and Game

Paul E. Smith
National Marine Fisheries Service

References

Ahlstrom, E.H. and J. Radovich. 1970. Management of the Pacific sardine. *In*: A century of fisheries in North America, N.G. Benson, ed. Special Publication No. 7, American Fisheries Society, Wash. D.C., pp. 183-193.

Barnes, J.T., L.D. Jacobson, A.D. MacCall, and P. Wolf. 1992. Recent population trends and abundance estimates for the Pacific sardine (*Sardinops sagax*). Calif. Coop. Oceanic Fish. Invest. Rep. 33: in press.

Baumgarter, T., A. Soutar, and V. Ferreira-Bartrina. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California. Calif. Coop. Oceanic Fish. Invest. Rep. 33: in press.

MacCall, A.D. 1979. Population estimates for the waning years of the Pacific sardine fishery. Calif. Coop. Oceanic Fish. Invest. Rep. 20:72-82.

Murphy, G.I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). Proc. Calif. Acad. Sci. Fourth Series 34(1):1084.

Parrish, R.H., R. Serra, and W.S. Grant. 1989. The monotypic sardines, *Sardina* and *Sardinops*: their taxonomy, distribution, stock structure, and zoogeography. Can. J. Fish. Aquat. Sci., 46:2019-2036.

PACIFIC HERRING

History of the Fishery

The Pacific herring (*Clupea pallasi*) fishery has peaked three times during this century in response to demand for herring. During the intervening years herring catches were low, with most of it used as pet food, bait, or animal food at zoos. The herring reduction fishery peaked in 1918 at eight million

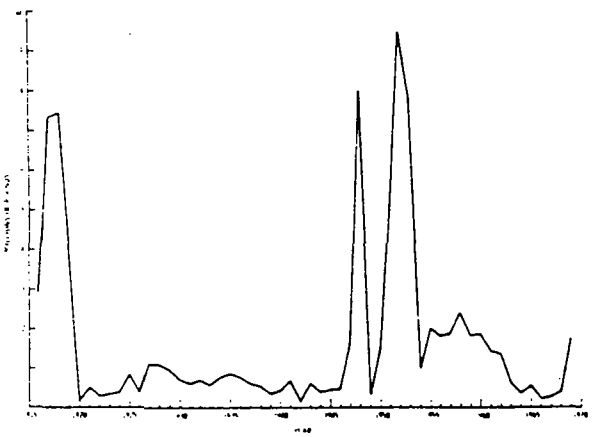
SMB-26822

pounds, but this fishery ended in 1919 when reduction of whole fish into fish meal was prohibited.

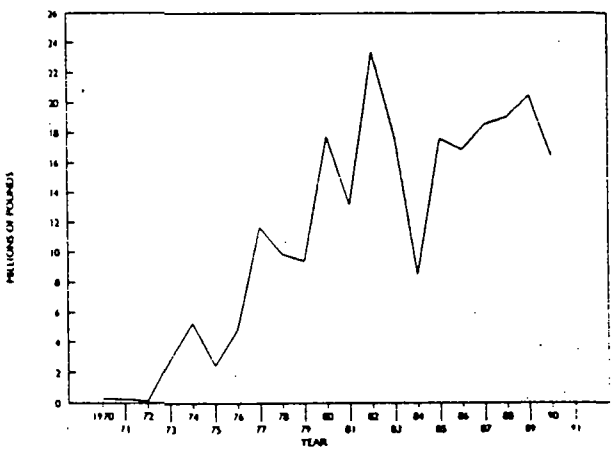
From 1947 to 1954 herring were canned to supplement the declining supply of Pacific sardines, and landings peaked in 1952 at 9.5 million pounds. Canned herring proved to be a poor substitute for sardines and the fishery for human consumption ended in 1954.

Since 1973, herring in California have been harvested primarily for their roe. The current herring roe fishery began when Japan became interested in herring from the west coast of North America due to poor catches of herring by Japanese vessels in the Bering Sea and a change in Soviet policy which closed the Sea of Okhotsk to Japanese herring vessels. By 1973 California, Oregon, and Washington were all exporting herring to Japan. California roe herring landings peaked in 1982 at 23 million pounds. Landings declined in 1984 when El Niño caused a corresponding decline in the herring population. However, most stocks have recovered, and landings have been over 18 million pounds from the 1987-1988 through 1989-1990 seasons.

Most of the herring catch is frozen whole and exported to Korea, where inexpensive labor is utilized to strip the roe from the carcasses. The roe is then graded and packed in salt before shipment to Japan.



California commercial landings of Pacific herring, 1916-1969.



California commercial landings of Pacific herring, 1970-1991.

In Japan, herring roe is an expensive delicacy called "kazunoko." The 1990 import wholesale price for top quality kazunoko was about $20 per pound, with retail prices believed to be $40 to $50 per pound. Herring roe is graded by size and color, and herring roe from California is often of such high quality that it is marketed under its own "Yellow Diamond" label. Although the Japanese herring market is primarily for herring roe, small amounts of whole herring are also marketed for human consumption.

Herring roe is available from California only during the November to March spawning season. Herring must be caught within one day of spawning or while spawning is in progress to provide the best quality roe. Herring within a few days of spawning are considered green by Japanese herring buyers and are of little value to them.

The herring roe fishery is limited to California's four largest herring spawning areas: San Francisco Bay, Tomales-Bodega Bay area, Humboldt Bay, and Crescent City Harbor. San Francisco Bay has the largest spawning population of herring and supplies over 90 percent of the state's herring catch.

The four spawning areas are managed separately by the California Department of Fish and Game, with catch quotas based on the latest population estimates from acoustic surveys and spawning-ground surveys. Quotas are adjusted annually and are generally set at about 15 percent of the amount of herring expected to return to spawn at each spawning area. Since quotas are set before the start of the spawning season, they are conservative and allow for potential declines in herring biomass. If the herring biomass declines and spawning escapement is less than expected, the herring quotas may approach the Department's recommended maximum harvest rate of 20 percent.

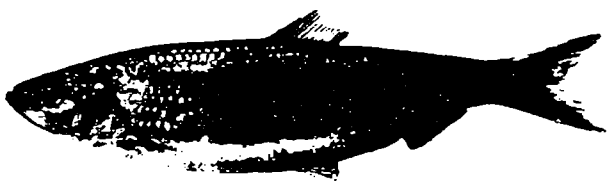
An orderly expansion of the fishery was allowed from 1975 to 1983. Since 1983, only five new permits have been issued, and the number of annual herring permits has stabilized at just over 450. About 400 of the permits are for the San Francisco Bay fishery. Tomales-Bodega Bay, Humboldt Bay, and Crescent City Harbor are restricted to gill nets only. In San Francisco Bay the catch is allocated 66 percent to gill net vessels and 34 percent to roundhaul vessels (purse seine and lampara).

Since 1980, with the exception of the 1983-1984 season, the ex-vessel seasonal value of the herring roe catch in California has averaged over $10 million. The value of a given catch is dependent on roe recovery: a yield of 10 percent or higher is considered good. Male herring are of little value; the higher the percentage of males in a given catch, the lower the price the fisherman receives. In 1990 the base price for 10 percent roe recovery was $1,000 per ton of whole fish. The price increases $100 per ton for each percentage point of roe recovery over 10 percent and can reach as high as $2,000 when starting from a base of $1,000 per ton. The base price for 10 percent roe recovery peaked at about $2,000 per ton in 1979 when some herring catches brought $4,000 per ton. In recent years the base price has been fairly stable at about $1,000 per ton.

Another lucrative phase of the herring industry is the roe-on-kelp fishery. Beginning in 1965, scuba divers harvested species of marine vegetation with herring eggs attached from Tomales and San Francisco Bays. This product known as

"kazunoko kombu" is also a Japanese delicacy. This fishery has evolved into the present roe-on-kelp fishery. Giant kelp is harvested from the Channel Islands off southern California, brought to San Francisco Bay, and suspended from 60 by 40 foot floating rafts. The rafts are towed to areas where herring spawning is expected to occur and are anchored. After spawning has ended, the kelp with herring eggs attached is removed from the rafts and packed in salt. This product reportedly has a per pound value much higher than herring roe. There are 10 roe-on-kelp permits for the 1991 fishery in San Francisco Bay. These permits are available to purse seine, lampara, or gill net permittees who are willing to exchange their net permits for roe-on-kelp permits.

Herring regulations changed yearly as the fishery expanded and new conflicts or issues were addressed. Management concepts new to commercial fishing in California were introduced as the herring fishery developed—limited entry, permits issued by lottery, individual vessel quotas, quota allocation by gear, the platoon system used to divide gill net vessels into groups, and finally herring roe fishery permits may now be sold. Many of these were controversial management decisions, but they have proven to be effective solutions to socioeconomic conflicts in a congested fishery.



Pacific herring, *Clupea pallasi*.

Status of Biological Knowledge

Pacific herring range from Baja California to Alaska and across the Pacific rim to Japan and China. Known spawning areas in California include San Diego Bay, San Luis River, Morro Bay, Elkhorn Slough, San Francisco Bay, Tomales Bay, Bodega Bay, Russian River, Noyo River, Shelter Cove, Humboldt Bay, and Crescent City Harbor. Most spawning areas are characterized as having reduced salinity, calm protected waters, and suitable spawning habitat such as marine vegetation beds or rocky intertidal areas.

Results of tag and recovery studies from Canada indicate that 25 percent of the herring may stray between adjacent spawning areas in British Columbia. The problem of stock identification has not been resolved in California, and it is not known whether adjacent spawning areas contain genetically distinct stocks. However, each spawning area in California where herring fishing is allowed is managed on the assumption that separate stocks exist.

During the spawning season, large schools of herring enter shallow bays and estuaries, where they may remain up to three weeks before spawning. When a school is ready to spawn, male herring initiate spawning by releasing milt. A pheromone in the milt triggers spawning by females which lay their adhesive eggs on suitable substrate. Fecundity is 220 eggs per gram of body weight, and a large female herring may lay 40,000-50,000 eggs. Female herring come in contact with the substrate while spawning. They lay a strip of adhesive eggs that is two to three eggs wide rather than broadcasting their eggs over a large area. Repeated passes by thousands upon thousands of females can build the eggs up to a thickness of 10 to 15 layers. Spawn depth distribution generally is shallower than 30 feet deep, but has been found to a depth of 60 feet in San Francisco Bay. A large spawning run may last a week and can result in 20 miles or more of shoreline covered by a 30-foot-wide band of herring eggs.

Herring eggs will hatch in about 10 days. During the incubation period the eggs are vulnerable to mortality from predation by marine birds, fish, and invertebrates. They may also die from desiccation or freezing during low tidal cycles. Normally, between 50 and 99 percent of herring eggs die before hatching.

The distribution of larval herring in bays and estuaries is not well known, but juvenile herring from San Francisco Bay have been found as far inland as the Delta Pumping Plant at Tracy. Juveniles may remain in the bay until summer or early fall, when they migrate to the open ocean.

Adult herring leave the bay immediately after spawning, and their life history while in the ocean is not well known. Herring first mature at age two, when they are about seven inches in length, and may live to be nine or 10 years old and reach a maximum length of about 11 inches.

While in the ocean, adult herring feed on macroplankton such as copepods and euphausiids. Larval and juvenile herring while in bays and estuaries are believed to feed on molluscan larvae and other zooplankton.

Herring themselves are a forage species for a diverse group of marine fishes, birds, and mammals. Such high level predators are opportunistic feeders and, while herring may compose a high percentage of their diet at times, herring are thought to make up a minor part of their annual food consumption. No species is known to be completely dependent on herring for survival.

Status of Population

The herring spawning populations in Tomales and San Francisco Bays are estimated annually from hydroacoustic and spawning-ground surveys. The San Francisco Bay herring biomass peaked in 1982 at 99,600 tons just prior to the 1983 El Niño. In the 1983-1984 season the population declined to only 40,000 tons. Since 1984, the San Francisco Bay population has been rebuilding and the spawning biomass has been over 65,000 tons from 1987-1988 to 1989-1990 seasons.

In Tomales Bay, on the other hand, spawning escapement declined about 90 percent during El Niño and has not recovered. From the 1983-1984 season to the 1986-1987 season, Tomales Bay alternated between very poor and normal spawning escapement. This pattern is believed to have been caused by a movement of herring initiated by the El Niño. The California drought, beginning with the dry winter of 1986-1987 has compounded the problem. During the seasons of 1987-1988, 1988-1989, and 1989-1990, herring spawning escapement in

SMB-26824

Tomales Bay has been poor, averaging 600 tons. During these three years herring nearly abandoned Tomales Bay. The four-year drought, coupled with new water impoundments and diversions, has reduced the amount of freshwater runoff into Tomales Bay to a trickle. The lack of turbid, low salinity water during the spawning season was a major change in the environment of Tomales Bay and is believed to be the primary factor causing the decline in spawning escapement.

In the 1990-1991 season, the herring population estimate for Humboldt Bay was 400 tons. The success of this small fishery suggests that the 60-ton quota is appropriate for the area. Individual spawning runs have been estimated in Crescent City Harbor, but no seasonal population estimates have ever been made for the area. However, observed spawning suggests that the population is large enough to support the minor fishery that occurs there.

Jerome D. Spratt
California Department of Fish and Game

References

Miller, D.J. and J. Schmidkte. 1956. Report on the distribution and abundance of Pacific herring, *Clupea pallasi*, along the coast of central and southern California. Calif. Fish and Game. 42:163-187.

Reilly, P.N. 1988. Growth of young-of-the-year and juvenile Pacific herring from San Francisco Bay, California. Calif. Fish and Game. 74:38-48.

Spratt, J.D. 1981. The status of the Pacific Herring, *Clupea harengus pallasii*, resource in California 1972 to 1980. Calif. Dept. Fish and Game, Fish Bull. 171. 107 p.

Trumble, R.J. and R.D. Humphries. 1985. Management of Pacific herring (*Clupea harengus pallasi*) in the eastern Pacific Ocean. Can. J. Fish. Aquat. Sci. 42(Suppl. 1):230-244.

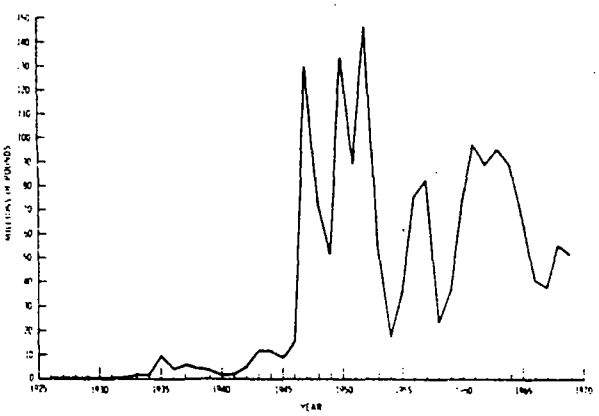
Ware, D. M. 1985. Life history characteristics, reproductive value and resilience of Pacific herring (*Clupea harengus pallasi*). Can. J. Fish. Aquat. Sci. 42(Suppl. 1):127-137.

JACK MACKEREL

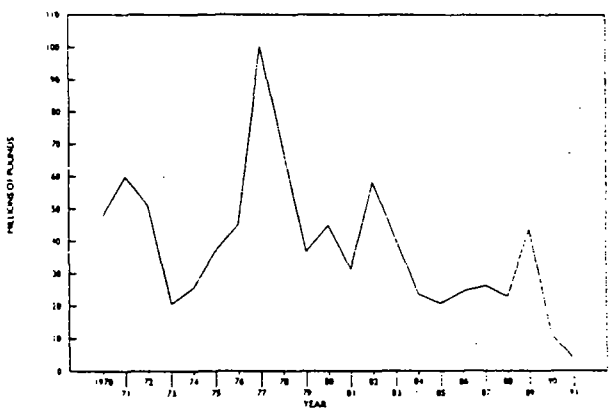
History of the Fishery

The jack mackerel (*Trachurus symmetricus*) was reported in the commercial catch as early as 1888, but was of minor importance before 1947. Commercially, it was less significant than the better known, more profitable, and more abundant Pacific sardine and the more desirable Pacific mackerel. Much of the catch between 1926 and 1946 was taken in schools mixed with sardine and Pacific mackerel and was sold at fresh fish markets where it did not spoil as quickly as Pacific mackerel. Landings were low, varying between 200 and 15,000 tons. During those years it was referred to as "horse mackerel" and had relatively little appeal as a canned product. During the 1947-48 season, the canning industry, after being hit hard by poor sardine landings, turned to jack mackerel as a substitute for sardines and the fishery landed approximately 71,000 tons. The U.S. Food and Drug Administration authorized the common name jack mackerel for use on all labeling in 1948. This name had more consumer appeal than horse mackerel, and jack mackerel has been a major contributor to California's commercial landings ever since.

Over 90 percent of the jack mackerel landed have been caught in southern California waters by purse seine and lampara vessels. Sporadic catches also occur off Monterey, to the north, as well as Ensenada, Mexico. Jack mackerel are fished throughout the year by the southern California fleet, nearshore from Point Conception to San Diego and offshore as far as San Nicholas Island and Tanner and Cortez banks.



California commercial landings of jack mackerel, 1926-1969.



Commercial landings of jack mackerel, 1970-1991.

In the early days of the fishery, shortly after 1947, the monthly catches were closely related to the activity of the fleet searching for sardines and Pacific mackerel. Fleet activity was most intense in the fall, when fishermen were searching for sardines, and slowest during the spring, when the sardine season closed and Pacific mackerel were scarce. Landings were highest in the fall and lowest in spring and summer. This seasonal trend soon disappeared when jack mackerel were found to be available throughout the year. In the 1970's landings were slightly higher in the summer when the anchovy fishery was closed and anchovy fishermen sought jack mackerel.

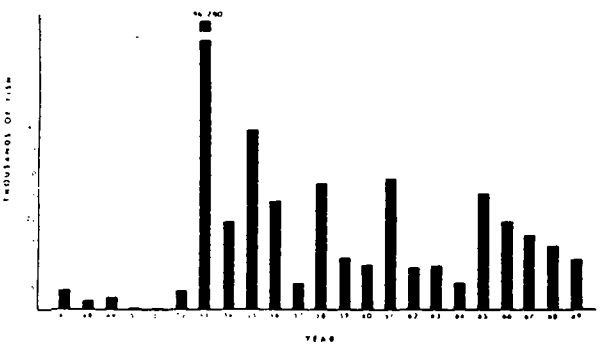
Jack mackerel landings have fluctuated widely. Many of these fluctuations were related to changing market demand and

SMB-26825

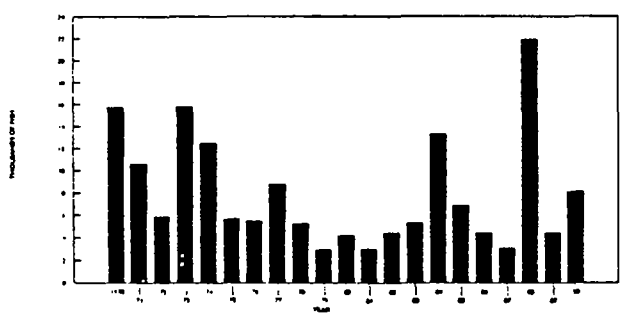
the ability of the fleet to fish for other species which were more profitable or more available. More fishing effort was directed toward jack mackerel when alternative species were unavailable. This happened with the decline of Pacific sardines in 1947 and of Pacific mackerel in 1966. When the Pacific mackerel population started to recover in 1978, the focus of the purse seine fleet's effort soon shifted back to that species, and jack mackerel became a secondary target.

The availability of jack mackerel also plays a part in the erratic catches, since there are unpredictable times when seiners cannot find jack mackerel schools for several months. Purse seiners can catch jack mackerel only when the young fish, less than six years old, form schools near the surface. As jack mackerel grow older, their behavior changes and they inhabit deeper waters farther offshore. There is currently no directed fishery for these older jack mackerel, but they are caught incidentally from California to Alaska, nearshore by salmon trollers, bottom and midwater trawlers, and offshore by albacore trollers.

In the first decade of the southern California fishery, the catch was mostly fish of age three to age six. Since 1965 the catch has been primarily fish of age zero, one, and two; fish older than age two have composed less than 20 percent of the catch. The reasons for the change in the age composition of the catch are not known. Because the purse seine fleet catches primarily age zeros, ones, and twos, the fishery depends on just three seasons' spawning production. If three seasons occur together which produce few young fish there will be very few jack mackerel available to the fishery.

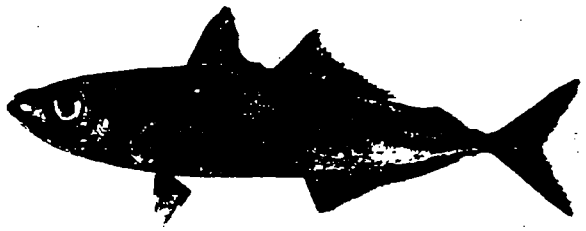


California commercial passenger-carrying fishing vessel (CPFV) landings of jack mackerel, 1947-1969.



California commercial passenger-carrying fishing vessel (CPFV) landings of jack mackerel, 1970-1990.

Large jack mackerel have occasionally contributed to the partyboat sport fishery. In 1953, a run of large fish was encountered in southern California which contributed 13 percent of the partyboat catch in southern California and 8.6 percent statewide. That was an exceptional year and, since then, jack mackerel have been of minor importance to the party boat fleet. Smaller jack mackerel are caught at times from fishing piers in southern and central California.



Jack mackerel, *Trachurus symmetricus*.

Status of Biological Knowledge

Jack mackerel are actually members of the jack family, Carangidae, and are not true mackerel. There are two different behavior patterns during their life. Small fish are found over shallow rocky reefs, generally less than 200 feet deep, and along rocky shorelines of the coast and islands off southern California and Baja California. Large fish, more than 16 inches in length, are found offshore and farther north; they do not form the dense, shallow water schools observed in young fish, but are either solitary or in loose aggregations. The older jack mackerel extend to the Gulf of Alaska and as far west as 162° W longitude. Their movement into the Gulf of Alaska appears to be related to summer warming of the surface waters. Not all the larger fish migrate north, since some large jack mackerel are caught off southern and Baja California waters throughout the year.

Like anchovy and Pacific mackerel, jack mackerel appear to be multiple spawners, but it is not known how frequently a female spawns during a season. Most (70%) female jack mackerel from the southern California fishery become mature near or just after their first birthday in July. By their second birthday, 90 percent of the females are spawning. Very young spawners produce fewer eggs and reach reproductive condition later in the season than do older spawners. Most of the eggs are spawned in 57° to 61° F water. Eggs are about .04 inch in diameter and float free in the ocean for three to five days before hatching, depending on the water temperature.

Jack mackerel spawn offshore from Punta Eugenia to Point Conception from March through August. Their eggs and larvae are uncommon within eighty miles of shore, and often are found as far as 400 miles offshore. This indicates the important contribution of eggs from the large offshore fish. Spawning extends to northern California waters and closer to shore in the Southern California Bight from July through September. Larvae have been taken 100 to 1,000 miles off Oregon and Washington in August and October; they feed primarily on copepods. Juvenile jack mackerel appear to move inshore to concentrate over shallow rocky reefs in the southern California

SMB-26826

Bight and along the Baja California coast, for few young fish are found elsewhere.

Young jack mackerel seem to prefer copepods, pteropods, and euphausiids, although at times they feed almost exclusively on juvenile squid and anchovies. Food habits of the older offshore fish are unknown. Jack mackerel, in turn, may be quite important food for billfish. They also contribute to the diet of seals, sea lions, some porpoises, yellowtail, white seabass, bonito, bluefin tuna, striped marlin, angel, and blue sharks.

Status of Population

The most recent estimate of biomass was made in 1983. Spawning biomass was estimated at 1.50, and total biomass at 1.63 to 1.99 million tons. These estimates must be viewed as tentative approximations of the population because of two factors. First, the spawning frequency of jack mackerel is not yet known, and so estimates were based on the spawning frequencies of other pelagic species. Second, estimates were derived from CalCOFI egg and larval surveys which did not cover the entire range of the spawning population, so assumptions were made for the contribution of older jack mackerel outside the CalCOFI area. The occurrence of only young fish in the fishery leaves the age structure of the rest of the population unknown, and it is uncertain how much the reproduction of these older fish contributes to the population of young fish in the Southern California Bight.

There has been a decrease in the percent of older fish in the catch since the 1960's, which has caused some concern. It is unclear whether this change is due to a decrease in the number of older fish or to a change in the distribution of the three to six year old fish. The population can probably continue to support the current level of fishing exploitation from the purse seine fleet, but it is difficult to predict the effects of increased exploitation, due to the limited knowledge of the composition and behavior of the older segment of the population and to the limited knowledge of reproduction and recruitment in jack mackerel.

Jan Mason
National Marine Fisheries Service

References

Blunt, C. E., Jr. 1969. The jack mackerel (*Trachurus symmetricus*) resource of the eastern North Pacific. Calif. Mar. Res. Comm., CalCOFI Rept. 13:45-52.

MacCall, Alec D., H.W. Frey, D.D Huppert, Eric H. Knaggs, J.A. McMillan, and G.D. Stauffer. 1980. Biology and economics of the fishery for jack mackerel in the northeastern Pacific. NOAA Technical Memorandum, NOAA-TM-NMFS-SWFC-4.

MacCall, Alec D., and Gary D. Stauffer. 1983. Biology and fishery potential of jack mackerel (*Trachurus symmetricus*). CalCOFI Reports 24:46-56.

MacGregor, J.S. 1966. Synopsis on the biology of the jack mackerel (*Trachurus symmetricus*). U. S. Fish and Wildl. Serv., Spec. Sci. Rept. Fish. 526 1-16.

PACIFIC MACKEREL

History of the Fishery

Pacific mackerel (*Scomber japonicus*), also called chub mackerel and blue mackerel, are harvested by three separate fisheries: the California commercial fishery, a sport fishery based primarily in southern California, and the Mexican commercial fishery. In the commercial fisheries, Pacific mackerel are landed by the same boats that catch jack mackerel and Pacific sardine.

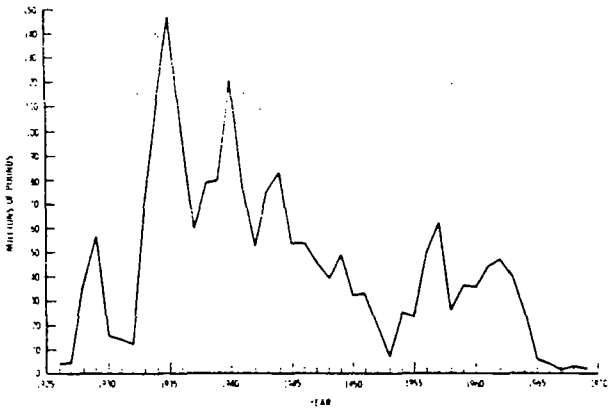
Pacific mackerel supported one of California's major fisheries during the 1930's and 1940's and again in the 1980's. The canning of Pacific mackerel began in the late 1920's and increased as greater processing capacities and more marketable packs were developed. Landings decreased in the early 1930's due to the economic depression and a decline in demand, and then rose to a peak of 73,214 tons in 1935. During this period, Pacific mackerel was second only to Pacific sardine in annual landings. The mackerel fishery then experienced a long, fluctuating decline. A moratorium was placed on the fishery in 1970 after the stock had collapsed.

In 1972, legislation was enacted which imposed a landing quota based on the spawning biomass. A series of successful year classes in the late 1970's initiated a recovery, and the fishery was reopened under a quota system in 1977. During the recovery period from 1977 to 1985, various adjustments were made to quotas for directed take of Pacific mackerel and to incidental catch limits. These measures were intended to lessen the impact of the recovering population on the jack mackerel fishery, and to accommodate the development of the Pacific mackerel fishery as the population increased. From 1986 through 1991, Pacific mackerel accounted for 74 percent of total mackerel landings in California. Pacific mackerel ranked first in volume of landings of finfish in California from 1984 through 1991.

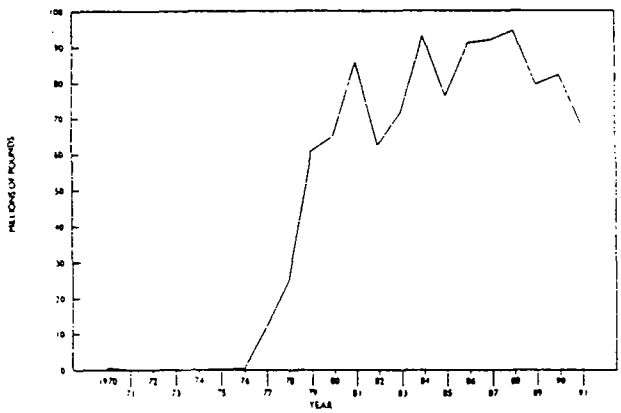
Before 1928, when canning began, Pacific mackerel were landed incidentally in the sardine fishery and used primarily as fresh fish. For many years, demand for canned mackerel was steady and exceeded supply. Since the recovery, the market for canned mackerel has fluctuated due to availability and economic conditions. At present, most Pacific mackerel is canned for human consumption and for pet food, with a small but increasing amount sold as fresh fish. Minor amounts of Pacific mackerel are used by anglers for live and dead bait. Mackerel prices increased from $45 per ton in 1956 to $315 in 1981, but have declined to $233 per ton in 1990. Domestic demand for canned Pacific mackerel appears to have decreased in recent years, and southern California processors and the traditional purse seine fleet are in economic difficulty. During the early fishery, Pacific mackerel were taken by lampara boats, which were replaced in the 1930's by the same purse seine fleet that fished for sardines. The purse seiners fished for Pacific mackerel until the moratorium in 1970, and were able to fish for jack mackerel, northern anchovy, and other species until the fishery reopened in 1977. Originally, fishing occurred near port but, by the late 1930's, it extended along the entire coast from San Diego to Santa Barbara and included the southern California

SMB-26827

islands. Beginning in the 1952-1953 season, fishing extended to Tanner and Cortez Banks.



California commercial landings of Pacific mackerel, 1916-1969.

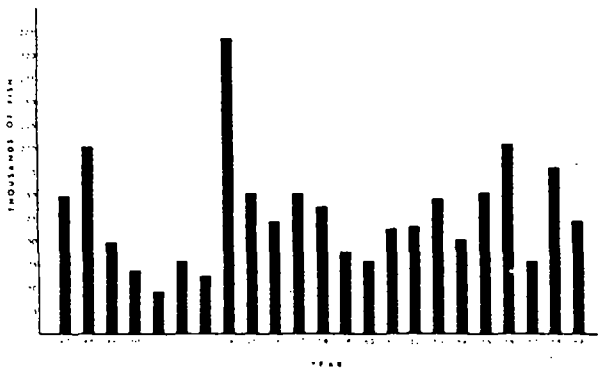


California commercial landings of Pacific mackerel, 1970-1991.

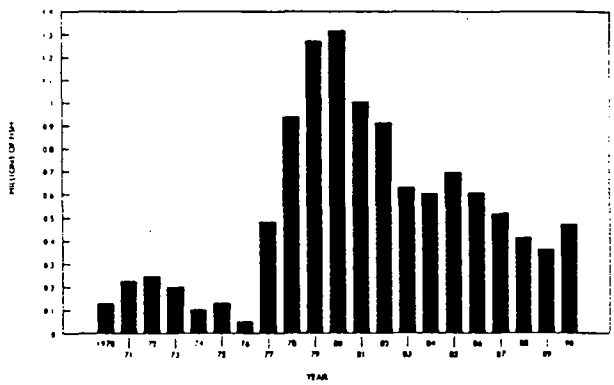
Until the mid-1950's, there was a seasonal pattern to the fishery. Pacific mackerel were mostly unavailable from January through May, then increased in availabilty until late fall. Most of the catch was taken by purse seiners until September, when the sardine fishery began. During the declining years of the fishery, catches became more sporadic, with no apparent seasonal patterns.

At present, the purse seine fleet fishes the Southern California Bight, including the southern California islands and offshore banks. A small portion of the catch (typically less than 5 percent) is taken in the Monterey Bay area. The purse seine fleet fishes year-round. Landings are typically slow during April and May, increase beginning in June, peak during the third quarter of the year, and decrease after September. Approximately 75 purse seiners participate in the mackerel fishery and take Pacific mackerel, jack mackerel, Pacific sardine, and squid. Other types of gear take Pacific mackerel incidentally.

Pacific mackerel fisheries in California are currently managed by the state, but a fishery management plan for coastal pelagic species, including Pacific mackerel, is being developed by the Pacific Fishery Management Council. State regulations, enacted in 1985, impose a moratorium on directed fishing when the total biomass is less than 20,000 tons, and limit the incidental catch of Pacific mackerel to 18 percent during a moratorium. A season quota equal to 30 percent of the total biomass in excess of 20,000 tons is allowed when the biomass is between 20,000 and 150,000 tons, and there is no quota when the total biomass is 150,000 tons or greater. Since 1985, the biomass has exceeded 150,000 tons and no quota restrictions have been in effect.



California commercial passenger-carrying fishing vessel(CPFV) landings of Pacific mackerel, 1947-1969.



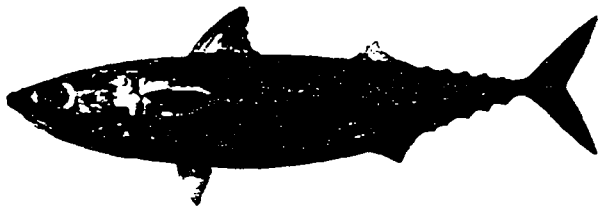
California commercial passenger-carrying fishing vessel (CPFV) landings of Pacific mackerel, 1970-1990.

Pacific mackerel have ranked among the top 11 most important sportfish caught in southern California waters, primarily because they are abundant rather than desirable. The recreational catch of Pacific mackerel averaged 1,473 tons from 1977 through 1991. During the commercial fishing moratorium, the sport fishery became the largest exploiter of Pacific mackerel in California. The recreational catch increased during the late 1970's and early 1980's, with over one million fish caught during the period 1979-1981. Recent estimates of annual recreational catches indicate a steady decline since 1981 to about 442,000 fish in 1991.

Demand for Pacific mackerel in Baja California, Mexico increased after World War II. Landings remained stable for several years, rose to 25,000 tons in 1963, then declined to a low of 1,334 tons in 1968. Catches remained insignificant until the mid-1970's. By 1980, landings had increased to 39,433 tons. At present Pacific

SMB-26828

mackerel landed in Mexico are mostly reduced to fish meal and oil in place of anchovies, which have been unavailable.



Pacific mackerel, *Scomber japonicus*.

Status of Biological Knowledge

Pacific mackerel occur worldwide in temperate and subtropical coastal waters. In the eastern Pacific, they range from Chile to the Gulf of Alaska, including the Gulf of California. They are common from Monterey Bay, California to Cape San Lucas, Baja California, but are most abundant south of Point Conception, California. Pacific mackerel usually occur within 20 miles of shore, but have been taken as far offshore as 250 miles.

Adults are found in water temperatures ranging from 50.0 to 72.0° F and larvae in 57.2 to 70.0° F. Adults occur from the surface to 1,000 feet deep. Sub-adult and adult Pacific mackerel in the northeastern Pacific move northward along the coast during the summer. The most northerly records occur during El Niño events. There is an inshore-offshore migration off California, with increased abundance inshore from July to November and increased abundance offshore from March to May. Pacific mackerel are typically found near shallow banks, and juveniles are commonly found off sandy beaches, around kelp beds, and in open bays.

The largest recorded Pacific mackerel was 24.8 inches and weighed 6.4 pounds, although commercially harvested Pacific mackerel seldom exceed 16 inches and two pounds. Growth is believed to be density-dependent, as fish reach much higher weights-at-age when the population size is small. The oldest recorded age, determined by otolith reading, was 11 years, but most Pacific mackerel in the commercial catch are less than four years old. Some Pacific mackerel mature as one-year olds, although most are not sexually mature until age two or three. Pacific mackerel become available to the commercial fishery in their first year of life and are not fully recruited to the fishery until age four. However, substantial numbers of younger fish are taken by the commercial fishery and make up the bulk of the catch.

Recruitment of Pacific mackerel is variable and loosely linked to the size of the spawning biomass. Reproductive success is somewhat cyclical, with periods of roughly three to seven years. The annual rate of natural mortality is thought to be approximately 40 percent in the absence of fishing.

There are three spawning stocks in the northeastern Pacific: one in the Gulf of California; one near Cape San Lucas; and one along the Pacific coast north of Punta Abreojos, Baja California. Spawning occurs from Eureka, California to Cape San Lucas, two to 200 miles off shore, and in the Gulf of California.

Off California, spawning occurs from late April to July at depths to 300 feet. Individual fish may spawn eight times or more per year and release at least 68,000 eggs per spawning. Off Baja California, spawning occurs from June through October. Pacific mackerel larvae eat copepods and each other. Larvae normally begin to feed within 50 hours of hatching. Juvenile and adult Pacific mackerel feed primarily on small fishes, fish larvae, squid, and pelagic crustaceans such as euphausiids.

Pacific mackerel larvae are subject to predation from a number of invertebrate and vertebrate planktivores. Juvenile and adults are eaten by larger fishes, marine mammals, and seabirds. Pacific mackerel school as a defense against predation, often with other pelagic species, including jack mackerel and Pacific sardine. Principal predators include porpoises, California sea lions, brown pelicans, striped marlin, black marlin, sailfish, bluefin tuna, white seabass, yellowtail, giant sea bass, and various sharks.

Status of Population

Historical estimates of Pacific mackerel biomass along the Pacific coast indicate a decline in total biomass from 1932 until 1952. After a brief resurgence, the population reached a peak in 1962, then declined to less than 10,000 tons by 1966 and remained low until the late 1970's.

A series of successful year classes beginning in 1974 brought about a resurgence, and the biomass peaked in 1982. Since then it has declined. Preliminary estimates indicate that the 1991 biomass of Pacific mackerel is about 160,000 tons. Information derived from deposits of Pacific mackerel scales on the sea floor indicates that the prolonged period of high biomass during the late 1970's and 1980's was an unusual event that might be expected to occur about once every 60 years.

It is estimated that the maximum long-term yield of Pacific mackerel might be 29,000 to 32,000 tons under management systems similar to that in current use. It is difficult to assess the effects on the catch of recent warm temperatures, possible changes in availability of young fish, and the deteriorating markets. However, it is unlikely that the recent high harvest levels can be sustained.

Eddy S. Konno
Patricia Wolf
California Department of Fish and Game

References

Fitch, J.E. 1952. The decline of the Pacific mackerel fishery. Calif. Fish and Game. 38:381-389.

Klingbeil, R.A. 1983. Pacific mackerel: a resurgent resource and fishery of the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 24:35-45.

MacCall. A.D., R.A. Klingbeil, and R.D. Methot. 1985. Recent increased abundance and potential productivity of Pacific mackerel (*Scomber japonicus*). Calif. Coop. Oceanic Fish. Invest. Rep. 26:119-129.

Parrish, R.H. and A.D. MacCall. 1978. Climate variation and exploitation in the Pacific mackerel fishery. Calif. Dept. Fish Game, Fish Bull. 167. 110 p.

Praeger, M.H. and A.D. MacCall. 1988. Revised estimates of historical spawning biomass of the Pacific mackerel, *Scomber japonicus*. Calif. Coop. Oceanic Fish. Invest. Rep. 29:81-90.

SMB-26829

PELAGIC WETFISH: DISCUSSION

For the most part, "pelagic wetfish" is an out-of-date expression which no longer aptly describes this group of species. The term "wetfish" was historically used to describe how these fish were processed in canneries. Unlike the tunas, which are cooked and then packed in the can, wetfish are first packed in the can, in a "wet" condition, and then cooked. Throughout the history of commercial utilization of this group, each species has, for varying periods of time, been taken primarily for canning for human consumption. Currently only jack mackerel and Pacific mackerel are taken primarily for canning. The industry has not yet been able to reestablish a viable market for canned sardines; so this resurgent resource is being caught primarily for bait, animal food, and fresh fish markets. Herring are caught primarily for their roe and anchovies are used primarily for bait and human consumption. Most of the herring roe is exported to Japan, while much of the fresh-frozen anchovy is shipped to Spain and Portugal.

Although there are many similarities in the life histories of these species, there also are differences. They are all open-ocean, relatively-nearshore, schooling fish for most of their life cycles, but herring is the only one dependent on estuarine habitat for part of its life cycle and jack mackerel is the only one known to occur as much as 600 miles offshore. Each matures at a relatively young age, one to three years old; and while jack mackerel live to be 20 to 25 years old, relatively few individuals of the other species attain half this age. In coastal areas the eggs and larvae of all the species are common, but beyond 200 miles from the coastline they are common only for jack mackerel. Anchovies, Pacific mackerel, and sardines are known to migrate seasonally along the coast. Herring migrate into bays and estuaries to spawn, but little is known about their seasonal movements when they return to the ocean. Jack mackerel migrate away from the nearshore banks and islands at a relatively young age (4-6 years) and, while they range from at least off Baja California, Mexico to the Gulf of Alaska, little is known about their migratory habits as older adults. The herring catch is concentrated in the bays of central and northern California, while the other species are primarily caught in open waters and near the islands and banks of the Southern California Bight. The commercial landings of each has been closely monitored, creating annual time series of age and length composition data that span several decades for most of the species. Time series estimates of biomass date back to the 1930's for sardines and Pacific mackerel, the late-1940's for anchovies, and the mid-1970's for herring. While there are no time series estimates of jack mackerel biomass, age and length composition data is available since the late 1940's.

The management history for each species can be characterized as almost lacking for jack mackerel (considered underutilized) to extensive for the other four species. Prior to the 1970's, management was generally nonexistent for all these species. When sardine and Pacific mackerel biomasses were declining to virtual economic extinction (in the mid 1960's), the commercial fishing industry began a quest to establish an anchovy reduction fishery. By the late 1960's, a reduction fishery was authorized by the California Fish and Game Commission, complete with quota, season, area, and size restrictions. Quick to follow was legislation in the early 1970's that established moratoria on the commercial take of Pacific mackerel and sardines. The resurgence of the Pacific mackerel resource, the establishment of the herring-roe fishery, and the transition to federal management (Pacific Fishery Management Council) of anchovy during the mid to late 1970's, were accompanied by strict management regimes which included requirements for annual quotas and assessments of biomass. The more recent resurgence of the sardine resource off California has also resulted in annual quotas and assessments. In 1991, the Pacific Fishery Management Council elected to develop a Coastal Pelagic Species Management Plan which would include sardines, Pacific mackerel, jack mackerel, and anchovy. The target date for plan implementation was early 1993. Pacific herring will continue to be managed by the California Fish and Game Commission.

The outlook for these resources and their fisheries ranges from optimism to thoughts of gloom. The herring resource should continue to support a viable fishery under the strict management of take by the California Fish and Game Commission and with continuing good markets for herring roe in Japan. The anchovy fishery's largest historical components were the reduction fisheries in California and Baja California. These have ceased to exist, primarily for economic reasons, and yet anchovies continue to be valued as live bait for the recreational fishing industry and, more recently, as a fresh-frozen product for human consumption in Europe. Pacific mackerel have sustained the southern California purse seine fleet for over a decade, with record average landings for this time span; but the recent transition of the Mexican fleet to this species and record landings suggest that this fishery and resource is overdue for a substantial decline. The Pacific sardine resource seemed destined to recover to levels of the 1930's under strict control of catches during the recovery period; yet Mexico's recent increases in catches of this species off northern Baja California has put a hold on this optimistic outlook. Jack mackerel, long thought to be underutilized, has provided much of the resource necessary for the southern California purse seine fishermen to survive the lulls caused by declines in the Pacific mackerel, sardine, and anchovy fisheries. However, a presumed large biomass of older fish looms somewhere outside the Southern California Bight. Its availability to other gear (e.g. large factory trawlers) has yet to be determined, but could result in a new chapter for the harvest of wetfish off California, particularly given the trend for continuing cannery closures over the last two decades.

Richard A. Klingbeil
California Department of Fish and Game

FLATFISHES

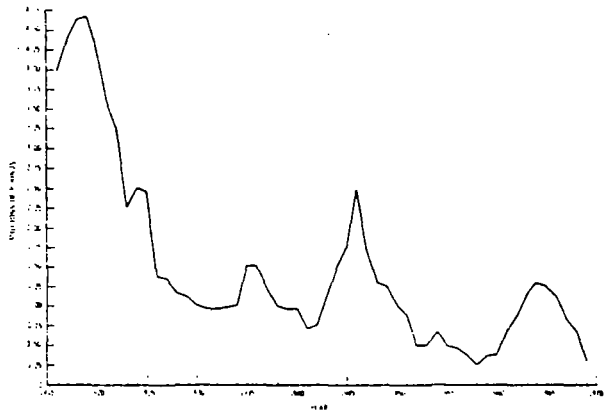
CALIFORNIA HALIBUT

History of the Fishery

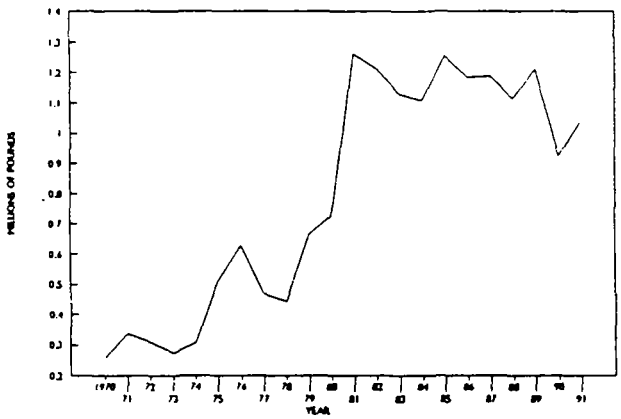
California halibut (*Paralichthys californicus*) is an important flatfish species in both the commercial and recreational

SMB-26830

fisheries of central and southern California. The highest recorded commercial landing of halibut was 4.7 million pounds in 1919, which was followed by an overall decline to a low of 950,000 pounds in 1932. Since 1932, the average annual catch has been 910,000 pounds, with four notable peaks in landings: 1936 (1.58 million pounds), 1946 (2.46 million pounds), 1964 (1.28 million pounds), and 1981 (1.26 million pounds).



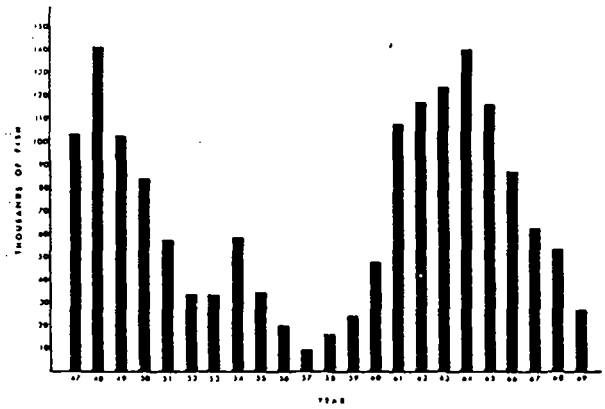
California commercial landings of California halibut, 1916-1969.



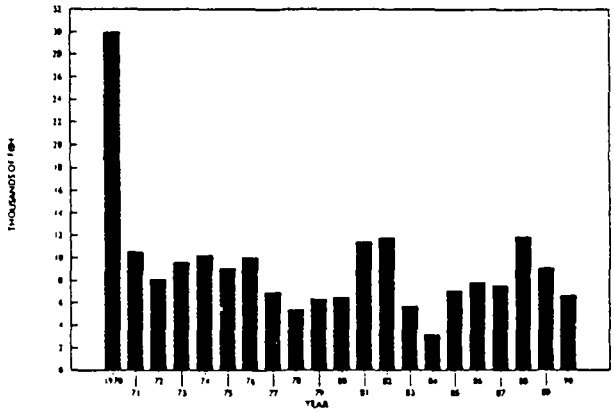
California commercial landings of California halibut, 1970-1991.

The decline in halibut landings after 1917 has been attributed to increased fishing pressure during World War I and to overfishing. Fishing restraints during World War II may have allowed halibut stocks to increase, resulting in peak landings in the late 1940's, followed by low catches in the 1950's. Warm water (El Niño) years in the late 1950's were followed by increased landings in the mid-1960's. The lowest landings occurred in the early 1970's, with the lowest recorded catch in 1970 of 257,000 pounds. Landings increased during the late 1970's to a peak in 1981. Since 1981, landings have remained relatively constant, exceeding one million pounds each year through 1989.

Catches by commercial passenger fishing vessels displayed trends similar to the commercial landings from 1947 through 1974, with peaks in 1942 (143,000 halibut) and 1964 (141,000 halibut). While the commercial catch increased in the late 1970's and steadied in the 1980's, the recreational catch remained low and variable with an average annual catch of 8,620 fish from 1971 to 1989.



California commercial passenger-carrying fishing vessel (CPFV) landings of California halibut, 1947-1969.



California commercial passenger-carrying fishing vessel (CPFV) landings of California halibut, 1970-1990.

To assist with the restoration of the California halibut resource through the protection of sub-adult fish, a regulation was adopted in 1971 that set a minimum size limit of 22 inches for sport-caught California halibut. Commercial landings increased slowly after this legislation, whereas recreational landings remained low and did not recover to former catch levels.

Although California halibut range from the Quillayute River, Washington to Magdalena Bay, Baja California, the commercial fishery is concentrated from Bodega Bay to Central Baja California. The contribution to California landings of halibut captured in Mexican waters has varied but has generally been insignificant since 1966. The fishery was historically centered off southern California and Baja California, but since the 1980's the greatest landings have been in Ventura and Santa Barbara counties, with exceptional landings in the San Francisco area during 1982 and 1983, coinciding with the 1982-1983 El Niño event. A limited amount of fishing occurs around the Channel Islands of southern California, with a catch of substantially larger halibut (average length = 27 inches) than those caught in the nearshore mainland fishery (average length = 24 inches).

SMB-26831

Gill and trammel nets as well as otter trawls are used for the commercial harvest of California halibut. Gill and trammel nets with 8.5-inch mesh and maximum length of 6,000 feet are the principal type of gear used in southern California. Gill and trammel net fishing is prohibited in shallow coastal waters north of Point Sal, in Santa Monica Bay, and is subject to many depth, area, and seasonal closures throughout the state. A Marine Resources Protection Zone was established in 1991 extending three miles off the southern California mainland coast from Point Conception to the Mexican border and within one mile or 70 fathoms (whichever is less) around the Channel Islands. Within this protection zone, the use of gill and trammel nets will be prohibited after December 31, 1993.

Trawling is permitted in federal waters (3 to 200 nautical miles offshore) using trawls with a minimum mesh size of 4.5 inches. Within three nautical miles, bottom trawling is prohibited except in the designated "California halibut trawl grounds," which encompasses the area between Point Arguello and Point Mugu in waters farther than one nautical mile from shore. Bottom trawls used in this area must have a minimum mesh size of 7.5 inches, and trawling is closed from March 15 to June 15 to protect spawning adults.

Commercial fishing laws prohibit the sale of California halibut less than 22 inches in total length, unless the weight is at least 4 pounds whole, 3.5 pounds dressed with the head on, or 3 pounds dressed with the head off. Four halibut less than the legal minimum size may be retained for personal use. The average price per pound to southern California fishermen is $2.25.

Recreational regulations also require a minimum size limit of 22 inches and generally no more than five halibut taken per day (only three per day in Bodega and Tomales Bays). Halibut can be taken in recreational fisheries using hook and line, spear, or hand.

California halibut, ***Paralichthys californicus***.

Status of Biological Knowledge

Adult California halibut inhabit soft bottom habitats in coastal waters generally less than 300 feet deep, with greatest abundance at depths of less than 100 feet. Adults spawn throughout the year with peak spawning in winter and spring. Pelagic eggs and larvae occur over the shelf, with greatest densities in water less than 250 feet deep and within four miles of shore. Halibut larvae appear to move inshore as they approach metamorphosis. Early larval stages (about 0.1 to 0.3 inches) occur in midwater more than one mile offshore, whereas transforming larvae occur within 0.6 mile of shore and occupy the neuston (surface zone) at night and the bottom during the day.

California halibut have a relatively short pelagic larval stage (less than 30 days), transforming and settling to the bottom at a small size (0.35 to 0.5 inches). Newly-settled and larger juvenile halibut are frequently taken in shallow-water embayments and infrequently on the open coast, suggesting that embayments are the important nursery habitats. However, settlement either in bays or along the open coast varies yearly and may reflect variability in nearshore currents that influence the onshore transport of larvae. The advantages of bays as nursery areas are probably a decrease in the risk of mortality of newly-settled juveniles and an increase in the growth rate of larger juveniles that feed upon the abundant small fishes in the bays. Juveniles emigrate from the bays to the coast at about one year of age and 6.9 to 8.7 inches in length.

Tagging studies have indicated that California halibut do not tend to move extensively. Sublegal halibut tagged and released from commercial passenger fishing vessels in southern California were recovered mostly within five miles from their tag sites, with only 12 percent found 10 miles or more from where they were tagged. Larger halibut appear to travel the greatest distances. One large tagged halibut (33 inches) was recovered 64 miles away 39 days after release.

California halibut may live to 30 years and reach 60 inches in length. The maximum recorded weight is 72 pounds. Male halibut mature at two to three years and eight to nine inches, whereas females mature at four to five years and 15 to 17 inches. Female halibut attain larger sizes at age than males and represent a greater fraction of the commercial landings (60 to 80 percent). Female halibut reach legal size (22 inches) at 5 to 6 years of age, about a year before males.

California halibut are ambushing predators. Adults prey primarily upon northern anchovies, squid, and other nektonic nearshore fish species. Small juvenile halibut in bays eat crustaceans primarily, including copepods and amphipods, until they reach about 2.5 inches. They are then large enough to eat gobies that are found commonly in bays but not on the open coast. Juvenile halibut become increasingly piscivorous with size. On the coast, juvenile halibut from 10 to 12 inches in length feed primarily on mysids and anchovies.

Status of Population

Abundance of larval California halibut in plankton surveys is correlated with commercial landings of halibut, suggesting that this species has a cycle of abundance approximately 20 years in length. However, the size of the halibut population may be limited by the amount of available nursery habitat, as juvenile halibut appear to be dependent on shallow water embayments as nursery areas. The overall decline in California halibut landings corresponds to a decline in shallow water habitats in southern California associated with dredging and filling of bays and wetlands.

Recreational and commercial fishermen are in conflict over the California halibut resource in southern California. A possible management alternative under consideration is a differential minimum size limit of 22 inches for the recreational

SMB-26832

fishery and 26 inches for the commercial fishery. This strategy would allow recreational anglers to harvest halibut between 22 and 26 inches in length before fish had grown large enough to recruit to the commercial fishery. Yield-per-recruit (Y/R) analysis indicated that: 1) differential size limits would provide an increased Y/R for the recreational fishery, whereas the commercial fishery would experience a loss; 2) that overall fishing effort was about twice the optimum level; and 3) that Y/R would probably increase with diminished fishing effort.

Prohibitions on the use of gill and trammel nets in nearshore waters off southern California beginning in 1994 are expected to reduce the commercial harvest of California halibut. This should result in increased availability of halibut to recreational anglers.

The total California biomass of the halibut resource obtained from virtual population analysis estimates in the late 1980's was 5,720,000 to 13,200,000 pounds, with annual recruitment of fish at age one estimated to be between 0.45 and 1.0 million fish. The number of juvenile halibut emigrating from southern California bays to the open coast (age one) estimated from beam trawl surveys ranged between 250,000 and 400,000 in the late 1980's.

Sharon H. Kramer
MBC Applied Environmental Sciences

John S. Sunada
California Department of Fish and Game

References

Allen, L.G. 1988. Recruitment, distribution, and feeding habits of young-of-the-year California halibut (*Paralichthys californicus*) in the vicinity of Alamitos Bay-Long Beach Harbor, California, 1983-1985. Bull. Southern Calif. Acad. Sci. 87:19-30.

C.W. Haugen (ed.). 1990. The California halibut, *Paralichthys californicus*, resource and fisheries. Calif. Dept. Fish Game, Fish Bull. 174.

Kramer, S.H. 1990. Habitat specificity and ontogenetic movements of juvenile California halibut, *Paralichthys californicus*, and other flatfishes in shallow waters of southern California. Ph.D. thesis, Univ. Calif. San Diego, 266 p.

MBC Applied Environmental Sciences. 1987. California halibut. Pages 217-224 *in*: Ecology of important fisheries species offshore California. OCS Study, Minerals Management Service 86-0093.

Reed, R.R. and A.D. MacCall. 1988. Changing the size limit: How it could affect California halibut fisheries. Calif. Coop. Oceanic Fish. Invest. Rep. 29:158-166.

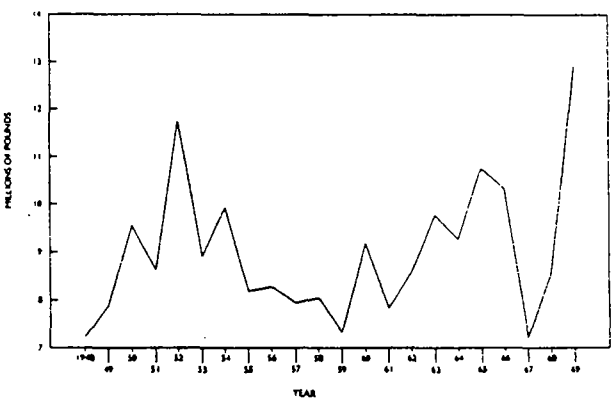
DOVER SOLE

History of the Fishery

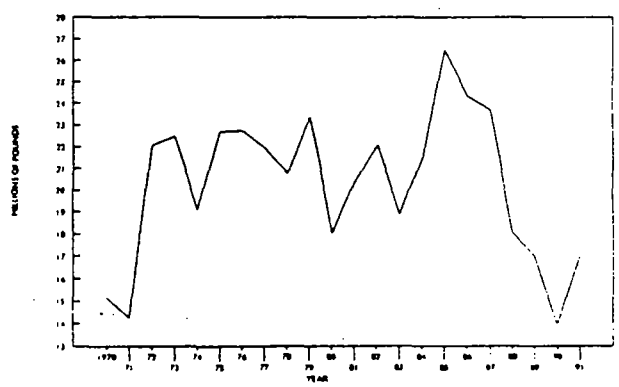
The stature of Dover sole (*Microstomus pacificus*) has evolved from that of an undesirable by-product of bottom trawling prior to the 1940's to become the most abundant groundfish in statewide landings. This phenomenal rise was the result of market demand during and following World War II and technological advances in fish handling and processing.

At the advent of trawling in the 1870's, Dover sole were inadvertently caught by lateen sailboats using paranzella nets. California's Dover sole fishery expanded from its beginning in San Francisco Bay to its present scope extending from Santa Barbara to the Oregon border. The developing trawl fishery experienced major changes in vessels and netting. Sailboats were replaced by steam, gasoline, then diesel-powered vessels. The original paranzella trawl net was supplanted by the more efficient otter trawl in the 1920's. By the 1980's, some trawl fishermen began to use roller or bobbin trawls to capture Dover sole and other deep-slope groundfish instead of more conventional trawls with rubber mudlines between the trawl doors and footrope to create a fish-herding mud cloud. A quick-freezing method, developed during World War II, hardened the soft flesh of the Dover sole to produce marketable fillets. This advance and the wartime demand for fish allowed trawlers to turn their attention to the large north coast population of Dover sole.

The directed Dover sole fishery began in 1943 when 28 tons were landed. Between 1944 and 1947, landings ranged from 62 tons to 1,400 tons. The fishery expanded to 3,600 tons in 1948, at which time Dover sole landing records were separated from nominal or unspecified sole landings, and rose further to 5,850 tons by 1952. Annual landings then remained stable at approximately 4,000 tons until 1969. From 1969 through 1989, landings have averaged 10,200 tons annually.



California commercial landings of Dover sole, 1948-1969.



California commercial landings of Dover sole, 1970-1991.

SMB-26833

Actual historical catches of Dover sole were undoubtedly higher than reported landings due to at-sea discarding as a result of market-imposed landing limits. Dover sole from deep depths are often "jellied" (have flesh with a high water content) and consequently have reduced market appeal. Because Dover sole are typically captured jointly with other marketable groundfish, especially sablefish and thornyheads, trawling would often continue for co-occurring species, even after landing limits had been reached.

Commercial Dover sole landing limits were imposed coastwide in 1989 and 1990 by the Pacific Fishery Management Council as a trip limit on the aggregate poundage of Dover sole, thornyheads, and sablefish on board. Prior to that time, market demand and gear regulations, not resource availability nor quotas, were the dominant forces controlling statewide Dover sole landings. The intent of this regulation was to reduce the harvest of sablefish by restricting deep water trawl effort for the complex of Dover sole, thornyheads, and sablefish.

The port of Eureka has historically supported the largest Dover sole fishery, followed by Fort Bragg, Crescent City, San Francisco, and Monterey. The Morro Bay-Port San Luis area supported a very minor deep water trawl fishery until 1983 (annual landings of 50 tons), at which time a wintertime influx of trawlers from northern California and Oregon began targeting Dover sole. Good winter weather, an absence of market limits, and a relatively unexploited resource caused landings to rise dramatically. From 1983 to 1989, landings into Morro Bay and Port San Luis have averaged 1,760 tons.

Sport utilization of Dover sole is practically nonexistent. The depth distribution of Dover sole normally places them beyond most sport fishing activity, and Dover sole, because of their feeding habits, are not vulnerable to hook-and-line fishing.

Dover sole, *Microstomus pacificus*.

Status of Biological Knowledge

Dover sole occur from the Bering Sea to northern Baja California on mud bottoms at depths from 180 to 4,800 feet. Although early tagging experiments off Oregon and California suggested Dover sole move inshore in the summer, a more recent California Department of Fish and Game (CDFG) tagging study discovered that not all Dover sole participate in the summer inshore movement. In fact, most of the mature fish tagged and released in deep water were recovered in deep water regardless of season. Thus the CDFG tagging data indicate that two substocks may exist : one that migrates and one that does not. Juvenile Dover sole settle on the continental shelf and gradually move down the slope over their lifetime, reaching the oxygen-minimum zone as they become sexually mature. Thus, fish composing the migratory substock may be younger than those composing the nonmigratory substock.

Fish size changes markedly with ocean depth. For example, the average weight of females increases from 0.61 pound in depths shallower than 1,500 feet, to 1.80 pounds in 1,500 to 3,300 feet, then to 2.46 pounds from 3,300 to 4,200 feet. The proportion of females also increases with depth, from two-thirds of the total biomass in shallow waters to over 90 percent at depths greater than 3300 feet.

Growth is rapid during the early years of life but decreases with age. Five-year-old Dover sole grow 0.65 inch per year, but, by 10 years of age, growth slows to 0.42 inch annually. Dover sole may attain an age of over 50 years and reach 30 inches in length. Fifty percent of Dover sole females 12.2 inches long are mature. The smallest mature Dover sole in 1987-1988 studies was six years old, whereas early studies reported mature five-year-old females.

Dover sole may spawn nine batches to release all eggs in a spawning season. Egg production is correlated with size. Fish of 0.55 pound produce 33,000 eggs, while 2.36-pound fish produce 54,000 eggs on average. The buoyant Dover sole eggs may experience a wide range of water temperatures, from 37 degrees F near the bottom to 59 degrees F at the sea surface. Thus, incubation time may vary from 10 days to one month. Larvae have a prolonged pelagic life of at least one year and are unusually large (one to two inches long) before settling to the bottom. Larvae have been found along the entire California coast, as far as 60 miles south of the U.S.-Mexico border and up to 280 miles offshore.

Dover sole feed commonly on polychaete worms, pelecypod and scaphopod mollusks, shrimp, and brittle stars. Only Pacific sleeper sharks and spiny dogfish are known to prey on Dover sole.

Status of Population

Population estimates of Dover sole in California waters are only available for limited geographic areas in central and northern California. In 1987 and 1988, the National Marine Fisheries Service (NMFS) conducted two surveys to assess the adult biomass of Dover sole in the area from Point Conception to Monterey Bay. The surveys found that 98 percent of the spawning biomass of Dover sole in central California waters live on the continental slope between 2,100 and 3,300 feet deep, an area characterized by low oxygen concentrations and very cold temperatures. Estimated biomass was 11,250 tons using one survey method and ranged from 15,400 to 18,700 tons using the other.

A Dover sole stock assessment using 1990 NMFS bottom trawl survey data and population modelling provided estimates of current biomass and yields for the area from Cape Mendocino, California to Cape Blanco, Oregon. Female spawning biomass was estimated to be 20,200 tons, with a likely range of 16,500 to 34,000 tons. Estimated maximum sustain-

SMB-26834

able yield for the Eureka area is 3,000 to 4,100 tons. The stock in this area was in equilibrium and near the target biomass level that would provide maximum sustainable yield.

A quantitative assessment has not been conducted yet on the Dover sole population in central California between Monterey Bay and Cape Mendocino.

Francis D. Henry
California Department of Fish and Game

N. Chyan-huei Lo
National Marine Fisheries Service

References

Hagerman, F.B. 1952. The biology of the Dover sole (*Microstomus pacificus*) (Lockington). Calif. Dept. Fish and Game, Fish Bull. 85. 48 p.

Hunter, J.R., J.L. Butler, C. Kimbrell, and E.A. Lynn. 1990. Bathymetric patterns in size, age, sexual maturity, water content, and caloric density of Dover sole, *Microstomus pacificus*. Calif. Coop. Oceanic Fish. Invest. Rep. 31:132-144.

Hunter, J.R., B.J. Macewicz, N.C.H. Lo, and C.A. Kimbrell. In press. Fecundity, spawning, and maturity of female Dover sole, *Microstomus pacificus*, with an evaluation of assumptions and precision. Fish. Bull., U.S.

Turnock, J. and R. Methot. 1991. Status of west coast Dover sole in 1991. *In*: Status of the Pacific coast groundfish fishery through 1991 and recommended acceptable biological catches for 1992. Pacific Fishery Management Council, Portland, Oregon.

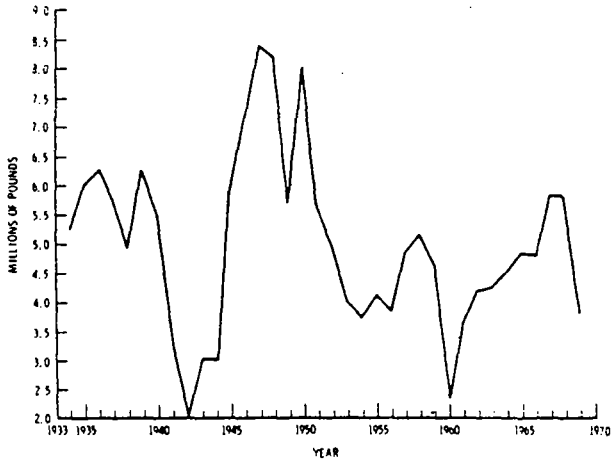
Quirollo, L.F. and P. Kalvass. 1987. Results of Dover sole tagging in waters off northern California, 1969-1971. Calif. Dept. Fish and Game, Mar. Resour. Admin. Rep. 87-4. 73p.

ENGLISH SOLE

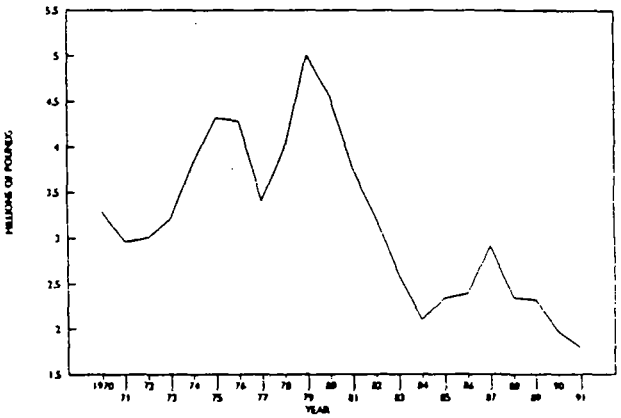
History of the Fishery

English sole (*Pleuronectes vetulus*) has been commercially important since the introduction of the first trawl net, the paranzella, in San Francisco in 1876. The use of trawl nets made the catch of "sole" species one of the leading categories of fish landed in California, and English sole was the leading flatfish in that group until Dover sole took first place in 1949. Since then, English sole has been second in pounds landed except for 1970-1972, when petrale sole was second. The peak year for English sole was 1929, when 8.7 million pounds were caught off central California and at new fishing areas off Fort Bragg and Eureka. Annual landings during the past 10 years have averaged just under three million pounds, mostly from grounds off the Eureka and San Francisco areas. Little is taken commercially south of Point Conception.

English sole are fished primarily by trawling in water 120 to 900 feet deep on sandy bottoms. They become vulnerable to the commercial fishery at three years of age (10 inches), but four- to eight-year-old fish (11-17 inches) predominate landings because markets request fish of at least 11 inches in order to produce reasonable size fillets. Female fish are often more abundant in the landings because they tend to be longer and heavier than the males. Fishing for English sole can be done by relatively small vessels because of the shallow water in which this species is found. Very little is taken by commercial hook and line or by gillnet, and it is not an important species for recreational fishing.



California commercial landings of English sole, 1933-1969.



Commercial landings of English sole, 1970-1991.

English sole is a desirable fish for the market and restaurant trade, primarily as a filleted product, but landings are affected by market demands and abundances of other flatfish and roundfish. Currently there are landings restrictions on certain rockfish and deep-water complexes of fish, and processors may request English sole from the fishermen to supplement total landings. Notwithstanding, landings of English sole have not increased since the implementation of restrictions on other fish. Demand for English sole is also affected by availability and price of imported fish products.

Status of Biological Knowledge

English sole range from San Cristobal Bay, Baja California to northwest Alaska in water as deep as 1,800 feet. Fish tend to move to deeper water in the winter and shallower water in the summer, and fishing effort follows these movements.

SMB-26835

English sole, *Pleuronectes vetulus*.

Tagging studies in California, Oregon, Washington, and British Columbia show that, although there is little overall migration, small seasonal north-south movements probably occur, and some fish have been found to move in excess of 200 miles. Analysis of tag returns also suggest that four separate stocks are found in California: south of Point Conception, Point Conception to Bodega Bay, Monterey to Eureka, and Eureka to southern Oregon. The overlap in areas is a result of apparent north-south movement of the stocks. Some seasonal intermingling between stocks probably also occurs.

Female English sole are usually mature at three years (10 to 14 inches), while males mature at two (8 to 11 inches). Spawning occurs over sand and mud-sand bottoms at depths of 200 to 360 feet from September to April, although some spawning probably occurs in all months. In California peak spawning occurs from December through February, with annual variations in timing apparently related to water temperature. Each fish probably spawns only once per year. A three-year-old, 12-inch female releases approximately 150,000 eggs, while a 10-year-old, 17-inch fish will release almost two million. Egg diameter is approximately 0.04 inch. Fertilized eggs are buoyant when first released, but shortly before hatching they begin to sink into the water column.

When the eggs hatch, in four to 12 days, the larvae are approximately 0.1 inch long. Typically the larvae are in the mid-water column but sink deeper as they approach metamorphosis. During development, the larvae can be carried towards shore on upper-level water currents. Spawning and development during times of rapid plankton growth may result in good recruitment. During their pelagic phase of six to 10 weeks, the larvae grow to about 0.75 inch, then settle to the bottom and metamorphose to the adult benthic body form. After metamorphosis, and for the first year of life, juvenile English sole are found in shallow bays and estuaries and feed all the way up to the intertidal zone. Juveniles are found in sand, mud, and eelgrass habitats. The population density of juvenile English sole in estuaries is several times higher than on the open coast; however, it is not known how important estuaries are to survival of juvenile English sole. In southern California the shallow open coast may be more important as juvenile habitat than it is further north. As the fish grow they tend to move to deeper water.

The largest recorded English sole, from British Columbia, was 22.5 inches, and 21-inch fish have been taken in California. The oldest recorded age is 22 years. English sole are aged by counting the annual rings on the interopercular bone.

While in the estuary and nearshore shallow-water environment, juveniles feed on copepods, the palps of segmented worms, siphons of small clams, brittle stars, and other small invertebrates. At the end of their first year of life (about five inches) most juveniles have moved to offshore waters. Adult fish are seldom found in estuaries. They are opportunistic feeders eating shallowly burrowed or surface-active prey such as worms, small crustaceans, clams, and occasionally small fish, crabs, and shrimp. Adults can also dig into the sediment to reach deeper prey.

The English sole is capable of interbreeding with the starry flounder producing an intergeneric hybrid called the hybrid or forkline sole or flounder.

Status of Population

Little information is available to estimate the status of the English sole stock in California. Catch-per-unit-of-effort data exist but are complicated by the multiple species aspect of trawl fishing. Analysis of catch information for the late 1970's suggests that stocks are at levels that produce maximum sustainable yield. Currently there is no quota on the English sole fishery, but landings are monitored and populations continually assessed for signs of biological stress. The fishery is currently managed by the Pacific Fishery Management Council through gear regulations such as mesh size for trawl nets.

Donald E. Pearson
National Marine Fisheries Service

Sandra L. Owen
California Department of Fish and Game

References

Jow, T. 1969. Results of English sole tagging off California. Pac. Mar. Fish. Commis. Bull. 7:15-33.

Krygier, E.E. and W.G. Pearcy. 1986. The role of estuarine and offshore nursery areas for young English sole, *Parophrys vetulus* Girard, of Oregon. Fish. Bull., U.S. 84:119-132.

Lassuy, D.R. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific northwest)—English sole. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.101). U.S. Army Corps of Engineers, TR EL-82-4. 17 p.

Rosenberg, A.A. 1982. Growth of juvenile English sole, *Parophrys vetulus*, in estuarine and open coastal nursery grounds. Fish. Bull., U.S. 80:245-252.

Toole, C.L. 1980. Intertidal recruitment and feeding in relation to optimal utilization of nursery areas by juvenile English sole (*Parophrys vetulus*: Pleuronectidae). Env. Biol. Fish. 5:383-390.

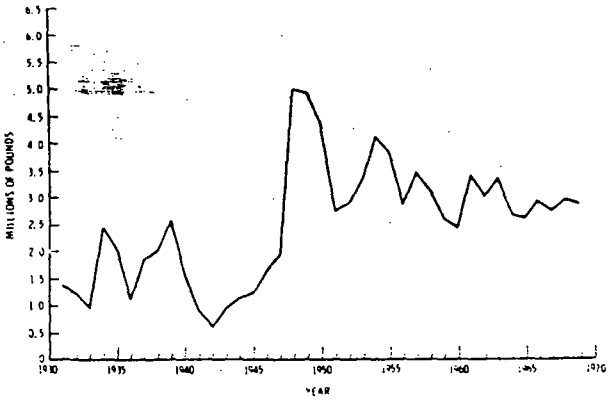
PETRALE SOLE

History of the Fishery

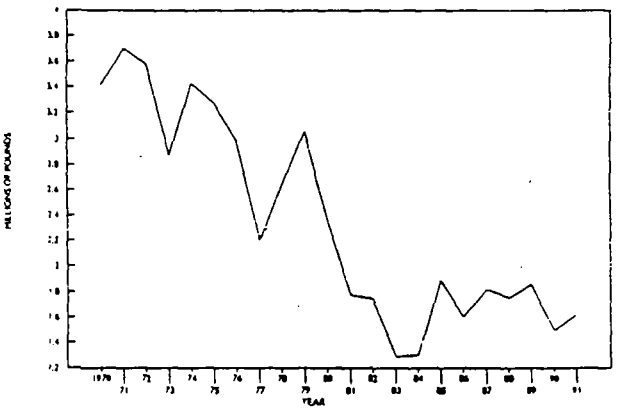
The California fishery for petrale sole (*Eopsetta jordani*) began in the San Francisco area during the late 1880's. Petrale were then, as they are now, a highly desirable flatfish. Most are

SMB-26836

filleted for the fresh fish trade, with the remainder being cleaned and smoked or dried. The majority of the petrale sole landed are taken commercially with otter trawls, along with various other flatfishes and rockfishes, although some are caught by longline or entangling nets. The sport fishery is negligible, with only a few thousand pounds being landed annually. The principal sport catch is made by partyboats fishing for bottomfish species such as rockfishes.



California commercial landings of petrale sole, 1931-1969.

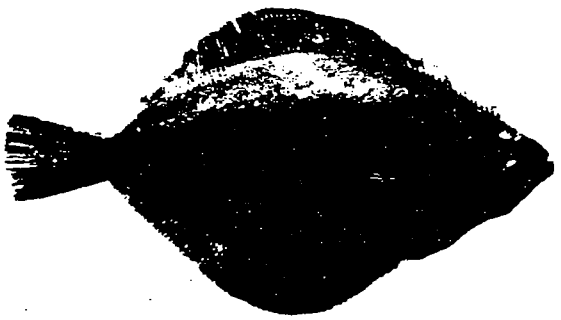


Commercial landings of petrale sole, 1970-1991.

In 1924, there were 66,000 pounds of petrale sole landed. From 1924 through 1933, annual landings averaged about 250,000 pounds, with over 1.4 million pounds being landed in 1931. The trawler fleet increased greatly in size and efficiency following World War II. New gear allowed trawling on new grounds at greater depths, resulting in larger landings. Also contributing to increased production was the discovery of the winter spawning grounds in depths of 900 to 1,200 feet. Concentrations were very dense and catches increased accordingly. Over five million pounds were landed in 1948. Between 1982 and 1991 landings averaged 1.7 million pounds.

Status of Biological Knowledge

Petrale sole are found from the Bering Sea to northern Baja California on sandy bottoms at depths ranging from 60 to 1,500 feet. These fish have been known to move great distances. tagged fish released off Eureka have been recovered in British Columbia. Nevertheless, most tagged petrale sole are recovered within short distances of the release point. Tagging studies in Washington, Oregon, and California indicate that petrale sole spawn in deep water during winter and, shortly after spawning, move inshore and northward through spring and summer months. During fall and winter months, there is an offshore and southerly movement associated with spawning. Within California, four spawning populations of petrale sole have been delineated by tagging experiments and by locating spawning fish. These are in the Cape Mendocino, Point Delgado, Point Montara, and Point Sal areas. Individuals tagged on spawning grounds indicate that there is some interchange of fish among these areas. Most movement among spawning populations has been northward. Seasonal catch distributions show the same pattern. Petrale sole are at their maximum concentrations during winter months in relatively deep water, where a targeted fishery develops. During summer, they disperse into nearby shallow waters and are caught in association with other groundfish.



Petrale sole, *Eopsetta jordani*.

Age and growth studies in California have been very limited. However, growth appears to be rapid during the first few years for both male and female fish, after which the growth rate becomes very disproportionate, with the females growing more rapidly than males. The maximum recorded sizes and ages of California petrale sole are 19.5 inches and 21 years for males and 25.2 inches and 25 years for females. Petrale sole enter the fishery at about three years of age, but most of the petrale catch consists of females between five and seven years old and about 14 to 17 inches long.

Petrale sole reproduce in water between 900 and 1,200 feet deep from November through March, with peak spawning during January and February. Males first reach maturity at three years of age and 11.7 inches long, and females at four years and 12.5 inches. About 50 percent of the males are mature when they are seven years old and 16 inches long. The largest immature male recorded was 15.2 inches and eight years old; the largest immature female, about 18.5 inches and nine years. The eggs are pelagic and hatch in about 8.5 days in 44.6 F water.

This fish is larger than most California flatfish and has a large mouth. Petrale sole feed on euphausiids, shrimp, anchovies, herring, juvenile hake, small rockfish, and other flatfish.

SMB-26837

Status of Population

Recent investigations into petrale sole yield-per-recruit relationships in the Washington-Oregon region suggest that stocks there are being harvested at or near maximum sustainable levels. On that basis, and using historical landing data, the maximum sustainable yield (MSY) for California stocks is estimated to be 3.3 million pounds. Recent landings are stable but about half the estimated MSY. At this time the Pacific Fisheries Management Council has not set a quota for this species.

David H. Thomas
California Department of Fish and Game

References

Best, E.A. 1963. Movement of Petrale sole, *Eopsetta jordani* (Lockington) tagged off California. Pac. Mar. Fish. Comm. Bull. 6:24-38.

Demory, R.L. 1987. Progress report on the status of petrale sole in the INPFC Columbia-Vancouver areas in 1987. Appendix E *in* Status of the Pacific coast groundfish fishery through 1985 and recommended acceptable biological catches for 1986. Pacific Fishery Management Council, Portland, Oregon.

Gregory, P.A. and Tom Jow. 1976. The validity of otoliths as indicators of age of petrale sole from California. Calif. Fish and Game 62(2):132-140.

Forrester, C.R. 1969. Life history information on some groundfish species. Fish. Bd. Canada, Tech. Rept. 105:1-17.

Ketchen, K.S. and C.R. Forrester. 1966. Population dynamics of the Petrale sole, *Eopsetta jordani*, in waters off western Canada. Bull. Fish. Res. Bd. Canada 153:1-195.

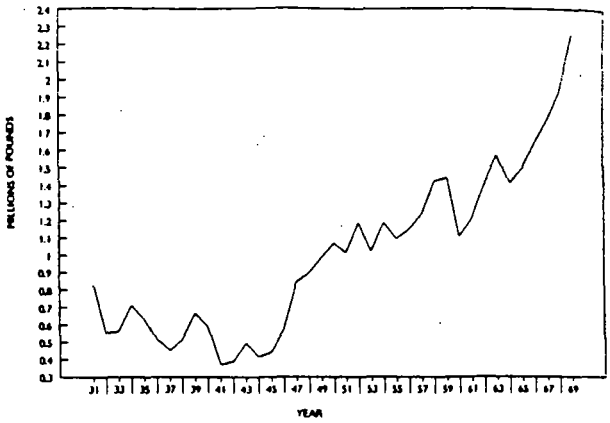
REX SOLE

History of the Fishery

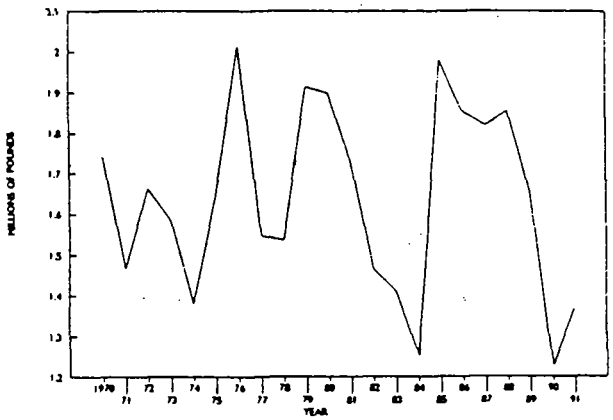
The rex sole (*Errex zachirus*) is taken commercially by bottom trawl nets from southern California to the Bering Sea at depths of 300 to 1,200 feet. Despite its wide distribution, this species does not lend itself to a high-production targeted fishery, because it rarely aggregates in any one location at any certain time of year. It is rarely taken by sports fishermen.

The commercial fishery for rex sole in California has been steady and stable for the past 20 years, with most catches made incidental to other groundfish species. Annual California landings of rex sole from 1970 to 1989 averaged 1.6 million pounds, with a range of 1.3 to 2.0 million pounds. Most of the landings in California have come from the Eureka-Crescent City area, where 900,000 pounds (56 percent of the annual catch) has been landed annually. Since 1985, rex sole landings from the Eureka-Crescent City area have been 38 percent of the annual total, while landings at Fort Bragg and Morro Bay have become significant at 15 percent and 19 percent, respectively.

Rex sole is primarily processed for the fresh food market, where it is held in high esteem by seafood connoisseurs because of its bright, white flesh and its sweet, distinctive taste. Most rex sole are marketed in a dressed form (eviscerated with the head off), which gives processors a 35 to 45 percent yield by weight. Rex sole is generally not filleted because its thin, slight body does not allow for efficient recovery.



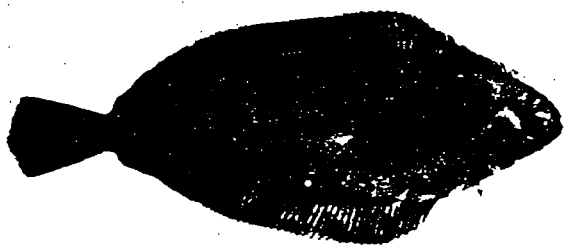
Commercial landings of rex sole, 1931-1969.



Commercial landings of rex sole, 1970-1991.

Status of Biological Knowledge

The rex sole belongs to the family Pleuronectidae, the right-eyed flounders. It is distinguished by a long narrow pectoral fin on the eyed side of the body, a short compressed head, a small mouth, and a nearly straight lateral line which lacks an accessory branch.



Rex sole, *Errex zachirus*.

Rex sole first appear in the trawl catch when they are about 12 inches long and 10.5 years of age. They can attain a length of

SMB-26838

23.25 inches and an age of 24 years. Male rex sole first spawn in their second year when about five inches long. Females first spawn at age three and about eight inches. Rex sole become fully mature at age four and about nine inches in length. After 3.5 years of age, females grow somewhat faster than males; they also tend to live longer.

There appears to be no definitive spawning season, as rex sole in spawning condition have been collected throughout the year. Peak spawning activity is from February through March off San Francisco and during the summer off Eureka. Spawning rex sole are most abundant at depths of 300 to 900 feet.

The number of eggs produced by a single female rex sole increases with size. A 9.5 inch female will produce about 3,900 eggs, while a 23.25 inch female can have as many as 238,000 eggs. Rex sole eggs average about 0.10 inch in diameter, are fertilized near the sea bed, become pelagic, and probably require a few weeks to hatch.

Rex sole eggs hatch to produce pelagic larvae which are about 0.25 inch in length. Larvae have been collected from nearshore to 200 miles offshore during CalCOFI surveys and are most abundant from April to July. The larvae retain an extended pelagic existence for about a year before settling out to a bottom existence as two-inch-long juveniles. The long pelagic phase may make rex sole larvae more susceptible to dispersal and drift by currents, a factor that might affect survival and subsequent year-class strength. Juveniles are common on the outer edge of the continental shelf, which is possibly used as a nursery area, at depths of 490-660 feet.

Little is known about rex sole movements and migrations. They are found from shallow water (60 feet) to depths of 2,100 feet, usually deeper than 200 feet. They show a preference for a muddy-sandy bottom, but also frequent both sand and mud bottoms.

Stomach analyses show that rex sole feed primarily on amphipods and polychaetes; shrimp are also eaten. Rex sole are preyed upon by sharks, skates, rays, lingcod, and some rockfish.

Status of Population

The rex sole is listed under the "other flatfish" category in the Pacific Coast Groundfish Plan. It is believed to be underharvested because a regulated 4.5-inch trawl mesh size results in the retention of only the larger fish. Insufficient information is available to determine stock abundance.

Lawrence F. Quirollo
California Department of Fish and Game

References

Hosie, M. J. 1976. The rex sole. Oregon Department of Fish and Wildlife Information Report 76-2:1-5.

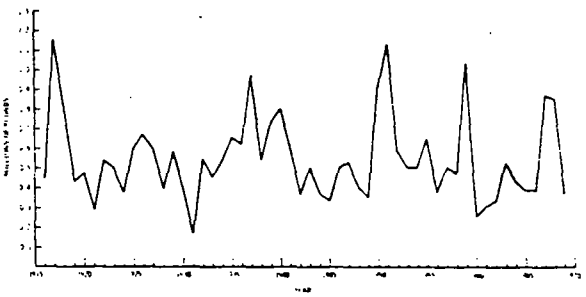
Hosie, M.J. and H.F. Horton. 1977. Biology of the rex sole, *Glyptocephalus zachirus*, in waters off Oregon. Fish. Bull., U.S. 75:51-60.

Pearcy, W. G. 1978. Distribution and abundance of small flatfishes and other demersal fishes in a region of diverse sediments and bathymetry off Oregon. Fish. Bull., U.S. 76:629-640.

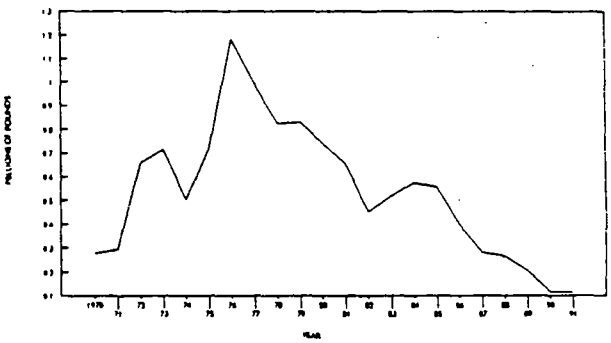
STARRY FLOUNDER

History of the Fishery

The starry flounder (*Platichthys stellatus*) is a common species in both the commercial and recreational fisheries of northern and central California. Though seldom targeted, it is often taken by commercial fishers seeking more valuable species such as petrale sole or California halibut. Historically, most of the commercial catch has been made by otter trawl. During the 1980's, many starry flounders were taken by gill and trammel nets in central California. However, trawlers must generally stay three miles off the coast, and, in recent years, gill and trammel nets have been prohibited from much of the nearshore area. The bulk of the starry flounder population inhabits the nearshore waters now closed to these gears and is, therefore, not available to them.



California commercial landings of starry founder, 1916-1969.



California commercial landings of starry flounder, 1970-1991.

Commercial landing figures for this species are imprecise, owing to an unspecified "flounder" category which, in northern California, may include an unknown quantity of arrowtooth flounders. Also, starry flounders are sometimes mixed with miscellaneous flatfishes and recorded as unspecified "sole."

The recreational catch of starry flounders is from piers, boats, and shore, usually in estuarine and adjacent coastal waters. The estimated annual recreational catch for this species in California from 1981 to 1986 ranged from less than 30,000 to 83,000 fish.

Status of Biological Knowledge

The starry flounder is probably the most easily recognizable of California's flatfishes. The dorsal and anal fins are

SMB-26839

prominently marked with alternating yellow or orange and dark bars. The body surface is rough owing to modified star-shaped scales that give rise to the names "starry" and "roughjacket," as this fish is often called by fishermen. It is very good at assuming the coloration of the substrate upon which it finds itself. Starry flounders in California are about equally divided between left-eyed and right-eyed fish, while those of Japan are nearly all left-eyed.

Starry flounders range from Korea and Japan, north to the Bering and Chukchi Seas and the Arctic coasts of Alaska and Canada, and southward down the coast of North America to southern California, although they are uncommon south of Point Conception. They are primarily a coastal species, living on sand and mud bottoms, and avoiding rocky areas. Though found to depths of 900 feet, they are much more common in shallower waters. They are frequently found in bays and estuaries, often one of commonest fishes in these settings. They are tolerant of brackish and even fresh water.

Tagging studies have not demonstrated extensive migrations, although there is some movement along the shore. There are also thought to be seasonal inshore-offshore movements of these fish, possibly related to spawning.

Most spawning seems to occur in shallow waters near the mouths of rivers and estuaries during the winter. In central California, December and January are the peak months of spawning. The number of eggs produced by each female depends upon her size: a 27-inch fish may produce about 11 million eggs. Fertilization is external.

Eggs of the starry flounder are pelagic, floating near the ocean's surface. Under laboratory conditions, eggs held at 51° F hatched in 4.5 days, while those held at 54.5° F hatched in 2.8 days. Newly hatched larvae are less than one-tenth inch long. Metamorphosis occurs 39 to 75 days after hatching. Newly settled juveniles less than one-half inch long are common in low-salinity estuarine waters, although settling also occurs along the open coast.

Females grow faster and reach larger sizes than do males. In central California, most males are sexually mature at two years averaging 14.5 inches, most females at three years and 16 inches. The maximum size reported is 36 inches.

Larval starry flounders feed on planktonic organisms. Newly metamorphosed fish feed largely on copepods and amphipods. As they grow, their diet changes. Five-inch fish have developed jaws and teeth that allow them to crush small clams and pull worms from their burrows. At 10 to 12 inches, they tend to graze on tips of siphons of clams too large to be ingested whole. Crabs and polychaete worms are also taken. Sand dollars, brittle stars, and fish are included in the diets of larger starry flounders.

Wading and diving seabirds such as herons and cormorants, as well as marine mammals such as harbor seals, feed on juvenile starry flounders in estuaries. However, sea lions and harbor seals feeding on fish caught in gill nets will pass up a dozen starry flounders to eat a more valuable California halibut, much to the consternation of the fisherman.

On occasion, a fish is caught that displays physical characteristics intermediate between a starry flounder and an English sole and may be a hybrid of those species.

Status of Population

No studies have been conducted to determine population size of the starry flounder; however, there is no evidence that the resource is being overexploited. Recruitment is largely determined by survival of larval and juvenile fish. Given the importance of bays and estuaries to the young of this species, the continued environmental health of these areas may be the most important factor in maintaining healthy populations of starry flounder.

Charles W. Haugen
California Department of Fish and Game

Reference

Orcutt, H.G. 1950. The life history of the starry flounder, *Platichthys stellatus* (Pallas). Calif. Dept. Fish and Game, Fish Bull. 78. 64 p.

SANDDABS

History of The Fishery

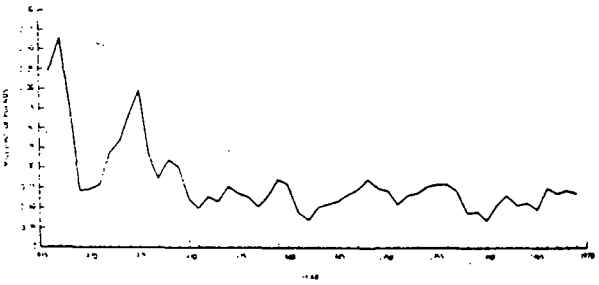
Commercial sanddab landings consist of three species. The Pacific sanddab (*Citharichthys sordidus*) is the most abundant and makes up the bulk of the landings. It is taken chiefly in central and northern California waters. The longfin sanddab (*Citharichthys xanthostigma*) is taken only in southern California waters. The speckled sanddab (*Citharichthys stigmaeus*) is taken all along the California coast. Because of their smaller size and fewer numbers landed, longfin and speckled sanddabs are not important contributors to commercial sanddab landings. Although not as important commercially as other flatfishes in quantity landed, sanddabs are nevertheless highly prized by the commercial industry and recreational anglers for their excellent edibility.

Recorded sanddab landings were highest in 1917 when 2.6 million pounds were landed. In 1918 landings decreased to 1.8 million pounds, and from 1919 to 1921 they remained less than 0.8 million pounds. Beginning in 1922 annual landings increased, reaching approximately two million pounds in 1925. From 1930 to 1974, annual landings were below a million pounds. Since 1975, landings fluctuated between 1.4 million pounds and 0.6 million pounds annually. During the last decade, landings have been above the historical annual average, except for 1983 and 1984. These were years with strong El Niño events. Landings rebounded in 1985 and have increased since then. Approximately 1.44 million pounds were landed in 1990, making it the third highest year since 1916.

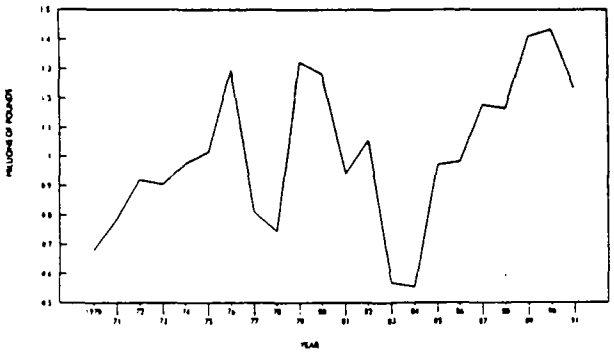
The major portions of sanddab landings have been in northern and central California. Since 1970, for example, 42.5 percent have been in the Eureka area, 42.6 percent in the San Francisco Bay area, and 12.6 percent in the Monterey Bay area.

Sanddabs are caught mainly by otter trawls and some by hook and line, especially in the Monterey Bay area. Many recreational anglers pursue them, mostly from small boats.

SMB-26840



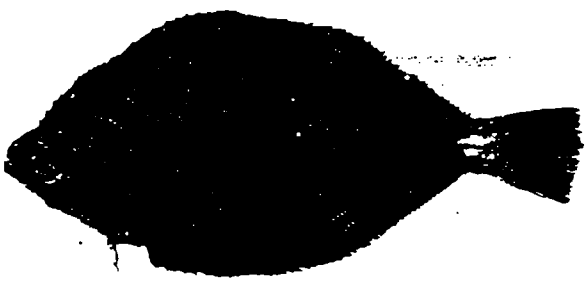
California commercial landings of sanddabs, 1916-1969.



California commercial landings of sanddabs, 1970-1991.

Status of Biological Knowledge

Sanddabs belong to the family Bothidae (lefteye flounders). The Pacific sanddab ranges from Cape San Lucas, Baja California, to the Bering Sea and is found on soft sand to sandy-mud bottoms at depths from 30 to 1,800 feet. The largest individual recorded measured 16 inches and weighed two pounds. Most, however, are smaller than 10 inches and weigh, at most, one-half pound. They live to a maximum of 10 years.



Pacific sanddab, *Citharichthys sordidus*.

Pacific sanddabs mature at about three years of age. Spawning begins in July, peaks in August, and ends sometime in September. Females may spawn twice during a season. The spawning period is an exception to that of other flatfishes, most of which generally spawn during late winter to early spring.

Sanddab larvae are pelagic and may be found near the surface and out to many miles offshore. Juveniles and adults feed on a variety of food, including shrimp, crabs, marine worms, squid, octopus, eggs, and small fishes. They, in turn, are preyed upon by larger fishes, diving birds, and marine mammals.

Status of Population

Commercial landing records indicate that sanddab populations are in good condition and currently are not being overharvested. The Pacific Fishery Management Council has not recommended a change in the minimal acceptable biological catch of incidentally caught "Other Flatfish" (which includes sanddabs) during the past decade, indicating a stable and likely underutilized resource.

Robert Leos
California Department of Fish and Game

References

Arora, H.L. 1951. An investigation of the California sand dab, Citharichthys sordidus (Girard). Calif. Fish and Game. 37:3-42.

Ripley, W.E. 1949. Bottom fish. Pages 63-75 *In*: The commercial fish catch of California for the year 1947 with an historical review 1916-1947. Calif. Div. Fish and Game, Fish Bull. 74.

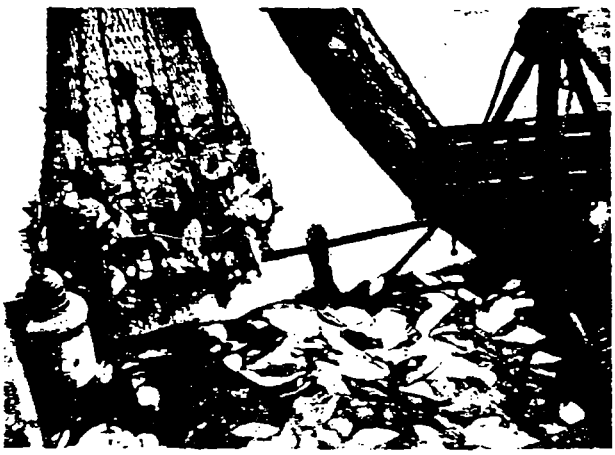
OTHER FLATFISHES

History of The Fishery

Several flatfish species are taken incidentally in commercial groundfish fisheries. These include the rock sole (*Pleuronectes bilineatus*), butter sole (*Pleuronectes isolepis*), fantail sole (*Xystreurys liolepis*), sand sole (*Psettichthys melanostictus*), slender sole (*Eopsetta exilis*), curlfin turbot (*Pleuronichthys decurrens*), hornyhead turbot (*Pleuronichthys verticalis*), spotted turbot (*Pleuronichthys ritteri*), C-O turbot (*Pleuronichthys coenosus*), diamond turbot (*Hypsopsetta guttulata*), arrowtooth flounder (*Atheresthes stomias*), and Pacific halibut (*Hippoglossus stenolepis*). Some of these, notably the Pacific halibut and diamond turbot, are taken by recreational anglers as well, but most are caught primarily by commercial boats.

Landings of most of these flatfish are difficult to extract from landings data for the early years (beginning in 1916), because many were combined with other categories of flatfish. For example, prior to 1931 turbots were included with soles. Also, some species such as Pacific halibut are included in California landings, even though most were landed elsewhere and shipped to California ports. Starting in the early 1950's, some of these flatfish landings, primarily arrowtooth flounder (1950) and soles (1953), were listed separately in the catch data.

Generally, incidental flatfish catches have contributed only a small amount to the annual statewide commercial landings. From 1953 to 1989, these annual flatfish landings averaged about 0.1 percent of the total statewide landings. During this period, soles comprised 40.4 percent of incidental flatfish landings, flounders (mostly arrowtooth flounder) 49.6 percent, turbots 8.4 percent, and Pacific halibut 1.6 percent.



A mixed catch of flatfish.

Incidental sole landings since 1953 averaged about 265,000 pounds per year, with a peak in 1979 when 800,000 pounds were landed. Since 1950, arrowtooth flounder averaged 307,300 pounds per year with high landings (about 600,000 to 1.1 million pounds) from 1954-1961. These high landings were due, in part, to the less desirable fishes, such as arrowtooth flounder, finding a market with the animal food industry, primarily as mink food. During 1962-1964, landings dropped considerably. In 1965 flounder landings increased somewhat and have averaged about 200,000 pounds per year since then. Turbot landings averaged about 51,000 pounds per year, with a peak of 176,000 pounds in 1954. Since 1969, annual turbot landings have averaged about 29,000 pounds. Pacific halibut contributed heavily to the commercial fisheries prior to the mid-1950's. The last good year for Pacific halibut landings was 1952, when 242,600 pounds were landed. These landings then began a rapid downward trend. From 1968 to 1985, only trace amounts were landed. In 1986, however, 34,500 pounds were landed.

Most of the incidental flatfish are taken by otter trawls. Trammel nets are used to catch some flatfish in central and southern California waters, and many small-boat commercial fishermen use hook and line to take flatfish. Recreational anglers occasionally catch soles or turbots while fishing for sanddabs, starry flounder, or California halibut. Diamond turbots are sought by recreational anglers in quiet coastal waters, bays, and sloughs.

Status of Biological Knowledge

In general, flatfish spawn during late winter and early spring. The larvae are pelagic and undergo metamorphosis to the adult form. After flatfish settle on the bottom, they eat small crustaceans, polychaetes, and mollusks. As they grow, they eat larger food forms of the same groups. Some, such as sand sole and Pacific halibut, include fish in their diet.

Status of Populations

Major fluctuations of commercial landings of soles, turbot, and flounder have occurred since 1950. Despite these fluctuations over the years, market sampling and commercial landing records indicate that these populations are in good condition and currently are not being overharvested. Although Pacific halibut landings in California have declined since the peak years during the 1930's and the species is considered uncommon in California waters, the population is apparently in good condition in waters north of California where it is more abundant.

Robert Leos
California Department of Fish and Game

References

Best, E. A. 1961. The California animal food fishery, 1958-1960. Pacific Marine Fisheries Commission, Bulletin. 5:5-15.

Nitsos, R.J. and P.H. Reed. 1965. The animal food fishery in California, 1961-1962. Calif. Fish and Game. 51:16-27.

Pacific Fishery Management Council. 1988. Status of the Pacific coast groundfish fishery through 1988 and recommended acceptable biological catches for 1989. Pacific Fishery Management Council, Portland, Oregon.

Ripley, W.E. 1949. Bottom fish. Pages 63-75 *in* The commercial fish catch of California for the year 1947 with an historical review 1916-1947. Calif. Div. Fish and Game, Fish Bull. 74.

FLATFISHES: DISCUSSION

Flatfishes have been important commercial and sport species since the beginning of California fisheries. Over 15 species are caught in waters along the California coast in areas extending from bays and estuaries to continental slope depths exceeding 3,000 feet. The leading flatfishes in landings are Dover sole, English sole, petrale sole, Pacific sanddab, rex sole, and California halibut. Smaller amounts of Pacific halibut, sand sole, rock sole, arrowtooth flounder, starry flounder, curlfin turbot, hornyhead turbot, diamond turbot, and several other species are also landed.

The largest part of the catch is taken in trawls. Entangling nets (gill nets and trammel nets) are the second most productive gear. Hook-and-line gear account for the remainder of the catch.

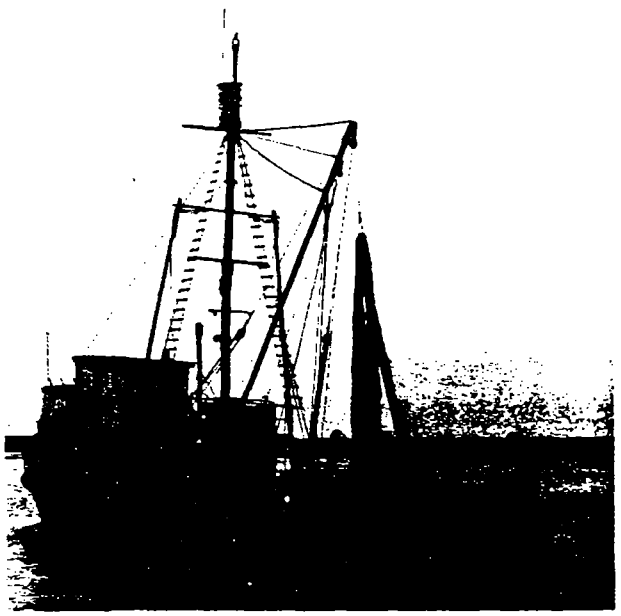
Trawling began in California in 1876 with the introduction of the paranzella, a trawl net towed by two vessels. At first, sailboats were used. They were replaced by steam trawlers, then gasoline vessels, and finally diesel-powered vessels. The paranzella was the predominant trawl until 1946; thereafter, the one-vessel otter trawl gradually replaced paranzellas and became the standard trawl.

San Francisco was the center of trawling for the first half century of commercial fishing. In 1929, trawlers began regular summer fishing off Fort Bragg and Eureka. The center of trawling operations shifted to Eureka around 1938.

Flatfish landings slowly increased until World War I, when landings increased to 17 million pounds in 1917. Flatfish landings declined to a low of 4.5 million pounds in 1942, when trawl fishermen were attracted to the lucrative shark-liver fishery and when early wartime restrictions were imposed on California's Italian fishermen. World War II was another period

SMB-26842

of increased demand for fish products. Demand, along with technological advances in fish handling and processing, led to utilization of Dover sole. The Dover sole fishery began slowly in 1943, when 56,000 pounds were landed. In 1949, Dover sole became the State's leading flatfish in landings. Factors which contributed to the rapid rise in Dover sole and flatfish catches were the expansion of fishing in 1948 to depths of over 1,200 feet and the transfer of wartime improvements in depth finding and navigation. Increased trawl effort in deep water also led to the discovery of petrale sole spawning grounds in 900 to 1,350-foot depths. Since 1948, annual flatfish landings have exceeded 17.5 million pounds. The peak year was 1979, when 37 million pounds were landed. For the 10-year period 1981 to 1990, annual landings of flatfishes have averaged 30 million pounds. Recent high landings are due in part to higher demand. Health consciousness and the benefits of fish in diets have added to product demand. During the past two decades, new trawlers have entered the fishery. State-of-the-art navigation electronics, high-resolution depth sounders, and hydraulic winches and net reels have become standard equipment of trawlers.



Old wooden trawler from northern California.

Entangling nets are used in central and southern California for California halibut. A small part of the commercial catch is taken by hook-and-line gear. Pacific halibut are taken by longlines in northern California. All the recreational catch of flatfishes is by hook and line.

Flatfishes are marketed as fillets, whole fish, or dressed fish with head and fins removed. Pacific halibut and a few large California halibut are sold as steaks. A specialty Asian market exists for large petrale sole which are dressed heads on, salted and dried. All flatfish species are processed and marketed in the fresh state. Dover sole, English sole, and petrale sole are the main filleted species. Fewer starry flounder, sand sole, arrowtooth flounder, and rock sole also enter the fillet market. Sole fillets, especially Dover sole, are frozen to fulfill military, institution, or fish broker orders. Sanddabs and rex sole are usually marketed whole or dressed with head and fins removed.

California halibut is the leading and most prized flatfish caught by recreational anglers. Other flatfishes taken by sport anglers are sanddabs, starry flounder, turbots, and petrale sole.

Current management of flatfishes include areas closed to trawling and gill and trammel netting, minimum mesh size regulations, and in some cases trip limits on deep-water fish associations.

Tom Jow
California Department of Fish and Game, Retired

ROUNDFISHES

SABLEFISH

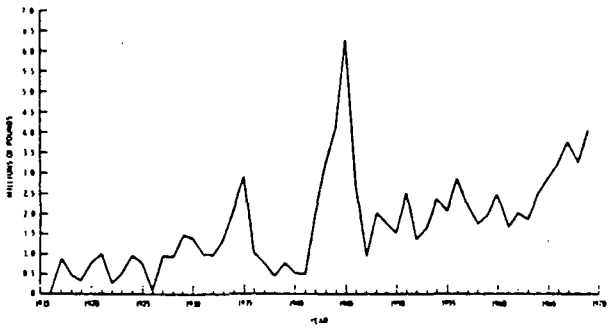
History of the Fishery

The sablefish (*Anoplopoma fimbria*) resource off California has a lengthy history of commercial exploitation. Before World War II, landings averaged about 500 tons annually. By 1935, annual landings had risen to 1,400 tons at a time when sablefish livers, because of their high vitamin A content, commanded a higher price than the edible parts of the fish. Landings increased to over 3,000 tons in 1945 due to strong wartime market demand, then varied from approximately 770 to 2,200 tons per year until 1972. More intensive exploitation of sablefish began in 1972 with the development and widespread use of sablefish traps, which proved highly effective. Distant-water fishing fleets from the U.S.S.R, Japan, and the Republic of Korea fished for sablefish off California from 1967 to 1979, catching relatively minor quantities in most years. However, in 1976 the Republic of Korea reported catches of 9,500 tons off California. The establishment of the U.S. 200-mile fishery conservation zone in 1977 phased out foreign fishing in those waters; consequently Japan, the principal foreign market for sablefish, became increasingly reliant on imports of U.S-caught sablefish. Japanese demand for sablefish helped drive California landings to a record high of 14,287 tons in 1979, followed by a market collapse the next year to just 5,141 tons.

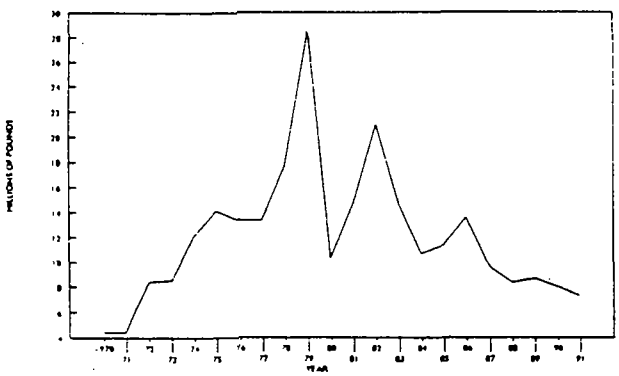
The first commercial sablefish landing limits were imposed coastwide in 1982 by the Pacific Fishery Management Council (Council). Prior to that time, market demand, not resource availability nor quotas, was the dominant force controlling statewide sablefish landings. From 1982 to 1989, Council regulations constrained statewide sablefish landings to an average of approximately 6,175 tons. Annual coastwide landing quotas remained at 19,183 tons from 1982 to 1984, then gradually declined to 9,800 tons in 1990 as the stock was fished down to the recommended long-term target level.

The economic importance of sablefish to California has increased considerably in recent years. In 1989, sablefish, worth $3.63 million, ranked fourth in ex-vessel value among

groundfish species. Sablefish are marketed commonly as "black cod" and smaller fish are often filleted and sold as "butterfish." The high oil content of the flesh produces an excellent smoked product, and most of the large individuals are sold domestically in this form. Sablefish are typically exported in frozen, dressed (headed-and-gutted) form. There is a large price difference with size.



California commercial landings of sablefish, 1916-1969.



California commercial landings of sablefish, 1970-1991.

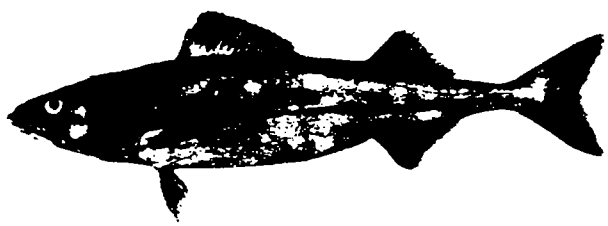
Sport utilization of sablefish is negligible, with rare instances of large catches when schools of small sablefish concentrate around public piers. The depth distribution of sablefish normally places them beyond most sport fishing activity.

Sablefish are captured with longline, trap, bottom trawl, and gill net gears. Before 1943 sablefish were landed principally by small two- to three-man longline boats fishing deep for large sablefish for the smoked fish market. Catches by trawlers became significant in 1944. The distribution of landings among gear types has varied considerably over time, but bottom trawlers have accounted for about 70 percent of annual California landings in recent years.

Trawls and gill nets capture sablefish in mixed-species catches with a variety of other groundfishes, whereas longline and trap gears target on sablefish. Off California, most trawl-caught sablefish are taken in association with Dover sole and thornyheads in deep (1,200-4,200 feet) water. Longlines and traps are also fished at such depths for sablefish, but gill net-caught sablefish commonly are captured with rockfish at depths less than 900 feet.

Because of the immense fishing power of the west coast groundfish fleet and a robust market demand, rather intensive management of sablefish became necessary in the 1980's to prevent overexploitation and to accomplish other management goals. Trip landing and frequency limits, a 22-inch minimum size limit, user-group allocations, as well as more commonly used quotas and gear restrictions, have been applied to the commercial sablefish fishery by the Council. Trip landing and frequency limits prevent early quota attainment, thereby reducing the discard of sablefish by-catch in non-directed fisheries and providing year-round availability of fresh sablefish to domestic consumers. The minimum size limit, implemented in 1983, prevents the excessive harvest of juvenile sablefish. Quota allocation distributes the harvest among user groups to achieve social and economic goals. Quotas and gear restrictions are designed to ensure the optimal long-term harvest of sablefish.

The sablefish resource is unique among west coast groundfishes, for the annual commercial catch quota has been allocated between trawl and nontrawl gears since 1986. Trawl/nontrawl allocations, based on historical shares and incidental catch requirements, have ranged from 58:42 to 52:48 during 1986 to 1990. Separate allocations are needed because trawl landing restrictions put trawlers at a disadvantage with nontrawl fishermen when both groups compete for a joint quota. Most nontrawl fishermen land only sablefish; thus an unrestricted open fishery followed by a closure is acceptable to them. Quota allocation allows each group to use their optimal harvest strategy within regulatory constraints.



Sablefish, *Anoplopoma fimbria*.

Status of Biological Knowledge

The geographic distribution of sablefish extends from the Asiatic coast of the Bering Sea to northern Baja California. Tagging studies by the National Marine Fisheries Service (NMFS), Department of Fisheries and Oceans-Canada, and the Alaska Department of Fish and Game indicated that adult sablefish are relatively sedentary, as most fish were recaptured within 50 nautical miles of release sites. However, some sablefish, particularly those tagged in southern California, have moved in excess of 1,000 nautical miles. Adult sablefish are found from less than 300 to more than 4,800 feet deep, but peak abundance off California is at about 1,200 to 1,800 feet. Length and age generally increase with depth.

The spawning season extends from October through February. A central California study determined that spawning occurs at depths greater than 2,700 feet. Initially, larval sablefish are found in surface waters offshore; later they move into nearshore nursery areas. Juveniles aggregate in water depths of less than 900 feet, then eventually disperse as sub-adults into

SMB-26844

continental slope and abyssal areas. The diet of juvenile sablefish includes copepods, amphipods, euphausiids, fish eggs, and fish larvae. Adults eat euphausiids, tunicates, and fish.

Approximately 50 percent of female sablefish reach maturity at 23.6 inches long and six years of age off California. Females grow faster than males from age two and attain a larger maximum size. Sablefish may attain an age of over 50 years and reach a size of 47 inches and 126 pounds, but are usually less than 30 inches and 25 pounds. Sablefish enter the trawl fishery as early as one year of age, but are fully selected by trawl and nontrawl fisheries at ages four to six. Large, older fish are most selected by the trap and longline fisheries.

Status of Population

For management purposes, a unit stock is assumed to exist in waters off California to the Canadian border. Considerable progress has been made in the 1980's towards understanding the dynamics, structure, and size of this stock. Two types of fisheries-independent surveys were conducted by the NMFS, triennial groundfish trawl surveys (initiated in 1977) from Monterey Bay to the Canadian border and biennial sablefish trap surveys in the INPFC Conception to Eureka areas (Mexican border to 43° 00' N latitude). In addition, a systematic landings sampling program and trawl logbook data provided insight into catch-per-effort, and age- and length-composition trends. In general, these disparate data sets presented a somewhat equivocal picture of stock status in California waters.

Bottom trawl groundfish surveys were conducted on the continental shelf in 1977, 1980, 1983, 1986, and 1989. Survey samples from the shelf area off California for fish greater than 16 inches (approximately two years and older) exhibited no apparent trend in abundance over this time series. Similarly, sablefish trap surveys in 1984, 1986, and 1988 revealed no trend in sablefish abundance off California. Age composition from the 1986 trap survey (the only available trap survey age data) revealed a considerable proportion of old (age 20 and older) individuals. Trawl fishery length and age distributions from 1986-89 were relatively stable, revealing no pronounced fluctuations in year class strength. These data depicted a stable sablefish population over this time period. However catch-per-effort data, from California trawl logs for the period 1978-1987 for the depth interval with the greatest historical landings suggested a 42 percent decline in fishable biomass. It is unclear whether this decline is real or is attributable to other causes.

A comprehensive coastwide sablefish stock assessment by NMFS scientists in 1990 calculated that the biomass of sablefish three years old and older in the INPFC Conception-Eureka areas in 1990 ranged from 59,500 to 140,000 tons. The best estimate was believed to be 96,600 tons, which was above the level calculated to produce a maximum sustainable yield of 4,850 tons.

Francis D. Henry
California Department of Fish and Game

References

Hastie, J.D. 1988. Catch and revenue characteristics of vessels harvesting sablefish off the west coast of the United States. NOAA Technical Memorandum NMFS F/NWC-144.

Hunter, J.R. B.J. Macewicz, and C.A. Kimbrell. 1989. Fecundity and other aspects of the reproduction of sablefish, *Anoplopoma fimbria*, in central California waters. Calif. Coop. Oceanic Fish. Invest. Rep. 30:61-72.

Melteff, B.R. 1983. Editor. Proceedings of the International Sablefish Symposium. Alaska Sea Grant Report 83-8. Alaska Sea Grant College Program, University of Alaska-Fairbanks.

Methot, R.D. and J. Hightower. 1990. Assessment of the west coast sablefish stock in 1990 and recommendations to management in 1991. *In* Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991. Pacific Fishery Management Council, Portland, Oregon.

Parks, N.B. and F.R. Shaw. 1989. Relative abundance and size composition of sablefish (*Anoplopoma fimbria*) in the coastal waters of California and southern Oregon, 1984-1988. NOAA Technical Memorandum NMFS F/NWC-167.

PACIFIC HAKE

History of the Fishery

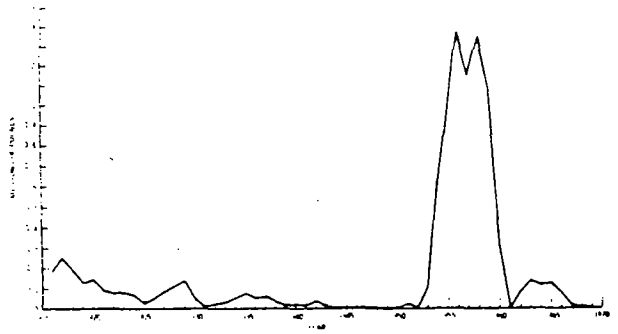
The Pacific hake (*Merluccius productus*), also known as Pacific whiting, makes up over 50 percent of the potential annual harvest of west coast groundfish off Washington, Oregon, and California and is the largest groundfish resource managed under the Pacific Groundfish Management Plan. Pacific hake was considered an underutilized domestic species until 1991, the first year the entire harvest was captured and processed by the U.S. seafood industry.

The fishery has been multi-national in character, having been exploited commercially since before 1900 by the U.S. fishing industry and since 1966 by foreign fleets. U.S. fishermen harvested the entire annual hake quota in 1989, eliminating the foreign directed fishery.

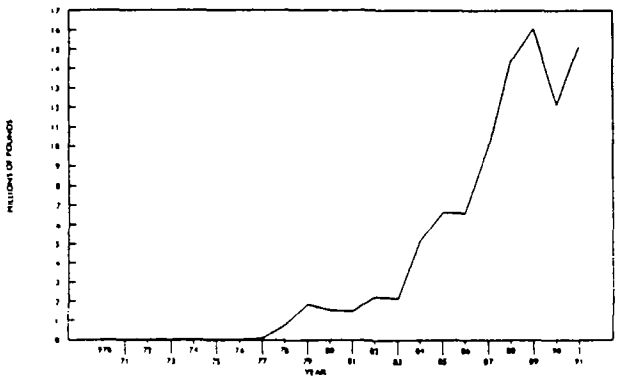
A small domestic fishery has existed for coastal hake since at least 1879. Most catches prior to 1960 were made incidental to the pursuit of more valuable trawl-caught species and were either discarded or delivered to reduction plants producing animal food and fish meal. The average annual California catch from 1959 to 1966 was 248 tons.

In 1964 the National Marine Fisheries Service, Seattle, demonstrated that large catches of hake (to 60,000 pounds per half-hour haul) could be achieved off coastal Washington and Oregon using newly developed depth telemetry systems on large midwater trawlers. This fishery grew from 484 tons in 1964 to 15,883 tons in 1967.

Knowledge of the large hake resource off the west coast attracted a large fleet of Soviet trawlers and accompanying support vessels in 1966. Between 1973 and 1976, Poland, the Federal Republic of Germany (West Germany), the German Democratic Republic (East Germany), and Bulgaria entered the fishery. Japan also participated in the fishery before 1977; their peak harvest was 9,104 tons in 1974. The estimated catches of Pacific hake during this period of expansion ranged from 130,000 tons to 262,000 tons. Catches peaked in 1976 and were subsequently reduced due to restrictions on foreign effort imposed by the Magnuson Fisheries Conservation and Management Act (MFCMA) of 1976.



California commercial landings of Pacific hake, 1916-1969.



California commercial landings of Pacific hake, 1970-1991.

Two types of fishing operations involving foreign vessels were conducted off Washington, Oregon, and northern California after the implementation of the MFCMA in 1977. In one fishery, known as the foreign trawl fishery (sometimes called the "directed fishery"), fish are caught and processed by foreign vessels. In a second fishery, known as the joint venture (JV) fishery, U.S. trawl vessels deliver their catch to foreign processing vessels at sea.

Trawl net full of Pacific hake.

The joint venture fishery for Pacific hake started in 1978 between foreign nations and the United States and Canada. Consistent with the intent of the MFCMA to encourage development of domestic fisheries, landings of hake declined in the foreign directed fishery while increasing in the JV fishery. In 1978 the foreign catch amounted to 98 percent of the total hake catch in the U.S. management zone. The foreign catch declined to 11 percent of the total by 1988, and in 1989 there was no foreign catch.

Combined U.S. and Canadian hake catches were below the recommended quota harvest levels from 1977 to 1986. In 1987, the combined catch exceeded the acceptable biological catch for the first time, leading to full utilization of the coastal stock. The 1989 combined catch reached 340,000 tons, the largest yield since the inception of the fishery.

Although shore-based deliveries of Pacific hake have grown, they have comprised less than five percent of the total annual foreign and domestic harvest since 1978. The domestic shore-based fishery has been concentrated off northern California with processing plants at Eureka and Crescent City. California landings have increased from 41 tons in 1980 to 7,772 tons in 1989.

The Pacific hake has been given little respect. It has been considered a trash fish by commercial fishermen and a nuisance species by sports fishermen, who have described it as a swimming sausage with a big mouth. It could not even go to market under its own name (hake), but had to assume the moniker of whiting to please finicky buyers. Its reputation was tarnished even further when it was discovered that the muscle tissue of one-half to one-third of the coastal stock of hake contained a myxosporidian parasite which triggered rapid postmortem enzymatic decomposition of the flesh. The fish had to be chilled, processed, and frozen within four to six hours of harvest. Freezing stops the decomposition and rapid high-temperature cooking prevents further decomposition during preparation.

Despite all its shortcomings, the Pacific hake fishery represents the archetypical high-volume, low-value fishery (ex-vessel prices have ranged from $0.04-$0.08 per pound). It is popular with anyone who appreciates high quality protein at bargain prices. It contains, on average, about 15 percent protein and three percent fat. Domestic production has been primarily geared towards the frozen headed-and-gutted market, shipped in high volume on a penny-a-pound margin. Market expansion has been towards fillet, breaded products, and high grade surimi consumers.

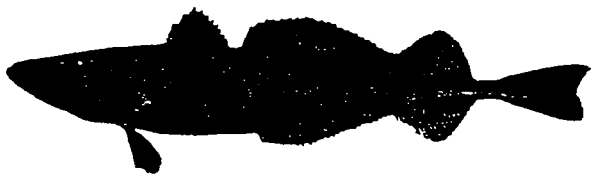
Economic contributions to the Pacific coast states of hake harvesting/processing varies according to product form and harvest/processing mode. Each pound harvested and processed in headed-and-gutted form contributes about $0.38 per round pound. For surimi, the contribution is between $0.27 and $0.32 per round pound. The 1991 hake fishery is expected to have a cumulative impact of $140 million to $151 million on the state economies.

The Pacific hake fishery in the 1990's will probably involve a redistribution of the catch among processors rather than an increase in landings. Growth in west-coast processing capacity could come from either existing Alaskan at-sea processors which move south or from increased shore-based processing. The demand for Pacific hake by processors greatly exceeded the amount available for the first time in 1991. Most of the expected increase in domestic production comes from displaced at-sea fish processors which were built to harvest pollock resources in Alaska. Reduced quotas, shortened seasons, and excess fishing capacity in Alaska have forced these vessels to seek other opportunities, such as the hake fishery, to

SMB-26846

maintain a continual revenue base throughout the year. Most of the technology used for pollock is directly transferable to hake.

An enzyme inhibitor has been developed recently which eliminates texture degradation of minced Pacific hake and allows for the use of hake in the vast production of "surimi," a highly refined form of minced fish. Surimi is used by the Japanese in "kamaboko" products and in the United States for the production of imitation crab meat, scallop, and shrimp products. The U.S. market of surimi has grown from about 60,000 tons in 1985 to over 276,000 tons in 1989.



Pacific hake, *Merluccius productus*.

Status of Biological Knowledge

Pacific hake are distributed from the Gulf of Alaska to the Gulf of California. Four major spawning aggregations of Pacific hake have been identified within this area. The most abundant and widely distributed stock (which is the subject of this report) spawns between central California and northern Baja California and is referred to as the "coastal stock." Two of these aggregations are generally referred to as the "inside stocks"; they live and spawn in Puget Sound and the Strait of Georgia. A fourth major spawning aggregation occurs off the west coast of southern Baja California.

The hake which spawn in Puget Sound during winter are considered a separate genetic stock from oceanic coastal hake. Puget Sound hake spawn and live their lives entirely within Puget Sound, are small in size (14-18 inches total length), and lack the specific myxosporidian parasite which causes rapid postmortem flesh decomposition in coastal stocks. The differences in parasitization between inside and offshore stocks indicate the absence of interchange between populations.

The oceanic coastal stock of adult Pacific hake is migratory and inhabits the continental slope and shelf within the California current system from Baja California to British Columbia. It is often classified as a demersal species (living on or near the sea bed), but its distribution and behavior suggests a pelagic existence. It exhibits extreme night and day movement during spring and summer feeding migrations as it feeds on a variety of pelagic fishes or animal plankton. It is commonly found at depths of 160 to 1,500 feet, but has been found from the surface to 2,600 feet.

Coastal Pacific hake are pelagic spawners which spawn during late winter and early spring (December to April) from San Francisco to Baja California at depths of 660 to 1,600 feet and as far as 300 miles offshore. Active spawners aggregate in broad, loose, stationary bands which can be up to 150 feet thick.

Coastal stock females mature at 16 inches total length or larger, and at weights greater than 0.9 pounds. These minimum sizes are achieved by some three-year-old fish and most four-year-old fish. Fecundity estimates range from 80,000 to 500,000 eggs per female, depending on body size. The pelagic eggs drift with the ocean currents and hatch in about three days. Larval hake are abundant from December through April within 25 miles of the coast from central California to northern Baja California. Peak occurrences of eggs and small larvae pinpoint January and February as the chief spawning months. The majority of eggs and larvae are found over the areas of the continental slope where bottom depths ranged from 430 to 1,640 feet.

Hake reach about 70 to 75 percent of their maximum length and about 50 percent of their maximum weight by 4.3 years, the age of sexual maturity and the onset of differential growth between the sexes. Average maximum sizes are 22 inches fork length (FL) and 2.25 pounds for males, and 24 inches FL and three pounds for females. The largest female hake measured off California was 34 inches FL.

In spring, adult hake migrate north in deep water overlying the continental slope to the summer inner-shelf feeding grounds off northern California, Oregon, Washington, and Vancouver Island. Large spawned-out hake arrive off San Francisco by early March, off Oregon and Washington by the third week in April, and off Vancouver Island by late May. The lead schools contain the largest adults, travel north at a rate of three to six miles per day, and make the most northerly migration. Hake caught from Oregon to Vancouver Island range from 16 to 18 inches FL and are four to 10 years old. Juveniles are concentrated off central and northern California; Pacific hake less than four years old and less than 16 inches FL are rarely found north of Cape Blanco in southern Oregon.

When northward-migrating hake inhabit waters overlying the continental shelf and slope, they form schools which may be characterized as long, narrow bands whose axis is usually oriented parallel to the depth contours. Exceptions to this generality are those schools which align perpendicular to the edge of the continental shelf and extend offshore at a uniform depth, such that they are high off the bottom over the continental slope. School sizes may vary in length from several hundred feet to 12 miles. The widths of schools have reached 7.5 miles at times. Most schools usually have a vertical height of 20 to 70 feet.

During the summer when feeding adults are distributed over the continental shelf, schools exhibit pronounced movement into midwater associated with night-time feeding activities. Hake feed during the evening on euphausiids, shrimp, and pelagic fishes. Vertical movement away from the seabed occurs at nightfall and descent back towards the bottom occurs near dawn. At dawn, coastal hake descend and begin to regroup into schools near the seabed (7 to 70 feet above the ocean floor), usually in the same area where they were the day before. The degree to which hake congregate during the day appears to be related to the type of food which was available during the feeding period. Schools are more dispersed when feeding on fish and other mobile nekton, but more compact when feeding on euphausiids.

The southward spawning migrations of the adults begins in autumn and may be triggered by the shift of wind direction in the fall and the appearance of the Davidson current. The schools begin their return migration by early September, moving westerly over the continental slope and southward. Availability of Pacific hake to bottom and mid-water trawls off Oregon,

SMB-26847

Washington, and Vancouver Island drops sharply in November and is practically nil during winter.

Hake are a favorite prey for a great many creatures, especially marine mammals such as seals, sea lions, porpoises, and small whales. Hake have also been found in the stomachs of swordfish, lingcod, soupfin sharks, Pacific halibut, electric rays, and an assortment of other piscivorous fishes.

Status of Population

The coastal Pacific hake fishery has been characterized throughout its history by irregular occurrences of strong year classes which appear about every three or four years and remain in the fishery for about five to seven years. Recruitment is highly variable and appears to be strongly influenced by oceanic environmental conditions, especially water temperature at the time of spawning. The current fishery is being supported by the 1980, 1984, and 1987 year classes, which contributed 24 percent, 42 percent, and 26 percent respectively towards the total U.S. hake catch in 1990.

The prospects for the Pacific hake resource in the immediate future are for stable or declining yields, depending on the timing of the next strong year class. An assessment survey conducted by the National Marine Fisheries Service in 1989 estimated the population biomass at 1.804 million tons, a decline of 24 percent from estimates made during a previous survey in 1986. The 1989 survey also found that there was no significant recruitment to the population since the 1984 year class and that 88 percent of the population biomass was age five and older. The total harvest of Pacific hake by the U.S. and Canada in 1990 was 296,000 tons, down from a high of 341,000 tons in 1989. The potential coastwide yield, including Canada, for 1991 is calculated to be 359,000 tons.

Lawrence F. Quirollo
California Department of Fish and Game

References

Bailey, K.M. 1982. The early life history of the Pacific hake, *Merluccius productus*, Fish. Bull., U.S. 80:589-598.

Bailey, K.M., R. Francis, and P. Stevens. 1982. The life history and fishery of Pacific hake, *Merluccius productus*. Calif. Coop. Oceanic Fish. Invest. Rep. 23:81-92.

Dark, T.A. 1975. Age and growth of Pacific hake, *Merluccius productus*. Fish. Bull., U.S. 73:336-355.

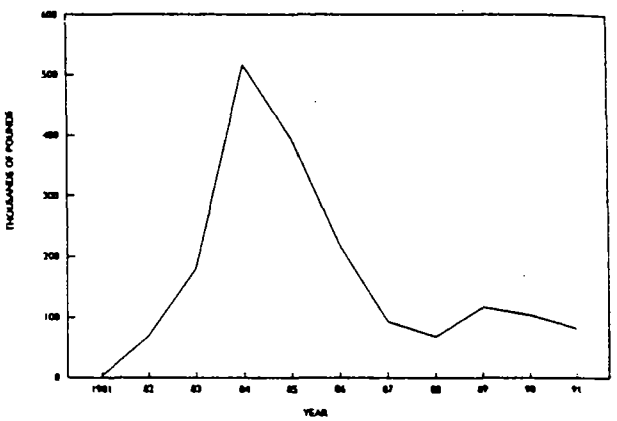
Dark, T.A. (ed.). 1985. Pacific whiting: the resource, industry, and management history. Mar. Fish. Rev. 47(2):1-98.

Dorn, M.W. and R. D. Methot. 1990. Status of the coastal Pacific whiting resource in 1991. *In*: Pacific Fishery Management Council, Status of the Pacific Coast groundfish fishery through 1991 and recommended acceptable catches in 1992, p.A1-A44.

OPAH

History of the Fishery

Although opah (*Lampris guttatus*) has been taken incidentally in the Pacific halibut, sardine, salmon and albacore fisheries, only recently has it become an important commercial species in California. Prior to 1976, few opah were landed in the state, but landings increased dramatically following the opening of the drift gillnet fishery. From 1976 to 1989, a total of 1,660,856 pounds of opah was landed in California. Annual landings ranged from zero to 516,126 pounds with the highest landings in 1984, following the El Niño event of 1982-1983. About 99.9 percent of the landings occurred from 1981 to 1989, with an annual average of 184,266 pounds. Most of the opah catch was from Santa Barbara to San Diego from depths of 18 to 78 feet in drift gillnets set at the surface. Longline fish are taken in excess of 1,000 feet deep.



California commercial landings of opah, 1981-1991

Commercial landings of opah off California from 1976 to 1989 had a total ex-vessel value of $533,206, with nearly all of that value coming in the 1981-1989 period. The ex-vessel value per pound ranged from $0.10 in 1976 to $0.58 in 1981, with a mean value of $0.40 from 1981 through 1989. The retail price of fresh opah ranges as high as $5.00 per pound.

Opah are caught incidentally in the sport fishery for albacore from British Columbia to Baja California, although most are taken in southern California from the Channel Islands to the Coronado Islands, just south of the U.S.- Mexico border. Sport fishermen using albacore gear take opah with live bait or artificial lures, which are hit by opah with considerable fury.

Opah flesh is tasty, can be prepared in a wide variety of ways, and is excellent when smoked. The salmon-colored flesh, darker over the pectoral fin, is very fatty just below the skin but is otherwise rich, dry, firm, and delicate.

Status of Biological Knowledge

Opah is a West African name. Also called African pompano, giant pompano, Hawaiian moonfish, moonfish, mariposa, and Jerusalem haddock, the opah has a compressed, oval body with a small, toothless mouth, an iridescent silvery-blue surface with white spots, and scarlet fins and mouth. It's forked caudal fin is probably used for low-speed swimming, both the caudal fin and body for acceleration, and the moderately long pectoral fins for maintaining normal cruising speeds.

Opah occur worldwide in temperate and tropical seas. In the eastern Pacific, they occur from Chile to Gulf of Alaska but

SMB-26848

are generally uncommon off California. All life stages of this species are pelagic and oceanic, occurring from the sea surface to a depth of 1680 feet. Seasonal movements are not known in the northeastern Pacific but, in the northeastern Atlantic, opah move into the North Sea and waters off Norway in the summer.

Opah, *Lampris guttatus*.

Spawning locations and seasons are not known. However, a ripe individual was taken in the spring off California. Neither fecundity nor the size of extruded eggs are known, but larvae range from 0.2 to 0.4 inches. By 0.4 inches opah resemble miniature adults in body form, have a complete set of fin rays, and are considered to be juveniles. Size and age at maturity are not known, but fish up to at least eight inches are juveniles and those greater than 41 inches are adults. Opah are known to grow to at least 54 inches (4.5 feet) in length, although they have been reported to reach 72 inches (6.0 feet). They are known to reach a weight of at least 160 pounds but are reported to reach 500-600 pounds. The maximum age of an opah is not known.

Larvae or juveniles probably eat small planktonic organisms. As adults, opah are midwater predators that eat cephalopods, crustaceans, and bony fishes such as anchovy, lancetfish, and cutlassfish. Aside from man, predators of opah are not known.

Status of Population

The size of the opah population worldwide or off California is not known. Opah are probably solitary fish and few are taken at any one time. Because the population is worldwide in temperate and tropical seas, landings from California probably have little impact on the species as a whole. It is not known whether local subpopulations exist or how far individual opah travel. If recent landings reflect the local availability of the species, then the species is likely to become more abundant off California following El Niño events. Although commercial landings of opah are recorded by the California Department of Fish and Game, opah is not presently a target species and the fishery is not managed.

M. James Allen
MBC Applied Environmental Sciences

References

Fitch, J.E., and R.J. Lavenberg. 1968. Deep-water Fishes of California. Univ. Calif. Press, Berkeley, CA. 155 p.

Freeman, K. 1984. Opah the moonfish. Pacific Fishing. August:25-27.

Herald, E. S. 1939. The opah (*Lampris regius*) and its occurrence off the California coast. Calif. Fish Game 25(3):228-232.

Palmer, G., and H. A. Oelschlager. 1976. Use of the name *Lampris guttatus* (Brunnich, 1788) in preference to *Lampris regius* (Bonnaterre, 1788) for the opah. Copeia 1976(2):366-370.

Rosenblatt, R. H., and G. D. Johnson. 1976. Anatomical considerations of pectoral swimming in the opah, *Lampris guttatus*. Copeia 1976(2):367-370.

Wierzbicka, J. 1980. The Didymozoidae trematodes in the north-east Atlantic *Lampris guttatus* (Brunnich 1788). Acta Ithyol. Piscat. 10(2):21-34.

LOUVAR

History of the Fishery

Off California, louvar (*Luvarus imperialis*) are taken incidentally by drift gill nets and by purse seines set for bluefin tuna. They are also occasionally found stranded on the beach or drifting dead at the sea surface. They seldom are caught by recreational fishermen.

From 1984 through 1989, a total of 48,796 pounds was landed in California; annual landings ranged from zero to 18,009 pounds, with the highest landings in 1984, following the El Niño event of 1982-1983. About 63 percent of the landings occurred from 1987 through 1989 with an average of 10,262 pounds per year. Most of the catches were from Santa Barbara to San Diego, with past catches being highest near San Clemente Island. In this drift gillnet fishery, louvar are caught at depths of 18 to 78 feet.

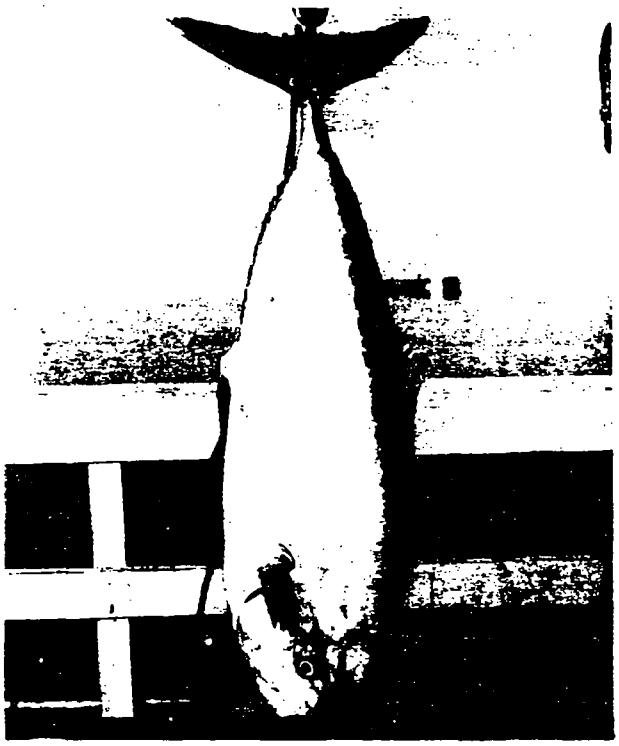
Landings of louvar off California from 1984 through 1989 had an ex-vessel value of $68,288, with 82 percent of the value occurring from 1987 through 1989. The ex-vessel price per pound ranged from $0.83 in 1984 to $2.82 in 1988, with a mean in the 1987-1989 period of $2.25. Louvar flesh is delicate and white, and is considered by many fishermen to be among the most delicious of fishes.

Status of Biological Knowledge

This striking tuna-like fish has a strongly compressed body and a blunt head with a small, terminal, toothless mouth and a horizontal groove above the eyes. The caudal fin is lunate with a keel on the caudal peduncle. Males have long filaments in front of the soft dorsal and anal fins. Adults have frothy pink bodies covered with dark spots and crimson fins, although after death the body turns silvery. Except for the blunt head, louvars are adapted for rapid swimming, with their lunate caudal fins and keeled caudal peduncles. When swimming slowly, louvar presumably scull with their caudal fins.

Louvar occur worldwide in temperate and tropical seas. In the eastern Pacific, they are found from central Washington to Chile. Although generally uncommon, they are relatively abun-

dant in southern California. All life stages of this species are pelagic and oceanic. Adults occur from the sea surface to a depth of 1,970 feet, but most are found at depths below 660 feet. The larvae have been taken at temperatures of 70.9-82.2° F. Spawning occurs in temperate waters between 40° N and 40° S latitude, from late spring to summer in the northern hemisphere. A ripe individual was taken off Morro Bay, California, in May. Louvar fecundity is very high, which is typical of nonschooling, oceanic fishes; a female 66.9 inches (5.6 feet) long had a fecundity of 47.5 million eggs.



Louvar, *Luvarus imperialis*.

Larvae range from 0.14 to 0.42 inches in length. The larvae and small juveniles look sufficiently different from the adult that they were once thought to be different species. They have strong, serrated dorsal and anal spines and a short body. The smallest juveniles have long, deep fins and dark spots on the body. Larger juveniles (four to eight inches) are similar to the adult but have longer dorsal and anal fins.

The size and age of louvar at maturity is not known; however, a 295-pound female was mature. Louvar grow to at least 74 inches (6.2 feet) in length and 305 pounds. Because the otoliths are tiny and not useful for ageing, the maximum age is unknown.

As midwater browsers, they feed primarily on gelatinous zooplankton such as jellyfish, ctenophores, and salps (including pyrosomes) but occasionally eat small fish. Only about 20 percent of the louvar taken have had food in their stomachs.

The louvar stomach is lined with numerous papillae and the coiled intestine is extremely long. The intestine of adults is about eight to nine times as long as the fish. These features presumably are adaptations for feeding on jellyfish.

An eight-inch louvar was found in the stomach of a wahoo. Otherwise, predators other than man are not known. Louvar guts are often parasitized by digenean trematodes.

Status of Population

The size of the louvar population worldwide or off California is not known. Louvar are solitary fish and few are taken at any one time. Because the population is worldwide in temperate and tropical seas, landings from California probably have little impact on the species as a whole. It is not known whether local subpopulations exist or how far individual louvar travel. If recent landings reflect the local availability of the species, then the species is likely to become more abundant off California following El Niño events. Although commercial landings of louvar are recorded by the California Department of Fish and Game, the louvar is not presently a target species and the fishery is not managed.

M. James Allen
MBC Applied Environmental Sciences

References

Decamps, P. 1986. Luvaridae. Pages 998-999 *In:* P. J. P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielson, and E. Tortonese (eds.), Fishes of the north-eastern Atlantic and the Mediterranean, Vol. 2. UNESCO, Paris, Fr.

Fitch, J.E., and R. J. Lavenberg. 1968. Deep-water Fishes of California. Univ. Calif. Press, Berkeley, CA. 155 p.

Gotshall, D. W., and J. E. Fitch. 1968. The louvar *Luvarus imperialis* in the eastern Pacific, with notes on its life history. Copeia 1968(1):181-183.

Nishikawa, Y. 1987. Larval morphology and occurrence of the louvar, *Luvarus imperialis* (Luvaridae). Jpn. J. Ichthyol. 34(2):215-221.

Tyler, J. C., G. D. Johnson, I. Nakamura, and B. B. Collette. 1989. Morphology of *Luvarus imperialis* (Luvaridae), with a phylogenetic analysis of the Acanthuroidei (Pisces). Smithson. Contrib. Zool. No. 485. 78 p.

ROCKFISHES

ROCKFISHES: OVERVIEW

History of the Fishery

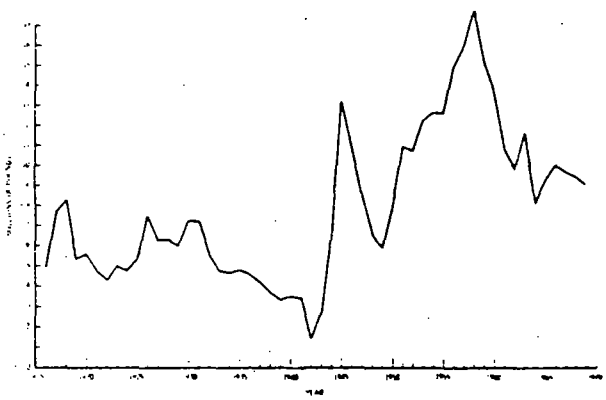
Rockfishes (*Sebastes* spp.) comprise one of the most important groups of commercial and recreational fishes, from the standpoint of economic value and biological diversity, occurring off the coast of California. Fifty-nine species are known from our marine waters, of which over 85 percent are utilized either in commercial or sport fisheries. In the scheme of classification, rockfishes belong to the family Scorpaenidae or scorpionfishes. In addition to the genus *Sebastes*, five other members of the family are known from Californian waters: the shortspine thornyhead (*Sebastolobus alascanus*), longspine

SMB-26850

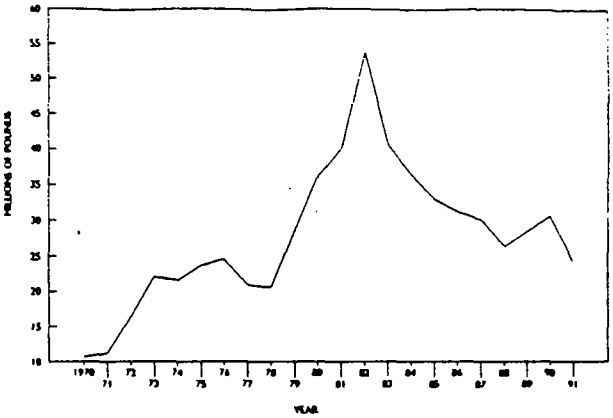
thornyhead (*Sebastolobus altivelis*), California scorpionfish (*Scorpaena guttata*), stone scorpionfish (*Scorpaena mystes*), and rainbow scorpionfish (*Scorpaenodes xyris*). The thornyheads are important commercial trawl fishes, while the California scorpionfish is taken both commercially and as a sport fish. These three species are treated in their own sections. (Editor's note: Until the mid-1980's, all landings of *Sebastes* and *Sebastolobus* were aggregated as rockfish. In recent years, landings are reported by species and groups of species.) The stone scorpionfish and rainbow scorpionfish are tropical species which are rare in Californian waters and their occurrences are most likely correlated to warm-water events such as the El Niño of 1982-1984.

Rockfishes have been utilized commercially since the mid-1800's, and many of the species were originally described from market samples taken during this period by such distinguished ichthyologists as David Starr Jordan, Charles Girard, William Ayres, Charles Gilbert, and Carl and Rosa Eigenmann. Rockfish historically and currently are sold primarily under the names of rockcod, red snapper, and snapper. These names are in fact misnomers as rockfishes are neither cods (family Gadidae) nor snappers (family Lutjanidae); however, the names are well entrenched and are for the most part understood by the consumer. For many years the rockfish catch was marketed fresh, sold both in the round and as fillets. Recently, much of the catch has been processed as frozen fillets. The carcasses that remain after filleting are often reduced to meal for livestock and poultry feeds. A certain number of "frames" are also sold to crab fishermen for baiting traps. Small species which are considered unmarketable due to size have been used for meal or at times for mink food.

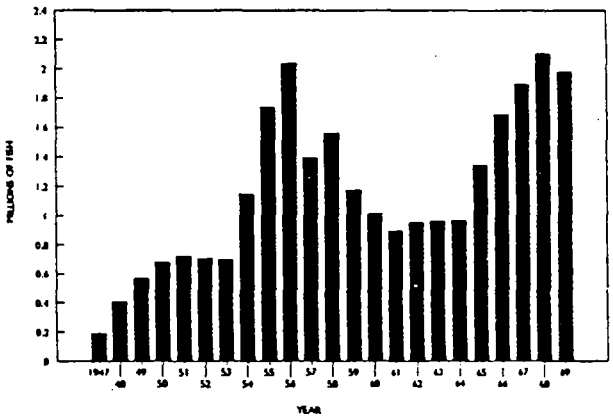
Species such as bocaccio and chilipepper have been primarily commercial species and are covered in their own chapters. Blue and olive rockfishes are principally sport species and are also covered in individual chapters. As recreational fishermen have developed the capabilities to fish at depths in excess of 600 feet and are now approaching the 1,200-foot mark, rockfishes which in the past were taken only by commercial vessels are now becoming a greater part of the sport take. These rockfishes include such deep-water forms as bank, blackgill, chameleon, rougheye, sharpchin, and other species previously beyond the range of the hook-and-line angler. A number of rockfishes are not covered in individual chapters and these are for the most part the small, uncommon, or little-utilized species.



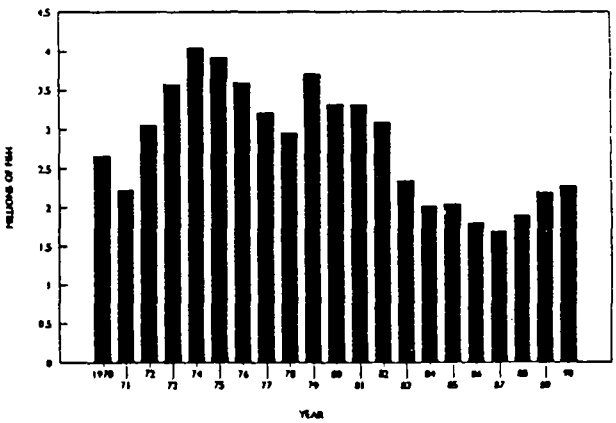
California commercial landings of rockfish, 1916-1969.



California commercial landings of rockfish, 1970-1991.



California commercial passenger-carrying fishing vessel landings of rockfish, 1947-1969.



California commercial passenger-carrying fishing vessel landings of rockfish, 1970-1991.

Status of Biological Knowledge

Rockfishes range in size from small, dwarf species such as dwarf-red, Puget Sound, and pygmy rockfishes which seldom exceed six inches in length to the gigantic forms such as cow cod, yelloweye and shortraker rockfishes which can reach over 36 inches in length and 40 pounds in weight.

SMB-26851

Geographically, rockfishes occur in both the Atlantic and Pacific oceans. However, the vast majority of species are found in the North Pacific Ocean, and the greatest number of these exist between the Gulf of Alaska and central Baja California; several species are also present within the Gulf of California. The copper rockfish is an example of one of the most broadly distributed species, known from the Kenai Peninsula, Alaska to the San Benito Islands off Baja California. Other species have more restricted distributions, such as the black-and-yellow rockfish, which ranges from Eureka to central Baja California.

Bathymetrically, rockfishes occur from the intertidal to over 2,400 feet. Grass and black-and-yellow rockfishes and treefish are examples of shallow-dwelling species which are found most commonly at depths of less than 60 feet; grass rockfish are often taken intertidally. Pacific ocean perch and rougheye rockfish occur at maximum depths (more than 2,000 feet) for members of the genus.

Rockfishes occur on and over various types of substrate including rocky bottom, siltstone, shale, sand, and mud. The association with substrate type is often quite specific. Gopher, black-and-yellow, and China rockfishes are rocky-bottom fishes, while brown and redbanded rockfishes occur on lower profile siltstone. Several nearshore species show a strong affinity for kelp forests; included in this category are blue, kelp, and olive rockfishes. A pelagic, midwater existence best describes such species as shortbelly, speckled, squarespot, and bank rockfishes.

Mode of reproduction is an important characteristic of this group and has been the focus of numerous scientific studies. Rockfishes are ovoviviparous, or live-bearing, the females releasing hundreds of thousands of relatively undeveloped larvae. These larvae become part of the plankton and remain in the water column for a period of one month to in excess of one year, depending upon species. The larvae then settle out as juveniles, often in association with the bottom.

Food items utilized by rockfishes vary widely and are often species specific. Juvenile rockfishes most commonly feed upon microcrustaceans, predominately copepods. Subadult and adult rockfishes feed predominately on larger crustaceans, cephalopods, and fishes. Bocaccio feed heavily on the young of other rockfishes. Young-of-the-year bocaccio are at times a major predator on young-of-the-year blue rockfish. All larval and juvenile rockfishes are important links in the food chain of the marine ecosystem. Shortbelly rockfish, for example, are major prey for chinook salmon off northern California.

As might be surmised by the number of species which are found in Californian waters, our biological knowledge for the various species of rockfishes varies greatly. Blue and olive rockfishes and bocaccio are species for which life-history parameters have been well established. At the other end of the spectrum, semaphore and dwarf-red rockfishes are species which are known from fewer than seven specimens. The diversity of the genus *Sebastes* off California makes it one of our most fascinating groups of marine fishes.

Status of the Resource

For many of the rockfishes our understanding of population size and their biological characteristics is incomplete. Within the scientific community there are concerns about the general status of rockfish stocks and the potential for over utilization.

Robert N. Lea
California Department of Fish and Game

Rockfishes Known to Occur off California and Their Importance to Commercial and Recreational Fisheries.

COMMON NAME	SCIENTIFIC NAME	IMPORTANCE[1]		
Aurora rockfish	*Sebastes aurora*	C	S°	
Bank rockfish	*Sebastes rufus*	C	S°	
Black rockfish	*Sebastes melanops*	C	S	
Black-and-yellow rockfish	*Sebastes chrysomelas*	C	S	
Blackgill rockfish	*Sebastes melanostomus*	C	S°	
Blue rockfish	*Sebastes mystinus*	C	S	
Bocaccio	*Sebastes paucispinis*	C	S	
Bronzespotted rockfish	*Sebastes gilli*	C°	S°	U
Brown rockfish	*Sebastes auriculatus*	C	S	
Calico rockfish	*Sebastes dalli*	C°	S	
Canary rockfish	*Sebastes pinniger*	C	S	
Chameleon rockfish	*Sebastes phillipsi*	C°	S°	U
Chilipepper	*Sebastes goodei*	C	S	
China rockfish	*Sebastes nebulosus*	C	S	
Copper rockfish	*Sebastes caurinus*	C	S	
Cow cod	*Sebastes levis*		C	S
Darkblotched rockfish	*Sebastes crameri*		C	S°
Dwarf-red rockfish	*Sebastes rufinanus*			Rare

SMB-26852

Rockfishes Known to Occur off California and Their Importance to Commercial and Recreational Fisheries.
(continued)

COMMON NAME	SCIENTIFIC NAME	IMPORTANCE[1]		
Flag rockfish	*Sebastes rubrivinctus*	C	S	
Freckled rockfish	*Sebastes lentiginosus*		S$_o$	U
Gopher rockfish	*Sebastes carnatus*	C	S$_o$	
Grass rockfish	*Sebastes rastrelliger*	C$_o$	S	
Greenblotched rockfish	*Sebastes rosenblatti*		S$_o$	U
Greenspotted rockfish	*Sebastes chlorostictus*	C	S$_o$	
Greenstriped rockfish	*Sebastes elongatus*	C$_o$	S	
Halfbanded rockfish	*Sebastes semicinctus*		S	
Honeycomb rockfish	*Sebastes umbrosus*		S	
Kelp rockfish	*Sebastes atrovirens*	C	S	
Mexican rockfish	*Sebastes macdonaldi*	C$_o$	S$_o$	U
Olive rockfish	*Sebastes serranoides*	C$_o$	S$_o$	
Pacific ocean perch	*Sebastes alutus*	C$_o$		U
Pink rockfish	*Sebastes eos*	C$_o$	S$_o$	U
Pinkrose rockfish	*Sebastes simulator*	C$_o$	S$_o$	U
Puget Sound rockfish	*Sebastes emphaeus*			Rare
Pygmy rockfish	*Sebastes wilsoni*			U
Quillback rockfish	*Sebastes maliger*	C$_o$	S	
Redbanded rockfish	*Sebastes babcocki*	C$_o$	S$_o$	U
Redstripe rockfish	*Sebastes proriger*	C$_o$	S$_o$	U
Rosethorn rockfish	*Sebastes helvomaculatus*	C$_o$	S$_o$	
Rosy rockfish	*Sebastes rosaceus*	C$_o$	S$_o$	
Rougheye rockfish	*Sebastes aleuticus*	C$_o$		U
Semaphore rockfish	*Sebastes melanosema*			Rare
Sharpchin rockfish	*Sebastes zacentrus*	C$_o$	S$_o$	
Shortbelly rockfish	*Sebastes jordani*		S$_o$	
Shortraker rockfish	*Sebastes borealis*			Rare
Silvergray rockfish	*Sebastes brevispinis*	C$_o$		U
Speckled rockfish	*Sebastes ovalis*	C$_o$	S	
Splitnose rockfish	*Sebastes diploproa*	C	S$_o$	
Squarespot rockfish	*Sebastes hopkinsi*		S$_o$	
Starry rockfish	*Sebastes constellatus*	C	S	
Stripetail rockfish	*Sebastes saxicola*	C	S$_o$	
Swordspine rockfish	*Sebastes ensifer*	S$_o$	U	
Tiger rockfish	*Sebastes nigrocinctus*	C$_o$	S$_o$	U
Treefish	*Sebastes serriceps*	C$_o$	S$_o$	
Vermilion rockfish	*Sebastes miniatus*	C$_o$	S	
Widow rockfish	*Sebastes entomelas*	C	S	
Yelloweye rockfish	*Sebastes ruberrimus*	C	S	
Yellowmouth rockfish	*Sebastes reedi*			Rare
Yellowtail rockfish	*Sebastes flavidus*	C	S	

[1]Symbols defined: C - commercial, S - recreational or sport, U - uncommon, o - occasionally taken, Rare - species which are either very poorly known or which have only been encountered in a few cases in California. *E.g.*, S$_o$ represents a recreational species which is only occasionally taken in the sport catch.

BLACK ROCKFISH

History of the Fishery

Black rockfish (*Sebastes melanops*), also known as black bass and black snapper, occur in the commercial and sport fisheries of California; however, they comprise only a moderate proportion of these fisheries. Eureka is the only port where black rockfish are numerous in the commercial catch. In recent years, the commercial landings of black rockfish have fluctuated from 42,402 pounds landed in 1987, with a value of $15,458, to 229,663 pounds landed in 1989, with a value of $82,558.

SMB-26853

Black rockfish, however, do constitute an important sport species to hook-and-line fishermen in northern and central California. South of Point Conception, a few are found off the northern Channel Islands and occasionally as far south as Santa Barbara. Two surveys of recreational anglers reveal the changing importance of black rockfish. The first of these surveys was conducted between 1957 and 1961. The most recent survey was conducted between 1979 and 1986. For all of California black rockfish ranked 17th by number and 10th by weight in the 1979-1986 survey. Looking only at locations from central and northern California, black rockfish ranked seventh by number and fourth by weight. This is a 6.6-fold increase in numbers landed and a 4.4-fold increase in weight from the 1957-1961 survey. The average weight of each fish dropped 25 percent from 2.89 pounds per fish in the 1957-1961 survey to 2.19 pounds per fish in the 1979-1986 survey.

Black rockfish are important to divers, too. In a 1972 survey of divers, black rockfish constituted 7.7 percent of all fish taken. During that year, divers took 1,852 black rockfish between Pismo Beach and the Oregon border.

Status of Biological Knowledge

Black rockfish range from Alaska to Santa Monica Bay in southern California. They are most commonly found swimming ten to twenty feet above shallow (to 120 feet) rocky reefs, but occasionally they are found midwater over deeper (to 400 feet) reefs. They have been reported as deep as 1,200 feet and occasionally wander far from their normal habitat; one fish that had recently spawned was caught 240 nautical miles from the nearest shallow rocky reef. Black rockfish attain a maximum length of 24 inches and a few individuals are known to have reached the ripe old age of 21 years.

As with all members of the genus *Sebastes*, fertilization and development of embryos take place within the female's body. Mating generally takes place between September and November. Females store the sperm until their eggs mature in December or January, at which time the eggs are fertilized by the stored sperm. The larvae develop within thirty days, and their black eyespots cause the eggs to change from a yellow-orange to a gray color between early January and March. The eyed larvae are released into the water from late January to May, peaking in February off California. Half of the males have spawned by the time they reach seven years of age and average 15.8 inches long. Half of all females have spawned by the age of six years when they are 13.8 inches in length.

Frequently, a few black rockfish are found in schools composed primarily of other rockfishes such as blue rockfish. These similar species do not compete with one another because they have different diets. The diet of black rockfish between 12 and 20 inches long consists of crab megalopae, ctenophores, other fish, amphipods and isopods.

Major predation occurs on black rockfish from the moment of larval release to the age of one year. This predation is by all larva-eating predators including some other rockfish species. Larger black rockfish are preyed upon by lingcod, sea lions, and the larger rockfishes.

Status of Population

Population size and structure are unknown, and until recently black rockfish have not been reported separately from other rockfishes in catch statistics. Some relative changes in the population have been identified, however. The average length and weight of black rockfish have declined over the past 30 years. This decline is almost certainly the result of fishing pressure. Although there are still plenty of adults to replenish the population, it will eventually be damaged if the decline continues. Black rockfish make up a larger portion of the recreational angler's catch now than they did 30 years ago because fishermen turned to fishing the black and blue rockfishes when the abundance of red rockfish declined.

James L. Houk
California Department of Fish and Game

References

Dunn, J.R. and C.R. Hitz. 1969. Oceanic occurrence of black rockfish (*Sebastes melanops*) in the central North Pacific. J. Fish. Res. Board Can. 26:3094-3097.

Hallacher, L.E. and D.A. Roberts. 1985. Differential utilization of space and food by the inshore rockfishes (Scorpaenidae: *Sebastes*) of Carmel Bay, California. Environ. Biol. Fishes. 12(2):91-110.

Miller, D.J. and J.J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp *Macrocystis pyrifera*, experiments in Monterey Bay, California. Calif. Dept. Fish and Game, Fish Bull. 158. 137 p.

Wyllie Echeverria, T. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. Fish. Bull., U.S. 85:229-250.

BLUE ROCKFISH

History of the Fishery

The blue rockfish (*Sebastes mystinus*), also known as bluefish, blue bass, and reef bass, is most commonly caught from the northern Channel Islands (in the Southern California Bight) to the Oregon border. Only a small portion of the blue rockfish landings is made by commercial fisheries, commercial catches between 1987 and 1989 having averaged 25,670 pounds with an average value of $9,287.

The blue rockfish is one of the most important sport species in California. It is taken by all fishing methods, ranking first in commercial passenger fishing vessel (partyboat) catches, second in skindiver catches, and from first to fifth in skiff catches. In a 1979-1986 survey of sport fish taken by hook and line between the southern boundary of Monterey County and Oregon, blue rockfish averaged fourth by numbers (902,000 fish) and second by weight (1,035,125 pounds). This is almost a three-fold increase in numbers and a 2.6-fold increase in weight since a simular survey was conducted from 1957 through 1961. In a diver survey conducted in 1972, blue rockfish ranked second in importance (to lingcod) with 10.5 percent of all the

SMB-26854

fish landed and were the most common rockfish taken by divers, comprising 29.6 percent of rockfish taken. They have been the subject of many management and research projects, and regulations (a bag limit of 15 fish) have been in effect for almost 20 years to protect the species from overfishing.

Usually filleted and skinned, with the white flesh baked or fried, blue rockfish are excellent in flavor.

Blue rockfish, *Sebastes mystinus*.

Status of Biological Knowledge

Blue rockfish range from the Bering Sea to Punta Baja, Baja California. They are not caught in large numbers south of the California Channel Islands or north of Eureka, California. They range in depth from tide pools to a maximum of 300 feet. Relatively small in comparison to other rockfishes, this species attains a maximum size of 21 inches, with the bulk of the catch ranging from 10 to 15 inches. Larger blue rockfish are most often taken in areas more than three to five miles from a public access point, usually over rocky depths of 80 to 120 feet.

Rockfishes are generally slow growing, but blue rockfish are among of the faster growing rockfish species. At the end of their first year, they reach a length of three to 3.5 inches. They are about six inches long by the end of the second year and attain a maximum size of about 21 inches in 23 years. Females grow at a slightly faster rate than males.

Age at first spawning is protracted for both sexes. Only about 10 percent spawn for the first time at three years of age. At five years (10.2 inches) half of the males have spawned. At six years (11 inches) half of the females have spawned.

In males the gonads increase in size from May to July, but in females the eggs begin maturing from July to October. Males transfer sperm to the females in October, but the embryos do not begin to develop until December when the eggs are fertilized by the stored sperm. Embryos develop within the female and hatch immediately upon being released into the water in January. Larvae live in the surface waters for several months, where they may be carried many miles in the ocean currents. Juveniles appear in the kelp canopy and shallow rocky areas by April or May, when they are about 1.2 to 1.4 inches in length. They are mottled reddish in color and appear in massive swarms in certain years in inshore areas, especially in the kelp canopy. Recent studies indicate that blue rockfish may be carried into nursery areas with fronts of cold upwelled water. In 1990, such events occurred at the same time over a substantial distance (130 miles) in central California. Continuing research is directed toward understanding the importance of fish refuge areas to protect adult spawning fish and to understand larval life history and juvenile recruitment to all areas of coastline in California.

Feeding habits vary considerably depending upon depth and locality. Deeper-water fish feed almost entirely on macroplankton consisting of tunicates (salps), scyphozoids (gonadal material of jellyfish), and crustaceans. In shallow areas and kelp beds, blue rockfish feed on the same types of macroplankton as those in deeper water, but they also feed on algae (several varieties), small fish, hydroids, and many types of crustaceans including amphipods and crab larvae.

Larval blue rockfish and juveniles, during their first few months on nearshore reefs, are preyed upon by most larger fishes. As adults, their predators include lingcod, harbor seals, sea lions, and, occasionally, larger rockfishes. Blue rockfish are most often found inhabiting kelp beds, where food is plentiful and protection from predators is provided by the kelp.

In inshore kelp bed areas, they form loose to compact aggregations. They can also often be found as solitary, wandering individuals moving in and about the kelp or swimming along with other rockfish species such as olive rockfish, yellowtail rockfish, black rockfish, and kelp rockfish. Under dense kelp canopies, they will sometimes form a column as wide as 12 feet and as deep as 80 feet and be as compact as sardines in a can. In deeper waters, they form dense aggregations that may extend from the surface to the bottom, but are usually in the mid-depth levels from 60 to 120 feet.

The California Department of Fish and Game has conducted marking studies on all size ranges of blue rockfish between 1.8 inches and 18 inches. A population study using freeze branding as a marking technique resulted in over 80,000 recently-settled blue rockfish being marked in a five-week period. These fish showed very little movement from an isolated reef 100 x 150 feet and, in fact, showed very little movement from one part of the reef to another.

Other tagging studies of adult blue rockfish indicate they do not migrate laterally along the coast. Nearly all recoveries of tagged adult fish were within one mile of the release point. The longest wandering movement was 15 miles. Several tagged individuals were captured and released up to five times at the same spot over a period of two years. While these studies show adult blue rockfish populations are more or less discreet at each fishing port, it is not known how much larval drift occurs between fishing areas.

Status of Population

The numbers of blue rockfish caught each year have increased over the last 20 years, but the population appears healthy. Areas in central and northern California that have heavy fishing pressure (Monterey, Santa Cruz, Morro Bay, Princeton) record smaller fish being landed. This is a normal occurrence and is offset by encountering larger fish in more remote, lightly utilized areas. There are periodic influxes of stronger blue rockfish year classes appearing at first in skiff

SMB-26855

catches when the fish are three to five years old. Fishing pressure reduces these strong influxes in two to three years.

James L. Houk
California Department of Fish and Game

References

Hallacher, L.E. and D.A. Roberts. 1985. Differential utilization of space and food by inshore rockfishes (Scorpaenidae: *Sebastes*) of Carmel Bay, California. Environ. Biol. Fishes. 12(2):91-110.

Klingbeil, R.A. 1976. Southern range extensions of the blue rockfish, *Sebastes mystinus*, the flag rockfish, *S. rubrivinctus*, and the shortbelly rockfish, *S. jordani*. Calif. Fish and Game. 62:160.

Miller, D.J., J.J. Geibel, and J.L. Houk. 1974. Results of the 1972 skindiving assessment survey. Pismo Beach to Oregon. Calif. Dept. Fish and Game, Mar. Resour. Tech. Rep. 23. 61 p.

Miller, D.J. and D. Gotshall. 1965. Ocean sportfish catch and effort from Oregon to Point Arguello, California, July 1, 1957-June 30, 1961. Calif. Dept. Fish and Game, Fish Bull. 130. 135 p.

Wyllie Echeverria, T. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. Fish Bull., U.S. 85:229-250.

BLACKGILL ROCKFISH

History of Fishery

Blackgill rockfish (*Sebastes melanostomus*) are the most important commercial rockfish species in southern California, and substantial numbers are also taken as far north as Fort Bragg. Until the late 1970's, blackgills were not a major commercial species, though they were targeted by a few of the Newport dory fishermen. In the late 1970's, fishermen extending their operations into deeper waters began targeting these fish, first by hook and line and then, in the 1980's, by gill nets. Currently, blackgills are also a common catch of the trawlers operating between Morro Bay and Eureka. In California waters, from 1986-1989, between 284,000 and 648,000 pounds were landed, worth between $134,000 and $321,000 to fishermen. Because they inhabit deep water, usually depths greater than 1,000 feet, blackgills are rarely taken by sport fishermen.

Blackgill rockfish, *Sebastes melanostomus*.

Status of Biological Knowledge

This species ranges from Washington State southward to central Baja California. Previous records of blackgills from Canada, Alaska and the Soviet Union probably refer to misidentified rougheye rockfish or other similar appearing species. Young fish are taken in water as shallow as 600 feet, but adults inhabit 720-2,520 foot depths. Though they can be found over soft bottom, blackgills are most abundant over hard bottom, steep dropoffs and sea mounts.

Blackgill rockfish grow to two feet and a few are mature when 13 inches long. Fifty percent are mature by 14 inches and all reproduce by 15 inches. Blackgills are probably viviparous; females spawn from January through June (peaking in February) and produce as many as 770,000 eggs. The larvae are spawned in one batch per season, are pelagic and are seldom taken below about 300 feet. Beginning in June, when they are about three-quarters of an inch long, the larvae metamorphose into pelagic juveniles and at one and a half inches these fish begin to settle on the bottom at a depth of about 600 feet. As the fish mature, they seek out deeper waters.

Status of Population

As of 1991, there had been no study of the blackgill rockfish population.

Milton Love
University of California

Reference

Moser, H. G. and E. H. Ahlstrom. 1978. Larvae and pelagic juveniles of blackgill rockfish, *Sebastes melanostomus*, taken in midwater trawls off southern California and Baja California. J. Fish. Res. Bd. Canada 35(7):981-996.

Love, M. S., P. Morris, M. McCrae and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: Sebastes) from the southern California Bight. NOAA Tech. Rept. NMFS 87, 38p.

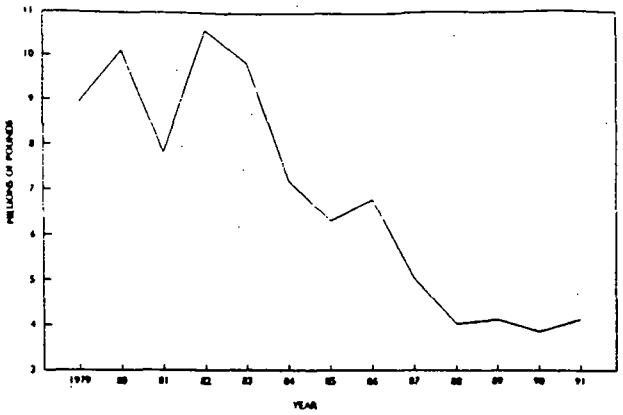
BOCACCIO

History of the Fishery

Bocaccio (*Sebastes paucispinis*), sometimes called red snapper, rockcod, grouper, salmon grouper, or tomcod (as juveniles), was the dominant rockfish in California's early longline fishery. It was the most abundant rockfish in the otter trawl fishery from Morro Bay to Fort Bragg until the mid-1980's. By 1989 two-thirds of the bocaccio landed were taken by otter trawl, with the remainder being taken by set net, longline, and the recreational fishery.

Accurate estimation of commercial bocaccio landings began in 1978. In the late 1970's, trawl landings averaged approximately four million pounds per year. Landings increased sharply, peaking in 1981 at about 10 million pounds, then gradually fell to about eight million pounds in 1984. Landings plummeted to near 2.5 million pounds by 1985 and have remained near this lower level. In 1978, nearly 40 percent of the sampled trawl landings contained half or more by weight bocaccio, but by 1990 less than 15 percent did. Since 1985, chilipepper has replaced bocaccio as the dominant rockfish in trawl landings.

SMB-26856



California commercial landings of the bocaccio-chilipepper rockfish group, 1979-1991.

Recreational catches of bocaccio are generally made on rocky reefs by partyboat fishermen at depths of 250 to 750 feet. In some years, however, juveniles concentrate in shallow sandy areas near piers off central and southern California, where they are easily taken on small baited hooks. Estimated catches for the recreational fishery are available from 1980 onward and averaged 27 percent of the trawl landings over the same period. Recreational catches since 1984 have showed the same decline as the trawl fishery. In general, the recent recreational catches have been greater in southern California than in northern California.

Since 1982, bocaccio have been managed under the Groundfish Management Plan of the Pacific Fishery Management Council. In response to concerns about stock condition, the Council established for the first time, a harvest guideline of 2.4 million pounds for 1991.

Bocaccio rockfish, *Sebastes paucispinis*.

Status of Biological Knowledge

Bocaccio range from central Baja California to Kodiak Island, Alaska and are common from northern Baja California to the Washington-British Columbia border. Migration and movements of bocaccio are not understood.

Among rockfishes, bocaccio are noted for their relatively rapid growth, large adult size, and high variation in year-class strength. They are known to attain a length of 36 inches, a weight of 15 pounds, and a maximum age of about 50 years. Some fast growing individuals are caught with trawl gear at age one, and substantial numbers are landed by age two at lengths of about 16 inches.

Bocaccio are live-bearing fish. At extrusion (release), larvae are about 0.25 inch in length and absorb yolk from the egg stage during the first eight to 12 days. They grow rapidly to about seven inches by the end of their first year. A few mature when they are three years old, about 14 inches long and one pound. Fifty percent are mature at 16.5 inches and four years. Males mature at a slightly smaller size than females. By the time they are 10 years old, they average over 24 inches and weigh five pounds. The number of developing eggs increases from 20,000 in a 15-inch fish to about 2.3 million in a fish 30.5 inches long.

Off central and northern California, larval release occurs from January through May, peaking in February. In southern California spawning takes place from October through July, peaking in January. In central California, most larvae that survive to the juvenile stage are born in January and February, but months of successful reproduction can shift substantially from year to year. In southern California, some females produce as many as three broods in a season, but multiple brooding is uncommon farther north.

Larval bocaccio are initially pelagic and are most common within 100 feet of the sea surface, where they feed on plankton. Larval bocaccio have been captured in plankton nets as far as 300 miles from shore. By late May or early June, they settle to the bottom at lengths of 1.5 to 2.5 inches, often in kelp beds. Before completing their first year of life, these fast growing young of the year start eating the young of other rockfishes, surfperch, jack mackerel, and various small inshore fishes. Adults are found from depths of 60 to 1550 feet. They feed on smaller rockfishes, sablefish, anchovies, lanternfish, and squid.

Status of Population

During the past decade bocaccio landings have been dominated by the 1977 and 1984 year classes. As a consequence of the high variability in year-class strength, the size and age structure of the population fluctuates greatly over time. It appears that recruitment in the late 1960's and early to mid-1970's was, on average, substantially higher than average recruitment over the 1978-1989 period.

Stock analyses, using fishery age-composition data, recreational effort data, and trawl survey data, strongly indicate that biomass and spawning stock size have declined substantially over the 1978-1989 period. Estimated biomass has fallen from about 150 million pounds in 1978 to approximately 20 million in 1989. The recommended yield for all fisheries combined ranged from 1.6 million to 3.4 million pounds compared to 1989 landings of 2.6 million pounds.

David H. Thomas
California Department of Fish and Game

James R. Bence
National Marine Fisheries Service

References

Bence, J.R. and J.E. Hightower. 1990. Status of bocaccio in the Conception/Monterey/Eureka INPFC areas in 1990. Appendix J.

SMB-26857

In Status of the Pacific Coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991. Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Avenue, Portland, OR 97201.

Moser, H.G. 1967. Reproduction and development of *Sebastodes paucispinis* and comparison with other rockfishes off southern California. Copeia. 1967:773-797.

Wilkins, M.E. 1980. Size composition, age composition, and growth of chilipepper, *Sebastes goodei*, and bocaccio, *S. paucispinis*, from the 1977 rockfish survey. Mar. Fish. Rev. 42:48-58.

CHILIPEPPER

History of the Fishery

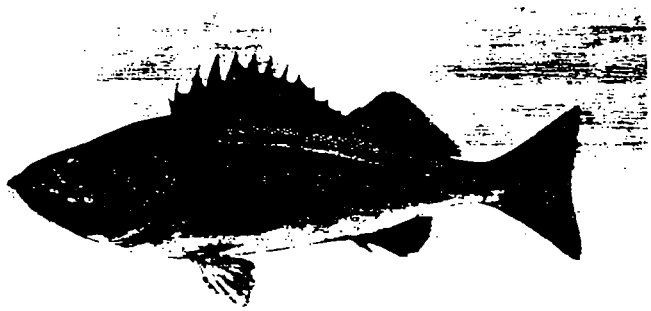
The chilipepper (*Sebastes goodei*) is one of California's most important rockfish species; it is a major contributor to commercial and sport landings. In 1989, chilipepper ranked second in statewide estimated commercial rockfish landings at over 4.5 million pounds. Estimated value for these landings total over 1.4 million dollars. Important ports of landing are Fort Bragg, Bodega Bay, San Francisco, Princeton, Monterey, Moss Landing, and Morro Bay. Chilipepper also contribute, although not so heavily, to southern California rockfish landings. Percent composition of chilipepper in rockfish landings from Santa Barbara to San Diego ranged from two percent in 1986 to over 13 percent in 1983.

In the late 1800's, chilipepper and other rockfish were caught by Portuguese longline fishermen who fished Monterey bay from small two- or three-person vessels. Longlines provided most, if not all, rockfish landings until the mid-1940's. Improvements in otter trawl technology a few years later led to the replacement of longlines as the primary gear used to catch rockfish. Trawl gear enabled fishermen to make much larger landings with larger vessels. Trawlers have since accounted for the bulk of chilipepper landings, followed by set gillnet and hook-and-line gear.

Modern steel-hulled trawler that often targets rockfish and flatfish.

Chilipepper enter the fresh and frozen markets and are sold in the round or as fillets. The average price paid to fishermen in 1990 was $0.33 per pound.

Historically, chilipepper was not considered an important component of the partyboat angler's catch in central and northern California due to its deep offshore distribution. In the early 1980's, Monterey and Santa Cruz partyboat skippers began fishing chilipepper schools appearing near the Monterey underwater canyon in late spring through summer. In contrast, southern California chilipepper partyboat landings peak during the winter months. Chilipepper was ranked third among rockfish taken by central and northern California anglers interviewed in 1989 to 1990.



Chilipepper rockfish, *Sebastes goodei*.

Status of Biological Knowledge

Chilipepper range from Queen Charlotte Sound, British Columbia to Magdalena Bay, Baja California. Adults are found on deep rocky reefs as well as on sand and mud bottoms, from 150 to 1400 feet; juveniles school and are frequently found in shallow nearshore waters, particularly in kelp beds. Spawning occurs from September to April with a peak occurring in December to January. About 50 percent of female chilipepper are sexually mature at four years when they are between 11 and 12 inches, while males mature at two years and between eight and nine inches. Chilipepper attain a maximum age of at least 20 years and a size of up to 22 inches.

Adults feed on small crustaceans, small squid, and assorted small fishes. Probable predators of chilipepper include marine birds and mammals, king salmon, lingcod, Pacific hake, sablefish, and other rockfish.

Status of Population

In 1986, a biological assessment of the chilipepper resource was completed and the resource appeared to be in good condition. The acceptable biological catch (ABC) was set at 3,960 short tons, an increase of 1,430 tons over 1985. The ABC has remained at 3,960 tons for 1990. Due to the decline in bocaccio abundance, chilipepper has become an increasingly important component of the rockfish fishery and will be the focus of further study.

Kenneth T. Oda
California Department of Fish and Game

References

Jow, T. and J.E. Hardwick. 1979. Status of the groundfish resource and a plan for its management. Calif. Dept. Fish and Game Mar. Resour. Management Rep. 2. 98 p.

SMB-26858

Love, M.S., P. Morris, M. McCrae and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the southern California Bight. NOAA Tech. Rept. NMFS 87. 38p.

Pacific Fishery Management Council. 1990. Status of the Pacific Coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991: stock assessment and fishery evaluation. Pacific Fishery Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, Oregon 97201. 58 p.

Phillips, J.B. 1964. Life history studies on ten species of rockfish (Genus Sebastodes). Calif. Dept. Fish and Game, Fish Bull. 126. 70 p.

Wyllie-Echeverria, T. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. Fish. Bull. (U.S.). 85:229-250.

OLIVE ROCKFISH

History of the Fishery

Olive rockfish (*Sebastes serranoides*), also called johnny bass or johnathans, are caught primarily by sport anglers near rocky reefs and kelp beds at depths less than 150 feet. They are often found schooling in mid-water in association with blue rockfish and yellowtail rockfish. This species is taken by shore and pier anglers and by divers but is most important to skiff and commercial passenger fishing vessel (CPFV) anglers.

During a 1958-1961 survey of sport fishing from Point Arguello to the Oregon border, olive rockfish averaged fourth by number and seventh by weight of all rockfish taken. During this survey, an average of 48,281 olive rockfish were caught annually, averaging 1.9 pounds each. A state-wide sport fish survey conducted from 1980 through 1986 ranked it among the top 10 rockfish species taken by skiff and CPFV anglers in northern California (Monterey-San Luis Obispo County line to the Oregon border). Here an average of 115,000 olive rockfish were taken annually, averaging 1.8 pounds each. In southern California (Monterey-San Luis Obispo County line to the Mexico border), the survey ranked this species as one of the six most important rockfish to CPFV anglers and one of the top three rockfish taken by skiff anglers. The estimated average annual catch for southern California was 260,000 olive rockfish weighing an average of 1.0 pound each.

Commercial catches, primarily for the fresh fish market, were made in the past with gill nets and hook and line. Today, commercial catches are taken only with hook and line. Because olive rockfish are not separated from other commercial rockfish landings as a market category, the commercial landings of this species are unknown.

Olive rockfish commonly occur in kelp beds and on rocky reefs from Monterey Bay south and also near offshore islands, particularly Santa Barbara and San Nicolas. CPFV and skiff anglers commonly take this fish using a multihook bottom fish rig. When fishing in kelp beds, some anglers prefer to use flies, streamers, or live bait on spinning gear. Olive rockfish will strike this gear near the surface and put up a lively fight.

Status of Biological Knowledge

Olive rockfish occur from Crescent City to the San Benito Islands, Baja California, nearshore to a depth of 480 feet. They reach a maximum age of 25 years and can reach a length of 24 inches and weigh as much as seven or eight pounds. Half of all olive rockfish mature and begin reproducing when they are about 13 to 14 inches long and four or five years old. Large females can produce up to 500,000 eggs per year. As in all rockfishes, eggs are fertilized internally, and the embryos develop within the female. They hatch into larvae and are released into the plankton from December through March. The larvae are pelagic for three to six months until they settle onto reefs and in kelp beds as juveniles when they are about one inch long.

Olive rockfish, *Sebastes serranoides*.

Tagging studies have shown that this species tends to spend its entire life near the same reef. This characteristic makes nearshore rockfish species particularly susceptible to overfishing. As fishing removes mature fish from a reef, they are replaced only through the transport of larvae and the settlement of juveniles produced elsewhere.

Olive rockfish are active, midwater predators. Juveniles feed on zooplankton and small fish, while adults feed on fish, squid, crab, and shrimp.

This species looks very similar to the yellowtail rockfish, although its body is more elongate and compressed. Olive rockfish have nine soft rays in the anal fin and yellowtail rockfish usually have eight.

Status of Population

The population size of this species is unknown. Like all nearshore species of rockfish, olive rockfish are susceptible to overfishing, and in heavily fished areas, it is common for anglers to catch immature fish. Typically, the average size of fish taken increases with distance from port.

Diana L. Watters
California Department of Fish and Game

References

Love, M.S. and W.V. Westphal. 1981. Growth, reproduction, and food habits of olive rockfish, *Sebastes serranoides*, off central California. Fish. Bull., U.S. 79:533-545.

Love, M.S. 1980. Isolation of olive rockfish, *Sebastes serranoides*, populations off southern California. Fish. Bull., U.S. 77 975-983.

VERMILION ROCKFISH

History of the Fishery

Vermilion rockfish (*Sebastes miniatus*), though highly desirable, are only of moderate importance in commercial and

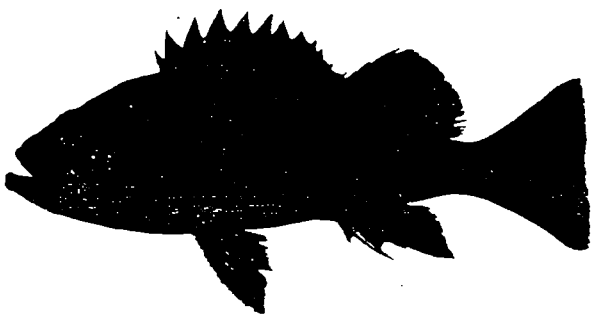
SMB-26859

sport fisheries. It is difficult to determine the percentage of the commercial catch that is comprised of vermilions, because they are combined with other red- and orange-colored rockfishes in the market category of "reds." During 1981 and 1982, vermilion rockfish ranging in size from 8.7 to 21.8 inches accounted for less than one percent of the combined hook-and-line and spearfish take of sport fishermen in Monterey. Information from competitive spearfishing meets indicates that this species may be quickly reduced by concentrated fishing. In 1981, vermilion rockfish comprised 11 percent of the take at competitive free diving spearfish contests held at Piedras Blancas. Six years later in 1987, the number of vermilion rockfish taken was less than one percent. This area is one of the few locations along the Big Sur coast that is easily accessible and is, therefore, heavily utilized by sport and commercial hook-and-line fishermen.

Intense fishing also causes a decrease in the size of the fish taken. In 1981, the average size of vermilion rockfish taken by sport hook-and-line fishermen from Point Pinos to Yankee Point in Monterey County was 18.8 inches. The average size dropped to 16.1 inches in 1983, 15.5 in 1985, and 14.3 inches in 1987. In 1989, surveys of commercial passenger fishing vessel (CPFV) trips from Port San Luis and Morro Bay in San Luis Obispo County, vermilion rockfish averaged only 13 inches in length and comprised 13 percent of the total catch. Along lightly fished areas of the central coast, fish of the same size comprised eight percent of the total CPFV catch. Fish taken north of Monterey were slightly larger but accounted for less then two percent of the catch.

In a survey of southern California CPFV's from 1985 through 1987, vermilion rockfish ranked third in species composition at 8.1 percent of the total rockfish catch. Between 1983 and 1988, they ranged from 2.2 to 5.2 percent of the sampled commercial catch of rockfish landed south of Point Conception.

Vermilion rockfish are marketed primarily in a fresh dressed form. Because the flesh has a short freezer life, it is rarely frozen. These rockfish are best when filleted, skinned, and deep fried. They are also delicious when baked with vegetables in the oven or microwave. As with most other members of the family, the flesh is white, fine in texture, and mild in flavor.



Vermilion rockfish, *Sebastes miniatus*.

Status of Biological Knowledge

Vermilion rockfish are found from Vancouver Island, British Columbia, to San Benito Island, Baja California, and occur over rocky bottoms from 40 to 660 feet. Large fish are more common at depths greater than 100 feet due to the combined fishing pressure in shallower waters from commercial and recreational fishermen. Vermilion rockfish generally remain on the same reef system on which they settle during their first year. Tagging studies have shown no movement of fish at liberty for one to three years. Vermilion rockfish are extremely long lived. The oldest individual aged was 25 years old, measured 20 inches, and weighted 5.4 pounds. Lengths up to 30 inches have been reported. They also have lengthy juvenile life stages. Fifty percent of the population is mature at eight years and these fish average 14 inches. The slow growth and long juvenile period make vermilion rockfish very susceptible to overfishing. Once large individuals are removed from a reef system they are replaced only by larval settlement.

Peak spawning months are September in central and northern California and November in southern California. The number of developing eggs increases from 63,000 in a fish 12.5 inches long to about 1.6 million in a 21.5-inch fish. Females are fertilized internally by males. Newly released larvae are free swimming and lead a pelagic existence for three to four months, then settle to the bottom. Juveniles are not strong swimmers and tend to be very secretive, often taking refuge in dense algae.

The pelagic young of vermilion rockfish feed primarily upon crustaceans, while adults feed on octopus, squid, and small fishes such as anchovies and blue lanternfish. At times, macroplanktonic organisms such as euphausiids, pelagic red crabs, and pyrosomes (pelagic colonial tunicates) are found in their stomachs.

Status of Population

No population estimates are available for vermilion rockfish, and the magnitude and size composition of the commercial and sport catch is poorly understood. The present exploitation rate is unknown.

David A. VenTresca
California Department of Fish and Game

References

Boehlert, G.W. and M.M. Yoklavich. 1984. Reproduction, embryonic energetics, and maternal-fetal relationship in the viviparous genus *Sebastes* (Pisces, Scorpaenidae). Biol. Bull. 167:354-370.

Echeverria, T. and W.H. Lenarz. 1984. Conversions between total, fork, and standard lengths in 35 species of *Sebastes* from California. Fish. Bull., U.S. 82:249-251.

Love, M.S. 1983. Movements of rockfishes. Abstract in F.D. Henry (ed.) Proceedings of the 1983 western groundfish workshop. Calif. Dept. Fish and Game.

Singer, M.M. 1985. Food habits of juvenile rockfishes (*Sebastes*) in a central California kelp forest. Fish. Bull., U.S. 83:531-541.

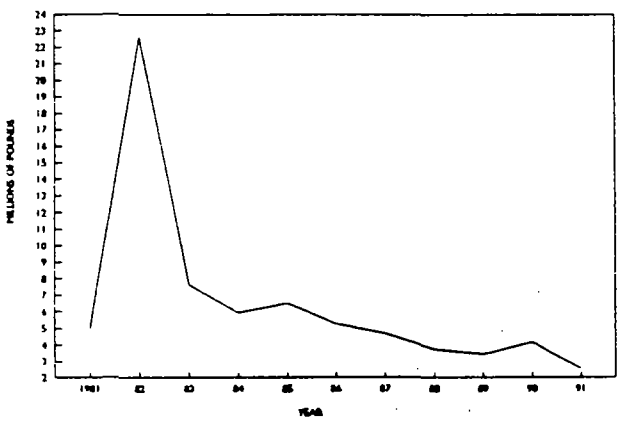
VenTresca, D.A., R.N. Lea, and R.D. McAllister. 1983. Movement of tagged rockfishes along the central California coast. Abstract in F.D. Henry (ed.) Proceedings of the 1983 western groundfish workshop. Calif. Dept. Fish and Game.

SMB-26860

WIDOW ROCKFISH

History of the Fishery

The widow rockfish *(Sebastes entomelas)* is one of the top three species in commercial landings of rockfish in California and is a minor component of recreational landings. Although there were reports of occasional large trawl catches made incidental to fishing for other species, commercial landings were minor until markets improved in 1979 and midwater trawl fishing began. At this time, fishermen began targeting on the species, and California landings exceeded 10,000 tons by 1982. Since 1983, strict regulations have limited commercial landings. Recent landings are about 1,500 tons. Annual landings are restrained by a quota that applies to the fisheries of California, Oregon and Washington. Trip landings and frequency are also regulated in order to maintain a long open season. Widow rockfish comprise about 60 percent of the commercial rockfish landings in Eureka, 35 percent in Crescent City, and 25 percent in Bodega Bay; they occur as smaller proportions of landings as far south as Santa Barbara. Most widow rockfish are filleted and marketed as Pacific red snapper or rockcod. The landed value approached $1,000,000 in 1989. Widow rockfish are mostly caught by trawlers. Before the advent of restrictive trip landing limits, most of the fish were caught with large midwater trawls. It can be difficult to avoid capturing more widow rockfish in a single tow with a midwater trawl than trip limits allow, and many vessels are now using only the less efficient bottom trawls. Widow rockfish are also captured with gill nets and longlines.



California commercial landings of widow rockfish, 1981-1991.

Status of Biological Knowledge

Widow rockfish are found from Todos Santos Bay, Baja California, to Kodiak Island, Alaska. Peak abundance is off northern Oregon and southern Washington, with significant aggregations occurring south to central California. While many commercial catches occur at bottom depths between 450 and 750 feet, young fish occur near the surface in shallow waters, and adults have been caught over bottom depths to 1,200 feet. Widow rockfish often form midwater schools, usually at night, over bottom features such as ridges or large mounds near the shelf break. The schooling behavior of widow rockfish is quite dynamic and probably related to feeding and oceanographic conditions. There appears to be some seasonal movement of fish among adjacent grounds, and there is evidence that fish move from area to area as they age, with fish of the same size staying together.

Widow rockfish, *Sebastes entomelas.*

The maximum recorded age for widow rockfish is 59 years, but fish older than 30 years are uncommon. Most are less than 21 inches in length, which corresponds to a weight of about 4.7 pounds. The maximum size is 24 inches or about 7.3 pounds. At first, growth is fairly rapid and by age five widow rockfish average 13.4 inches. By age 15 growth has slowed, and the average size is 18.7 inches for females and 17.6 inches for males. About 50 percent of widow rockfish are mature by age five, and almost all are mature by age eight when they are 16.6 inches. Off California, fecundity ranged from 55,600 eggs for a 12.8-inch female to 915,200 eggs for a 18.8-inch fish. The release of larvae by widow rockfish peaks in January-February and appears to occur in the same areas where they are caught during that season. The larvae are about 0.2 inch when released. The young fish lead a pelagic existence until they are about five months old. During the latter part of the pelagic stage, the two-inch fish feed mostly on copepods and small stages of euphausiids. Adult widow rockfish feed on midwater prey such as lantern fish, small Pacific whiting, euphausiids, sergestid (deep water) shrimp, and salps. Juvenile rockfish, including widow rockfish, are important prey items for sea birds and chinook salmon in May and June. Little is known about predation on adult widow rockfish.

Status of Population

The population was virtually unfished prior to 1979. By 1982, it became obvious that the population was being rapidly fished down and would soon be overfished, if catches were not restricted. The fishery was placed under stringent regulations in 1983. The population is now estimated to be at about the level chosen by management to maintain a viable spawning stock. The 1991 quota is 7,700 tons for the combined landings of California, Oregon and Washington. While the annual quota is likely to change as weak or strong year classes pass through the fishable stock, the long-term average is expected to be at about the 1991 level.

William H. Lenarz
National Marine Fisheries Service

References

Boehlert, G. W., W. H. Barss, and P. B. Lamberson. 1982. Fecundity of the widow rockfish, *Sebastes entomelas*, off the coast of Oregon. Fish Bull., U. S. 80:881-884.

Gunderson, D.R. 1984. The great widow rockfish hunt of 1980-82. N. Am. J. Fish. Manage. 4:465-468.

Hightower, J.E. and W.H. Lenarz. 1990. Status of the widow rockfish fishery in 1990. Appendix F [In] Status of the Pacific Coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991. Pacific Fishery Management Council, Portland, Oregon.

Lenarz, W.H., and D.R. Gunderson (editors) 1987. Widow rockfish: Proceedings of a workshop, Tiburon, California, December 10-11, 1980. U.S. Dept. Commer., NOAA Tech. Rep. NMFS 48.

SHORTBELLY ROCKFISH

History of the Fishery

The shortbelly rockfish *(Sebastes jordani)* is the most abundant rockfish off California but has been fished very little. A directed fishery occurred in 1982, when a joint venture with the USSR caught 700 tons off central California. Otherwise, a few shortbelly rockfish occasionally appear with other rockfish landed in California ports. There is no domestic market for shortbelly rockfish at present. If a market develops, special permits will be required, because fishing with legal mesh sizes is not practical for this small species. Large catches of shortbelly rockfish can be made using midwater or bottom trawls with fine mesh cod ends. Research has shown, however, that while directed fishing for shortbelly rockfish results in low incidental catches of other species when mid-water trawls are used, high incidental catches can occur when bottom trawls are used. Because of the concern that bottom trawls would take unacceptably high numbers of small fish of other important species, scientists have recommended against the use of bottom trawls for shortbelly rockfish.

The potential fishery for shortbelly rockfish is controversial. Fishermen express concern that significant amounts of salmon may be caught incidentally to fishing for shortbelly rockfish, but scientists have not observed incidental salmon catches and believe that a fishery for shortbelly rockfish is likely to be offshore from concentrations of salmon. Fishermen and environmental groups also express concern because young-of-the-year shortbelly rockfish are forage for salmon, sea birds and marine mammals. Scientists have recommended quotas that are thought to be sufficiently low so as not to impact either the recruitment or the availability of young-of-the-year shortbelly rockfish for forage. Scientists have also recommended close monitoring of fishing for shortbelly rockfish to verify that high incidental catches and/or depletion of forage do not occur.

The 1991 quota for catches off California, Oregon and Washington is 14,300 tons. Recent applications by joint venture companies to fish for shortbelly rockfish were not approved. These companies intended to use the catch for surimi. There has also been some interest expressed by domestic firms to utilize shortbelly rockfish for surimi, but they have not submitted a permit request.

Shortbelly rockfish, *Sebastes jordani.*

Status of Biological Knowledge

Shortbelly rockfish are found from Punta Baja, Baja California, to La Perouse Bank, British Columbia. Peak abundances are between the Farallon Islands and Santa Cruz, and off the Channel Islands. Young-of-the-year shortbelly rockfish have been observed in the surf line, and adults have been reported as deep as 930 feet. The peak abundance of adults is over bottom depths of 400 to 700 feet. Adults commonly form very large schools over smooth bottom near the shelf break. Schools are often near or on the bottom during the day and tend to be less dense and higher in the water column during the night. The size of shortbelly rockfish tends to increase with bottom depth.

The maximum recorded age for shortbelly rockfish is 22 years, but fish older than 10 years are uncommon. Most are less than 11.5 inches in length, which corresponds to a weight of 0.5 pound. The maximum size is 12.8 inches, or about 0.7 pound. Early growth is fairly rapid, and by age three the average size is 7.8 inches for males and 8.3 inches for females. Growth has slowed by age eight, and the average size is 9.7 inches for males and 10.3 inches for females. About 50 percent of female shortbelly rockfish are mature by age three, and almost all are mature by age four. The fecundity ranges from 6,200 eggs for a 6.8-inch fish to 50,000 eggs for a 12.0-inch fish.

Plankton surveys during the January-April parturition season indicate that larvae are released in the same areas inhabited in the summer and fall by large aggregations of adults. However, the fish may be more dispersed during the late winter season because aggregations of adults have been difficult to locate then. The larvae are about 0.2 inch when released. The young fish lead a pelagic existence until June, when they are about five months old. In June, the young shortbelly rockfish begin to take on the behavior of adults. Divers occasionally observe them in large, compact, schools in fairly shallow water. Large numbers of moribund young-of-the-year shortbelly rockfish are sometimes found on beaches after periods of wind patterns that are thought to cause currents which carry them into shallow waters. These fish have not appeared to be either starved or diseased. They appear to be maladapted to contact with the abrasive bottom when in the nearshore environment.

During the latter part of the pelagic stage, the two to three-inch shortbelly rockfish feed mostly on copepods and small stages of euphausiids. Adults feed primarily on euphausiids, but also consume some copepods. Young-of-the-year shortbelly rockfish are important prey items for salmon and sea birds

SMB-26862

during the latter part of the pelagic stage. They have also be found in the diet of lingcod and northern fur seals. Adult shortbelly rockfish are occasionally found in the diet of larger predators such as lingcod.

Status of Population

The population is at the unfished level. Biomass estimates have been attempted on four hydroacoustic surveys from Santa Cruz to the Farallon Islands. Large aggregations needed for the hydroacoustic technique were found only for two of the four surveys. The two biomass estimates were 168,000 tons and 325,000 tons. It was estimated that the biomass in this area could support annual catches of at least 14,800 tons without reducing the spawning stock below levels thought to be needed to maintain good recruitment.

William H. Lenarz
National Marine Fisheries Service

References

Chess, J. R., S. E. Smith, and P. C. Fisher. 1988. Trophic relationships of the shortbelly rockfish, *Sebastes jordani*, off central California. CalCOFI Rep. 29:129-136.

Kato, S. 1981. Checking out shortbelly rockfish - Colintino Rose II's mission accomplished. Pacific Fishing (November, 1981):96-100.

Lenarz, W. H. 1980. Shortbelly rockfish, *Sebastes jordani*: a large unfished resource in waters off California. Mar. Fish. Rev. (March-April):34-40.

Pearson, D. E., J. E. Hightower, and J. T. H. Chan. 1991. Age, growth, and potential yield for shortbelly rockfish (*Sebastes jordani*). Fish. Bull. 89:403-409.

BROWN ROCKFISH

History of the Fishery

There is no regular monitoring of commercial landings of brown rockfish (*Sebastes auriculatus*); however, occasional large catches of brown rockfish do occur. In the San Francisco Bay area, freshly caught whole fish are in demand for sale in oriental restaurants.

The brown rockfish recreational catch from 1979 to 1986 averaged 296,000 pounds, or two to four percent of the total recreational rockfish catch in California. Northern and southern California catches are almost equal. In the Puget Sound area, brown rockfish are a major portion of the recreational catch.

Status of Biological Knowledge

Brown rockfish, sometimes called bolina rockfish, range from southeastern Alaska to central Baja California. They are widely distributed in shallow waters and bays, but have been taken to depths of 420 feet. Subadults are strongly residential to their home sites and often occur near piers and rocky points.

Both male and female brown rockfish begin maturing at about three years old, at which time they are around 10 inches long. Half of these are mature at five years old, when they are about 12 inches long, and all are mature by age ten, when they are about 15 inches long. A 12-inch female will have approximately 42,500 eggs, a 15-inch female 76,600 eggs, and an 18-inch female 266,000 eggs. Maximum adult size is 22 inches.

Brown rockfish, *Sebastes auriculatus*.

Brown rockfish, as do all rockfish, bear their young live. Females release larvae into the pelagic environment during December and January, and may do so again during May and June. The larvae remain in the pelagic environment until they transform into juveniles, after which they enter benthic habitats near shore. Benthic juveniles are known to inhabit shallow water habitats, often in bays, and to migrate to deeper waters as they grow older.

Brown rockfish feed on progressively larger prey as they grow. During their early benthic stage, juveniles feed on small crustaceans, amphipods, and copepods, but when they grow to around 5 inches, shift to crabs and small fish. Adult brown rockfish (greater than 12 inches) feed on larger fish, shrimps, and crabs.

Little is known about predation on brown rockfish, but probably it is similar to predation on other rockfish species. Presumably, they experience the most predation during their pelagic larval and juvenile stages, and less predation as they grow larger. Probably adults are only occasionally taken as prey.

Status of Population

Without regular monitoring of catch data, there is no way to assess the brown rockfish population size. Currently, there are no indications of stress on these populations.

Peter B. Adams
National Marine Fisheries Service

References

Matthews, K. R. 1989. A comparative study of habitat use by young-of-the-year, subadult and adult rockfishes on four habitat types in central Puget Sound. Fish. Bull., U. S. 88(2):223-239

Ryan, C. J. 1986. Feeding habits of brown rockfish, *Sebastes auriculatus*, associated with a dock in San Francisco Bay, California. MS Thesis. San Francisco State University, San Francisco, California, 88 p.

SMB-26863

Washington, P. M., R. Gowan, and D. H. Ito. 1978. A biological report on eight species of rockfish (*Sebastes* spp.) from Puget Sound, Washington. NOAA, NMFS, Northwest and Alaska Fisheries Center Processed Report No. 256, 50 p.

COPPER ROCKFISH

History of the Fishery

Copper rockfish (*Sebastes caurinus*) occur only sporadically in California commercial catch records. Commercial landings of copper rockfish are small and often included in the category of "other rockfish"; however, three-month landings of over 14,000 pounds have been recorded from Eureka. Although currently there are no significant commercial landings of copper rockfish in the United States, they were reported as the most commonly caught fish in otter trawls in Puget Sound in the 1930's.

Copper rockfish are a small, consistent portion of the statewide recreation catch of rockfish, averaging from two to three percent. The catch has no apparent trend and ranges from a high of over 500,000 fish in 1980 to 238,000 fish in 1986. Approximately two-thirds of the California recreational caught copper rockfish are taken from Monterey south versus one-third from north of Monterey. Copper rockfish are a major component of the recreational fishery further north, particularly in the Puget Sound-British Columbia area.

Copper rockfish, ***Sebastes caurinus***.

Status of Biological Knowledge

The copper rockfish and the whitebelly rockfish (*S. vexillaris*) are virtually identical in appearance, except that the whitebelly rockfish tends to be more reddish. The meristics of the two species are the same, but there are chromosomal differences. Both are shallow water species usually found in rocky areas, but may be found as deep as 600 feet. Very limited tagging indicates that adult copper rockfish are strongly residential. The copper rockfish ranges from the Kenai Peninsula, Gulf of Alaska, to Monterey, and the whitebelly rockfish from Crescent City to San Benito Islands, Baja California.

Male copper rockfish begin maturing at three years old when they are about 12 inches; one-half are mature at four years old or 13 inches; and all are mature by seven years old or 16 inches. Females begin maturing at five years old or about 12 inches; one-half are mature at six years old or 13 inches; and all are mature by eight years old or 16 inches. A 13-inch female will have approximately 97,000 eggs, a 16-inch female 245,000 eggs, and a 20-inch female 654,000 eggs. The oldest copper rockfish found to date is 35 years old and is from Canadian waters.

In California, larvae are released from the female in February, but, in Washington and British Columbia, they are released in March and April. These fish remain as pelagic larvae and juveniles in offshore waters until May. From late May until July, juvenile copper rockfish first appear in kelp habitats high up in the water column, and later migrate to the bottom. As they grow, copper rockfish move into more typical adult rocky reef habitats.

Adult copper rockfish feed primarily on crabs and fish. Studies in Humboldt Bay found juvenile Dungeness crab to be a major part of their diet. Copper rockfish feed on small fish such as herring, anchovies, blennies, and small surfperch, but also on occasion have eaten spiny dogfish. Juvenile copper rockfish feed on calanoid copepods, caridean shrimp, and gammarid amphipods.

Like other rockfish, coppers are most vulnerable to predation as larvae and juveniles. During these stages, they are prey to salmon, lingcod, other rockfish, marine mammals and birds. As they grow older and larger, they are susceptible only to occasional predation by lingcod or marine mammals.

Status of Population

Although there are no population or mortality estimates for copper rockfish, there is no indication that stocks of this species are overfished in California waters. In the Gulf of Alaska and British Columbia, copper rockfish are the target of an expanding hook and line commercial fishery, and this fishery is having a significant impact on those stocks. If such a fishery were to develop in California waters, this species would require monitoring.

Peter B. Adams
National Marine Fisheries Service

References

Haldorson, L., and L. J. Richards. 1987. Post-larval copper rockfish in the Strait of Georgia: Habitat use, feeding, and growth in the first year. *In*: Melteff, B. R. (ed.), Proceedings of the International Rockfish Symposium, p. 129-141. Alaska Sea Grant Report 87-2.

Patten, B. G. 1975. Biological information on copper rockfish in Puget Sound, Washington. Trans. Amer. Fish Soc. 102(2):412-416.

Prince, E. D., and D. W. Gotshall. 1976. Food of copper rockfish, *Sebastes caurinus* Richardson, associated with an artificial reef in south Humboldt Bay, California. Calif. Fish Game 42(4):274-285.

Richards, L. J., and A. J. Cass. 1987. The British Columbia inshore rockfish fishery: Stock assessment and fleet dynamics of an unrestricted fishery. *In*: Melteff, B. R. (ed.), Proceedings of the International Rockfish Symposium, p. 299-308. Alaska Sea Grant Report no 87-2.

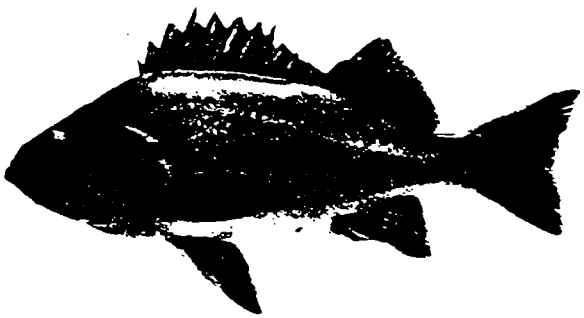
SMB-26864

CANARY ROCKFISH

History of the Fishery

The commercial trawl catch of canary rockfish (*Sebastes pinniger*) in California has declined from over two millon pounds to 183 thousand pounds in the nine-year period from 1981 to 1989. (Previous to 1981, rockfish landings were not recorded separately by species.) Eureka and Fort Bragg together contribute 88 percent of the canary rockfish trawl catch, which is only seven percent of the rockfish landings for Eureka, and eight percent for Fort Bragg. The only non-trawl commercial landings are in a small hook-and-line fishery that operates from San Francisco southward.

Canary rockfish represent a small but consistent portion of the sport catch. From 1979 to 1986, the average annual catch was 280,000 fish per year, slightly less than three percent of the total for all rockfish species. The average catch from Monterey northward was more than twice what it was to the south: 194,000 fish per year (five percent of the rockfish catch) as compared to 86,000 fish per year (one percent of the rockfish catch).



Canary rockfish, *Sebastes pinniger*.

Status of Biological Knowledge

Canary rockfish, referred to as orange rockfish in older reports, occur from Baja California to southeast Alaska. Their center of distribution is the Washington-British Columbia area, and in California they have commercial importance only as far south as Bodega Bay. Electrophoretic differences indicate that canary rockfish may have two separate subpopulations: one north, the other south of central Oregon. Canary rockfish have been caught at depths below 1,000 feet, but are taken in abundance only to 500 feet.

Canary rockfish grow rapidly until they reach maturity at about 16 inches, then more slowly to a maximum age of 60 years. Most populations have few individuals older than 20 years. For example, at one year, females average 6.7 inches and males 7.9 inches; at 4 years, females are 13.4 inches and males 13.8 inches; by age 12, females average 20.4 inches and males 19.7 inches. By age fifty they have added little length (females = 22.4 inches; males 21.2 inches.)

Females begin to mature sexually at 10.6 inches, reaching 50 percent maturity at 17.3 inches, and 100 percent maturity at 21.2 inches. Males begin to mature at 11 inches, reaching 50 percent maturity at 15.7 inches, and 100 percent maturity at 17.7 inches. A 10.6-inch female carries about 69,000 eggs; a 17.3-inch female about 489,000 eggs; and a 21.2-inch female about 1,113,000 eggs.

Canary rockfish are viviparous, meaning that the females bear free-living young and contribute some energy to their young while they are inside the mother. Males fertilize the females around December, and the females hold their young until December to March. Pelagic juveniles occur in the upper 100 feet of the surface waters from April to June. It is assumed that the juveniles descend to benthic habitats after mid-June.

Adult canary rockfish feed primarily on euphausiids. Next in importance as prey are fish: mainly myctophids and adult shortbelly rockfish which are most abundant in fall and winter diet. Gelatinous zooplanktors and associated hyperiid amphipods are common prey, but are a minor part of the diet. Pelagic juvenile canary rockfish feed on copepods, and euphausiid eggs and larvae.

Predation on canary rockfish is most severe during the pelagic larval and juvenile stages. Juveniles (one to three inches) are commonly found in the stomach contents of chinook salmon. Undoubtedly other predators of juvenile fish (other fishes, mammals and birds, including the common murre) prey on juvenile canary rockfish. After the juveniles descend to the benthos and become adults, they are much less vulnerable to predators.

Status of Population

The canary rockfish catch has declined sharply during the last ten years, particularly in Eureka. The mean length of canary rockfish has declined approximately 10 percent during this period at both Eureka and Fort Bragg. While estimates of population size or exploitation rates for canary rockfish in California waters are unavailable, these declines warrant increased surveillance of this species.

Peter B. Adams
National Marine Fisheries Service

References

Golden, J.T. and C. Woods. 1990. Status of canary rockfish in the INPFC Vancouver, Columbia, and Eureka areas and recommended ABC for 1991. *In* Pacific fishery management council: Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991. Appendix H, 44 pp..

Pearson, D.E. and S. Ralston. 1990. Trends in landings, species composition, length-frequency distributions, and sex ratios of 11 rockfish species (Genus *Sebastes*) from central and northern California ports (1978-88). NOAA-TM-NMFS-SWFC-145. 65 pp.

BANK ROCKFISH

History of the Fishery

From about Fort Bragg to the Mexican Border, bank rockfish (*Sebastes rufus*) are an important part of the commercial rockfish catch, taken primarily by gill net and otter trawls

equipped with roller gear, but also occasionally by hook and line. In recent years, this species has been among the three most commonly taken commercial rockfish species from Morro Bay southward. Until the late 1970's, they made up a very minor part of the fishery, but surged in importance as fishermen began to target rockfishes with monofilament gill nets and with otter trawls equipped with roller gear (the rollers allow the trawls to be towed over the hard bottom favored by bank rockfish). Until 1987, catch statistics from bank rockfish were grouped with those from all other rockfish species and so the exact poundage and value are unknown. In 1987, about 81,000 pounds, worth $33,000 (ex-vessel) were taken; in 1988, 114,000 pounds ($36,000) and, in 1989, 35,000 pounds ($9,376). They are also taken by sport fishermen fishing for deepwater rockfishes, but rarely do bank rockfish compose a majority of the catch.

Bank rockfish, *Sebastes rufus*.

Status of Biological Knowledge

Found from off Newport, Oregon to central Baja California, bank rockfish are common from about Fort Bragg southward into northern Baja California. These are midwater, aggregating fish, which live over hard bottom and on bank edges over depths of 102-810 feet. Fragmentary evidence suggests that juveniles usually inhabit waters shallower than adults. Mature fish are usually found in 600 feet or more.

Bank rockfish reach 20 inches. A few fish mature at 12-13 inches, 50 percent are mature by about 14 inches, and all are reproductive at 15 inches. These are slow growing fishes; some live to at least 50 years. Bank rockfish spawning occurs from December through May, peaking in January in southern California and in February in central and northern California. In southern California (but apparently not farther northward) females spawn two or more times per season. Females produce between about 65,000 and 610,000 eggs per season. Bank rockfish are midwater feeders, eating mostly gelatinous planktonic organisms such as tunicates, but also preying on small fishes and krill.

Status of Population

As of 1991, there had been no study of the status of the bank rockfish population.

Milton Love
University of California

References

Echeverria, T.W. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. Fish. Bull. US 85:229-250.

Love, M. S., P. Morris, M. McCrae and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: Sebastes) from the southern California Bight. NOAA Tech. Rept. NMFS 87, 38p.

OTHER NEARSHORE ROCKFISH

History of the Fishery

Several species of rockfish that inhabit nearshore rocky areas and kelp forests make small contributions to sport and commercial fisheries in California. Kelp rockfish (*Sebastes atrovirens*), black and yellow rockfish (*Sebastes chrysomelas*), gopher rockfish (*Sebastes carnatus*), China rockfish (*Sebastes nebulosus*), grass rockfish (*Sebastes rastrelliger*), and treefish (*Sebastes serriceps*) are the most commonly encountered species in this group. While some of these species are quite distinctive in appearance, others are difficult to distinguish; so catch records for these and other rockfish are often lumped (consciously or not) and records for the different species are frequently unreliable.

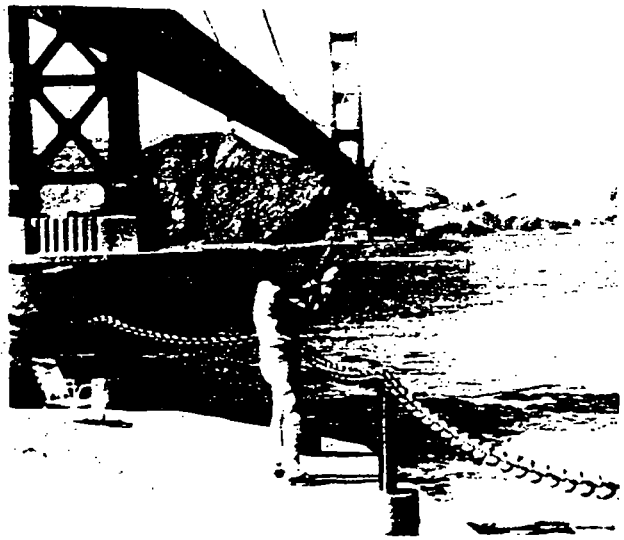
China rockfish, *Sebeastes nebulosus*.

Commercially, these species are taken largely by hook and line and sold unfilleted (and sometimes alive) in fresh fish markets. Landings during the period from 1987 (when the species were first segregated in summary statistics) to 1989, ranged from about 100,000 to 175,000 pounds and up to about $210,000 in value. Landings of misidentified individuals of other species, such as copper or brown rockfish, could be included in these figures.

The largest catches of these species are probably recreational. Their nearshore habits make them available to divers and to anglers working from shore, skiffs, and party boats. Because of its shallow depth distribution, the grass rockfish is best represented in the shore fishery. Kelp, black and yellow, gopher, and China rockfish are well-represented in catches by divers and skiff anglers. Gopher and China rockfish are relatively better represented in the party boat fishery, because of

SMB-26866

their deeper depth distributions. None of these species is the dominant component of any fishery, but as a group may contribute from one percent to over 20 percent of the total catch in these fisheries, and may make larger contributions in particular areas.



Angler fishing rocky area under the Golden Gate Bridge.

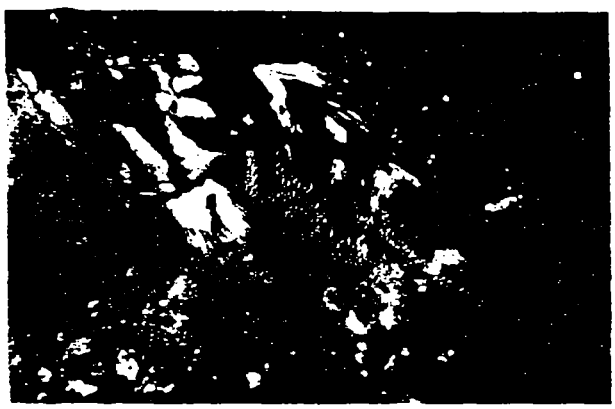
Several of these species are also important in non-consumptive uses. Colorful, accessible, or both, treefish and kelp, black and yellow, gopher, and China rockfish are frequently observed and photographed by divers.

Status of Biological Knowledge

Kelp, black and yellow, and gopher rockfish are relatively well-studied, while treefish, China rockfish, and grass rockfish are, to differing degrees, less well-known.

Most of these species occupy somewhat restricted ranges of geography or habitat. The treefish is most common in depths of less than 100 feet or so on rocky reefs, and is restricted largely to the region south of Pt. Conception. The kelp, black and yellow, and gopher rockfishes are not abundant north of Sonoma County, and range south to the region of Point Eugenia, Baja California. Each has a restricted habitat, with kelp rockfish occurring almost exclusively in kelp forests, black and yellow rockfish occurring in high-relief rocky bottom at depths shallower than about 60 feet, and gopher rockfish occurring on rocky reefs from 40 feet to perhaps 150 feet. The geographical range of the grass rockfish extends throughout California and into southern Oregon, but its habitat is restricted to rocky areas shallower than about 20 feet. The China rockfish is abundant into Washington, British Columbia, and southeastern Alaska, declining in abundance south into California. It is quite rare south of Point Conception, and seems to inhabit progressively deeper water in the southern part of its range.

Five of the six species are relatively small for rockfish. The grass rockfish, at about 20-22 inches, reaches the largest size of the six species. The largest individuals of the other five species rarely exceed 15-17 inches; among the five, the China rockfish may reach slightly larger sizes than the others, followed in rough order by treefish, kelp rockfish, and gopher and black and yellow rockfish. Grass rockfish and treefish have not been aged, and ageing for kelp, black and yellow, and gopher rockfish has been more complete than for China rockfish. These four species occasionally reach ages in excess of 20 years, and typically mature at three to four years of age. Treefish and kelp, black and yellow, gopher, and China rockfish appear to reproduce once per breeding season, and little is known of the spawning habits of grass rockfish. The latter four species seem to reproduce in winter-spring, later than many other nearshore rockfish. Kelp rockfish bear young the latest in the year, preceded by black and yellows and gophers. The period of parturition in China rockfish has not been defined as clearly as the others.



Gopher rockfish, *Sebastes carnatus*.

The adult movement of most of these species may be even more restricted than other rockfishes. Individual black and yellow, gopher, and kelp rockfish have been shown to inhabit restricted home ranges, and it is likely that grass rockfish, China rockfish, and treefish share this behavior. Aggressive behavior has been observed in all except grass rockfish (for which observations are limited), and gopher rockfish and black and yellow rockfish are definitely territorial. However, some evidence from artificial reefs suggests that typically sedentary individuals may occasionally wander indeterminate distances, on the order of tens of yards, from their home ranges.

Status of Populations

While there have been several studies of local abundance in some of these species (particularly black and yellow, gopher, and kelp rockfish), there is no comprehensive assessment of their populations. Each species is probably subject to local depression in abundance and average size where diving, skiff fishing, and party boat activity is concentrated. The low fecundity, restricted habitats, and limited movements of these species make them vulnerable to local fishing pressure. Depending on the extent of larval dispersal, however, areas with limited access for divers and skiffs may act as population reserves.

Ralph J. Larson
San Francisco State University

SMB-26867

References

Haaker, P. L. 1978. Observations of agonistic behavior in the treefish, *Sebastes serriceps* (Scorpaenidae). California Fish and Game 64:227-228.

Hallacher, L. E., and D. A. Roberts. 1985. Differential utilization of space and food by the inshore rockfishes (Scorpaenidae: *Sebastes*) of Carmel Bay, California. Environmental Biology of Fishes 12:91-110.

Larson, R. J. 1980. Competition, habitat selection, and the bathymetric segregation of two rockfish (*Sebastes*) species. Ecological Monographs 50:221-239.

Larson, R. J. 1980. Influence of territoriality on adult density in two rockfishes of the genus *Sebastes*. Marine Biology 58:123-132.

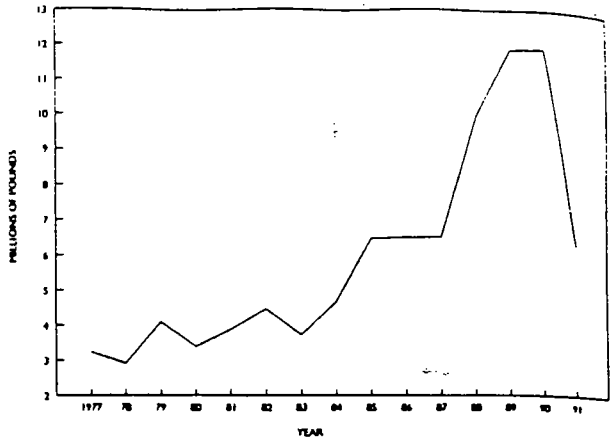
THORNYHEADS

History of the Fishery

The two species of thornyheads (genus *Sebastolobus*) in California waters are most abundant at depths where Dover sole and sablefish live. Shortspine thornyhead (*S. alascanus*) are taken by the commercial fishery at depths as shallow as 600 feet, and it is likely that thornyhead landings were predominately shortspine during the early years when the fishery operated in relatively shallow water. Longspine thornyhead (*S. altivelis*) were probably not landed in large quantities until later when the fishery expanded into deeper water. Although there are consistent differences between the two species, distinguishing between them can be difficult under field conditions. Landings and other data for each species may, therefore, be less reliable than data for thornyheads as a group.

From 1953 to 1969 total thornyhead landings in California ranged from just over 3,000 pounds to 900,000 pounds. Thornyheads became common as incidental catch when California trawlers began fishing intensively for Dover sole in the early 1970's. In 1970, total thornyhead landings in California exceeded one million pounds for the first time and averaged 2.8 million pounds per year from 1970 to 1979. Thornyhead landings increased to an average of six million pounds per year from 1980 to 1989.

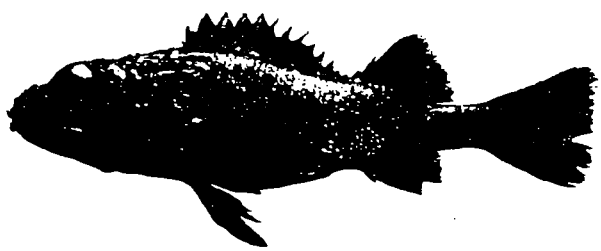
Thornyheads were originally marketed as a rockfish product (usually fillets) in domestic markets. Increased landings during the 1980's were the result of increased prices and demand for thornyheads, primarily as a headed and gutted product exported to Japan. Changes in species composition and markets for thornyheads occurred during the late 1980's as the fishery moved into deeper water to harvest longspine thornyheads. As export markets developed, prices paid to fishermen more than doubled from $0.17 to $0.40 per pound (all prices and revenues in 1989-equivalent dollars). Gross revenues for thornyheads landed in California rose from $576,000 in 1980 to $5,425,000 in 1990 as the result of increased prices and landings. The relative value of thornyheads in the groundfish fishery also increased during that time. Revenues from thornyheads were only 12 percent of total revenues for the deepwater fishery (thornyheads, sablefish, and Dover sole) during 1980, but increased to 39 percent by 1990.



California commercial landings of thornyheads, 1977-1991.

Fishing for thornyheads is typically by bottom trawl and longline gear in relatively deep water (1,800 to 3,000 feet) on sand or fine sediment. Fishermen report that there are areas where shortspine and longspine thornyheads are found together and other areas where longspine thornyhead predominate. Most of the thornyheads landed in California are taken in the Eureka, Fort Bragg, and Morro Bay areas. Few thornyheads are taken south of Point Conception. With the 4.5-inch mesh in cod ends currently used in the commercial trawl fishery, thornyheads become vulnerable to bottom trawls at about five to seven inches in length and at an age of about eight to nine years. Thornyheads are seldom taken by gill nets or in the recreational fishery because of the depths at which they live.

Thornyheads are managed by the Pacific Fishery Management Council under the Groundfish Management Plan. Shortspine and longspine thornyheads are managed as a group because of difficulties in separating the two species during fishing and in the landings. Catch quotas for thornyheads were first used in the fishery during 1990.



Shortspined thornyhead, *Sebastolobus alascanus*.

Status of Biological Knowledge

Thornyheads belong to the same family (Scorpaenidae) as the rockfishes (*Sebastes* spp.) but are distinguished from them in having more dorsal and head spines, in losing their swim bladder at the time they settle to the bottom, and in spawning gelatinous egg masses. Shortspine thornyheads grow to larger size and are found in shallower water than longspine thornyheads. The adults of both species are major components of the assemblage of fishes of the continental slope where they co-occur over a broad depth range of 1,600 to 4,900 feet. Both

SMB-26868

species have special enzymatic adaptations which allow metabolic activity despite the high pressure and low temperature at the depths where they live.

Shortspine thornyhead are found at depths of about 100 to over 5,000 feet along the west coast of North America from northern Baja California to the Bering Sea and across the north Pacific to the coast of Japan. It is not known if separate stocks exist. Off California, shortspine thornyhead spawn during late winter and early spring. Males off Alaska may spawn at about 6.5 inches in length (estimated age 5). About half of all females off California are sexually mature at 8.25 inches in length (estimated age 13) and almost all are sexually mature at 13.5 inches (estimated age 28). Estimates of ages are based on counts of growth rings in thin-sectioned otoliths. This approach has not yet been validated for either species of thornyhead, so all ages must be regarded as estimates. A female may release as many as 400,000 eggs annually in gelatinous egg masses that float to the surface. Larvae free themselves from the egg when about 0.25 inch in length and transform to juvenile fish at about 0.75 inch. Larvae and young juveniles are pelagic for 14 to 15 months and settle to the bottom when about one inch long during January to June of the year after they hatch. Juveniles settle in shallow water along the upper boundary of their habitat and move to deeper water as they grow. They spend the rest of their lives closely associated with the bottom.

Shortspine thornyheads can grow to 30 inches and may be quite long-lived. It is particularly difficult to determine the age of older individuals, but recent estimates indicate that the maximum age of shortspine thornyheads off California may be in excess of 100 years.

Shortspine thornyheads in Alaska are known to eat crustaceans, crabs, worms, clams, octopus, sea cucumbers, and fish. Longspine thornyheads feed primarily on polychaetes and small crustaceans.

Longspine thornyheads are found from Cape San Lucas, Baja California to the Aleutian Islands in water from about 1,000 to over 5,000 feet deep. It is not known if separate stocks exist.

Like shortspine thornyheads, longspine thornyheads spawn in the late winter and early spring. Half of the females are sexually mature at about 7.5 inches in length (estimated age 14) and most are mature at 8.75 inches (estimated age 18). A female may produce as many as 100,000 eggs annually, which, like the eggs of the shortspine thornyhead, are released in gelatinous egg masses that float to the surface. Two to four batches of eggs may be spawned each year. Larval fish are pelagic after hatching and transform into juveniles during July to December. Young juveniles are pelagic for as long as 20 months and begin settling to the ocean bottom when about two inches long. Settling starts during the summer of the year after they hatch. Juvenile longspine thornyheads settle on deeper bottoms than do shortspine thornyheads, with newly settled juveniles occupying a broad range of depths from approximately 1,600 to 4,000 feet. There does not appear to be a tendency for individuals to move deeper as they grow. Longspine thornyheads grow to a maximum length of 15 inches. Their maximum age is probably at least 45 years.

Status of Population

Recent estimates from research trawl survey data indicate that total biomass of thornyheads off California north of Point Conception is between 34,100 and 151,800 tons. Most of the total biomass (14,400 to 101,200 tons) probably consists of longspine thornyheads. The extent to which fishing has reduced abundance of thornyheads is not known since no information about historical biomass levels is available.

Sandra L. Owen
California Department of Fish and Game

Lawrence D. Jacobson
National Marine Fisheries Service

References

Best, E.A. 1964. Spawning of longspine channel rockfish, *Sebastolobus altivelis* Gilbert. Calif. Fish and Game. 50:265-267.

Jacobson. L.D. 1991. Thornyheads - stock assessment for 1991. Pages C1-C67 *in* Status of the Pacific coast groundfish fishery through 1991 and acceptable biological catches for 1992, Stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, OR.

Moser, H.G. 1974. Development and distribution of larvae and juveniles of *Sebastolobus* (Pisces; Family Scorpaenidae). Fish. Bull., U.S. 72:865-884.

Pearcy, W.G. 1962. Egg masses and early developmental stages of the scorpaenid fish, *Sebastolobus*. J. Fish. Res. Board Can. 19:1169-1173.

Wakefield, W.W. 1990. Patterns in the distribution of demersal fishes on the upper continental slope off central California with studies on the role of ontogenetic vertical migration in particle flux. Ph.D. dissertation. University of California, San Diego. 281 p.

CALIFORNIA SCORPIONFISH

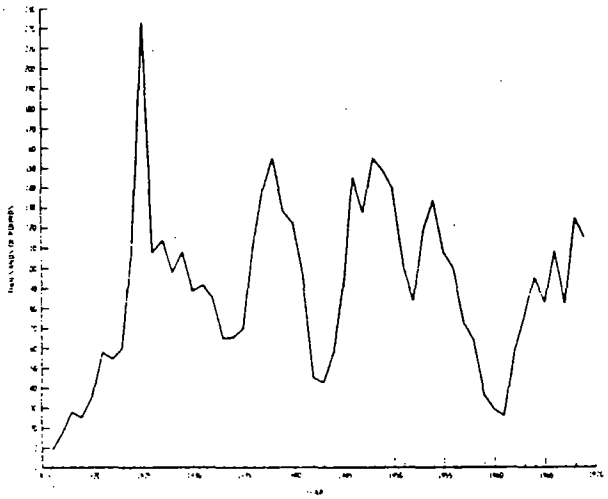
History of the Fishery

California scorpionfish (*Scorpaena guttata*) form a minor commercial fishery in California. They are taken almost exclusively with hook and line (primarily set lines) and incidentally by otter trawl and round haul nets; all fish are sold fresh. This fishery (in California centered between Santa Monica Bay and San Diego) has experienced a very long decline, with peak catches of 223,000 pounds in 1925. This was followed by a downward trend until 1933, when 64,100 pounds were landed. Commercial catches averaged 130,000 pounds from 1935-1940 but were under 100,000 pounds during World War II. Although the commercial catch rebounded in the late 1940's, catches never approached the previous peak year. Since about 1950, catches have fluctuated, but generally in a downward direction. Catches in the 1980's ranged from 17,000 to 62,000 pounds, worth between $16,000 and $51,000 to fishermen.

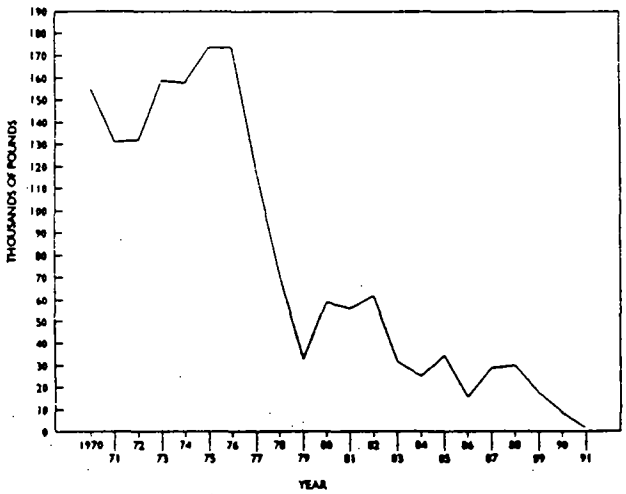
Currently, much of the catch is made by dory fishermen out of Newport, who specialize in this species. These fishermen concentrate their activities on the spawning grounds offshore of

SMB-26869

Long Beach. As the precise time of fish aggregation varies from year to year, occasional exploratory trips are made to the grounds beginning in May. Using long lines, the fishermen deploy 1,200-2,000 hooks on the bottom. The hooks (baited with anchovies, cut mackerel or other fish) are usually set about one hour before sunrise and pulled one to two hours later. Traditionally, almost all of the catch is made from June through August, when fishermen target spawning aggregations. The recent birth of a live fish fishery (where fish are delivered alive to restaurants and markets) has increased interest in this species, as scorpionfish are very hardy and quite popular with consumers.

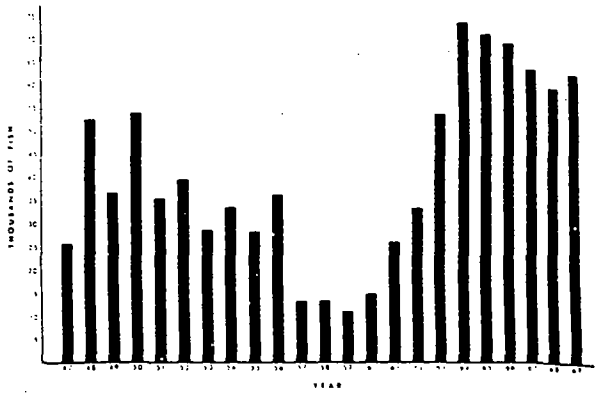


California commercial landings of scorpionfish, 1916-1969.

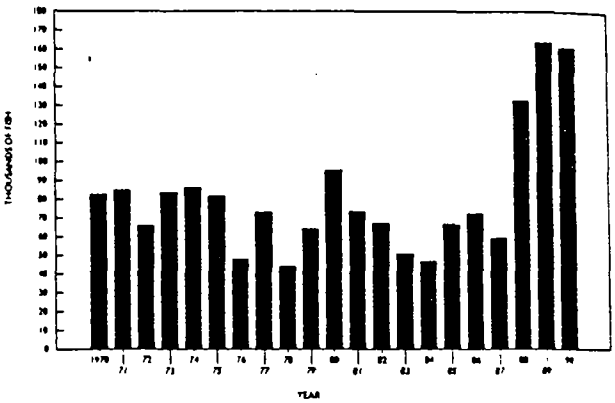


California commercial landings of scorpionfish, 1970-1991.

California scorpionfish are a moderately important part of the sport fishery in southern California. They are taken primarily aboard party and private vessels, occasionally from piers and jetties, mostly from Pt. Mugu southward. A creel census conducted in the mid-1970's indicated that this species ranked twelfth in abundance among all fish taken aboard sport fishing party vessels from Pt. Mugu southward.



California commercial passenger-carrying fishing vessel (CPFV) landings of scorpionfish, 1947-1969.



California commercial passenger-carrying fishing vessel (CPFV) landings of scorpionfish, 1970-1990.

Status of Biological Knowledge

California scorpionfish live from tide-pool depths to about 600 feet (usually in about 20-450 feet) from Santa Cruz south along Baja California and into the Gulf of California. Preferring warmer water, the species is common as far north as Santa Barbara. While they are most abundant on hard bottom (such as rocky reefs, sewer pipes and wrecks), they are also found on sand. California scorpionfish make extensive spawning migrations in late spring and early summer, when most adults move to 12 to 360 foot depths, forming large spawning aggregations on or near the bottom. Spawning occurs in the same areas year after year, and it is likely that the same fish return repeatedly to the same spawning ground. When spawning ends, the aggregations disperse and many (though not all) of the fish move into shallower waters.

California scorpionfish grow to 17 inches and some live at least 21 years. After four years of age, females grow faster than males and reach a larger size. Although a few fish mature at six inches (one year), over 50 percent are mature by seven inches (two years) and all reproduce by nine inches (four years). Spawning occurs from April to August, peaking in June and July. During spawning, scorpionfish aggregations rise up off the bottom, sometimes approaching the surface. Scorpionfish are oviparous, have external fertilization and females produce

SMB-26870

eggs imbedded in the gelatinous walls of hollow pear-shaped "egg-balloons." These paired structures, each five to 10 inches long, are joined at their small ends. The walls of these "balloons" are about 0.1 inch thick, transparent or greenish in color, and contain a single layer of eggs. Each egg is about .05 inch in diameter. The egg masses float near the surface and the eggs hatch within five days. Very young fish live in shallow water, hidden away in habitats with dense algae and bottom-encrusting organisms. Small crabs are probably the most important food of California scorpionfish, although other items, such as small fishes, octopi, shrimps and even pebbles are sometimes eaten. These animals are primarily nocturnal and catch food at night.

California scorpionfish, *Scorpaena guttata*.

The sharp spines on the dorsal, anal, and pelvic fins are poisonous. The toxin is produced in glands which lie at the base of each spine and run up to the tip through a groove. A wound, although painful, is seldom fatal, and the pain can be reduced by bathing the wound in hot water. The heat alters the toxin's structure making it harmless.

Status of Population

No population estimates exist for California scorpionfish. The decline in numbers of fish taken in the commercial fishery over the past 65 years is at least partly due to a decrease in the number of fishermen targeting this species (fishing effort), rather than an actual decrease in abundance. However, data from trawl studies conducted by the Southern California Coastal Water Research Project and the Orange County Sanitation District from 1974-1984 show that there are substantial short term fluctuations in California scorpionfish abundance within the southern California Bight.

Milton Love
University of California

Reference

Love, M. S., B. Axell, P. Morris, R. Collins and A. Brooks. 1987. Life history and fishery of the California scorpionfish, *Scorpaena guttata*, within the southern California Bight. Fish. Bull. US 85(1):99-116.

ROUNDFISH: DISCUSSION

The diverse roundfish group is composed of benthic (bottom-dwelling) and a few pelagic species which are typically harvested as an assemblage (with some notable exceptions such as Pacific hake). Roundfish form the mainstay of California's commercial trawl, trap, and line fisheries, as well as the commercial passenger fishing vessel fishery in central and northern California. The relative importance of this group to the southern California sport fishery is diminished by the seasonal availability of other desirable fish, such as tunas, jacks, and basses.

In 1990, the commercial roundfish fishery in California was worth $21.3 million dollars to the fishermen. Most of the commercially valuable roundfish, particularly rockfish, are marketed in fillet form. The marketing of line-caught rockfish and lingcod in whole, and even live, form has risen dramatically in recent years, due in part to a prohibition on the use of gill nets to take rockfish in state waters, declines in salmon troll fisheries, and heightened consumer demand for high-quality fresh fish in major urban centers.

This is a mature, relatively stable fishery, and pronounced landings fluctuations are unlikely in the foreseeable future. However, the unfished population of shortbelly rockfish in central California holds great fishery potential, for scientists estimate that at least 14,800 tons could be harvested annually. The domestic fishery for Pacific hake (marketed as whiting) off California could expand as well. Until the late 1980's, the hake population was only moderately exploited and a small shore-based trawl fishery existed in Eureka and Crescent City. But heightened foreign and domestic demand for headed-and-gutted whiting and the development of a surimi or minced fish product has caused greater landings and complete coastwide utilization of the fishable population. The Pacific Fishery Management Council (PFMC) has an allocation plan under development to apportion the available catch among shore-based, trawler/processor, and offshore processor sectors. Such a plan could benefit California's traditional shore-based hake fishery by providing an increased quota share to shore-based operations.

Most roundfish populations are at or near full utilization. In addition, the fishing power of vessels targeting roundfish has increased tremendously. Consequently, catch quotas, additional gear restrictions, and other regulations have become increasingly necessary to prevent overexploitation. In 1992, catch limits were applied to bocaccio, widow, chilipepper, and shortbelly rockfishes, sablefish, and Pacific hake. Future regulatory actions are likely to focus on user group conflicts, excess fishing effort, and other socio-economic issues. Currently, commercial/recreational user conflicts over rockfish catches on common fishing grounds and trawl/nontrawl disputes over sablefish catch allocations have engendered complicated depth, season, and area prohibitions, as well as contentious catch-sharing ratios. To curb surplus fishing effort, the PFMC plans to implement license limitation in the commercial groundfish fishery in 1994 and is studying the desirability of individual fishing quotas.

Francis D. Henry
California Department of Fish and Game

SMB-26871

ALBACORE

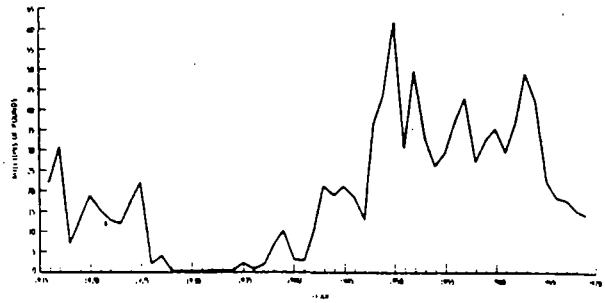
History of the Fishery

The albacore (*Thunnus alalunga*) is a highly migratory species valuable to commercial and sport fisheries in California. Commercial albacore fishing began off southern California near the turn of this century. In 1903, an experimental pack of 700 cases of albacore led to the development of the U.S. tuna canning industry. The fishery expanded quickly in response to the almost instantaneous high demand for canned tuna, which quickly outpaced the supply of albacore. By the 1920's, bluefin, yellowfin, and skipjack tunas were also being canned. However, albacore is the only tuna species which may be marketed as "white meat tuna," and it brings a premium price at the dock and in the can.

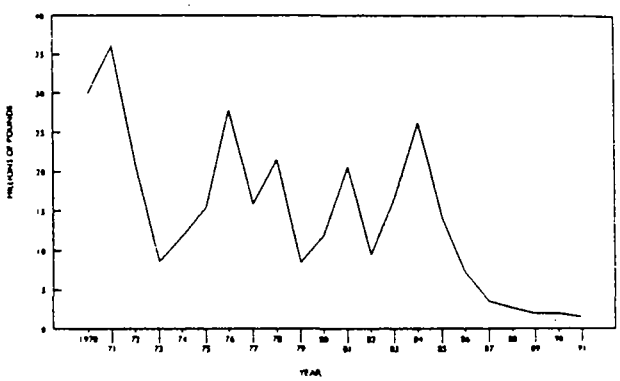
The geographic range of the U.S. north Pacific albacore fishery has expanded during the past eight decades. Early commercial fishermen made one-day trips within coastal waters off southern California. The fishery extended northward and seaward, and by the late 1930's it reached to waters off the Pacific northwest and several hundred miles offshore. There was a major offshore extension in the mid-1970's across the central Pacific to about the Dateline. However, beginning in the mid-1980's, there has been a general shrinking of the breadth of the fishery to within about 500-600 miles of the Pacific west coast.

Since the early 1980's, about 90 percent of the annual albacore catch has been made by trolling jigs and 10 percent by live-bait pole-and-line fishing. In earlier years, live-bait fishing sometimes accounted for up to 40 percent of the annual catch. In some years, up to a few hundred tons of albacore may be caught by purse seine vessels, usually incidental to bluefin tuna fishing. California-based drift gillnet vessels also catch small quantities of albacore incidental to shark and swordfish fishing. Generally, two fishermen conduct fishing operations from troll vessels and three to five fishermen from live-bait vessels. Many vessels which fish for albacore also take part in other fisheries. Their participation in the albacore fishery depends on the price and availability of albacore, the success of other fisheries, and weather conditions during the albacore season. In the 1940's, there were about 500 vessels in the albacore fleet. A high of 3,000 boats was reached in 1950; the number dropped to about 1,000 vessels by 1960, climbed to 2,100 vessels during the 1970's, and dropped to fewer than 500 boats in the late 1980's. The average size of albacore jigboats is about 45-50 feet, with a sea-keeping capability of about one to two weeks. In recent years, there has been a steady increase in vessels of 60-80 feet, which are capable of fishing at sea for six to eight weeks. The larger vessels may participate in a virtual year-round albacore fishery by fishing in mid-North Pacific waters, the North American coastal fishery, and in the recently established south Pacific albacore fishery.

The North Pacific albacore stock is also harvested by Asian fisheries, including a Japanese pole-and-line fishery in the spring, which targets two to five year old fish off the Japanese coast eastward to near the Emperor Seamount chain. There are also Japanese, Taiwanese and South Korean longline fisheries, which target five to seven plus year old albacore in subtropical and temperate waters across much of the Pacific during winter. Beginning in the early 1980's, Asian high-seas drift gillnet fisheries have targeted two to four year old albacore across much of the Pacific. In addition, there is a relatively small Canadian troll fishery for albacore during years when they are distributed in waters off British Columbia.



California commercial landings of albacore, 1916-1969.



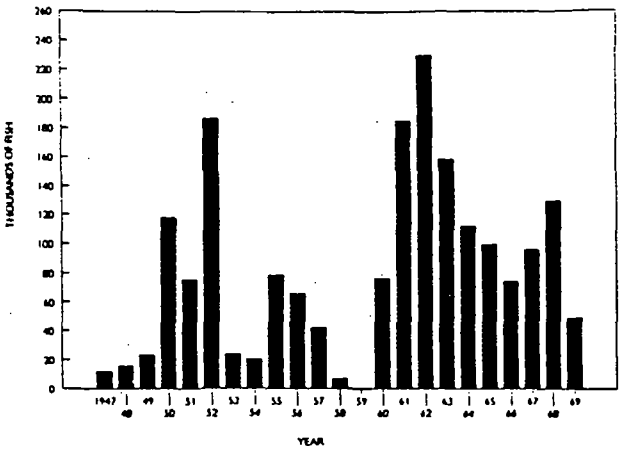
California commercial landings of albacore, 1970-1991.

In the late 1890's and early 1900's, sport fishermen on private boats would fish for large bluefin tuna inside the Channel Islands. The 10-20 pound albacore, which would strike the bait intended for a 100 pound bluefin, were considered a nuisance and were usually tossed over the side after landing. Gradually, some boats began to carry sports anglers as paying passengers, who quickly came to appreciate the fighting and eating qualities of the albacore, or "longfin tuna," as they are often called. The fishing for hire partyboats gained in popularity in southern California, and, by the 1950's, about 100-150 fished for albacore in nearshore waters.

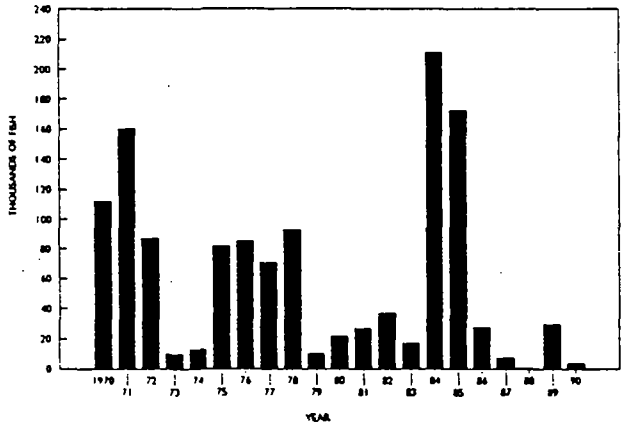
In the 1960's, the albacore runs began to shift outside the Channel Islands and to waters off upper Baja California, over 50 miles from southern California ports. In response to this, larger commercial passenger fishing vessels with a greater range were built. Today, there are about 40 large commercial passenger fishing vessels, mostly in southern California and some in the Morro Bay and San Francisco area, that are capable of carrying 20 to 60 sport fishermen on one to three-day fishing

SMB-26872

trips. In addition to the large vessels, there are about 50 to 60 smaller vessels that typically are chartered to smaller fishing parties of around six.



California commercial passenger-carrying fishing vessel landings of albacore, 1947-1969.

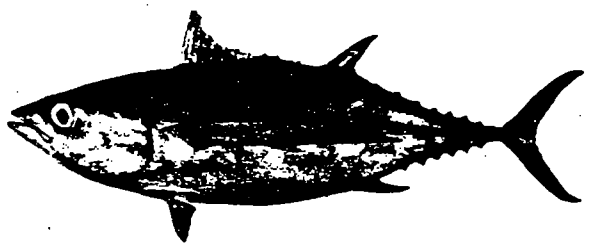


California commercial passenger-carrying fishing vessel landings of albacore, 1970-1990.

As the result of increased numbers of private boats, the ready availability of modern commercial passenger-carrying fishing vessels (CPFV), and improvements in sport fishing gear, albacore sport fishing has become increasingly attractive to California anglers. In fact, the first albacore of the season caught in southern California waters sets off "albacore fever" among recreational fishermen. No other sport fish in southern California elicits the excitement exhibited each year by the thousands of fishermen pursuing albacore. Over 120,000 anglers go out on southern California CPFVs in search of albacore during the course of a season. Albacore sport fishing in southern California contributes about $23 million to the local economy through the purchase of the boat ticket, tackle, food, gas, licenses, and lodging.

Status of Biological Knowledge

The albacore is a highly advanced teleost with many specialized adaptations. It is capable of thermoregulation, has a high metabolic rate, an advanced cardiovascular system, specializations in the circulatory system and blood/gas exchange systems, distinctive enzyme and complement systems, and high energetic costs for migration which may be partly met by utilization of stored fat.



Albacore, *Thunnus alalunga.*

The distribution of albacore is cosmopolitan in subtropical and temperate waters of all oceans. Off the coast of North America, the distribution during summer and fall months may range from lower Baja California, northward to the Queen Charlotte Islands, Canada, and occasionally into the Gulf of Alaska.

There is a growing body of evidence that the North Pacific albacore population is not as homogeneous as is usually assumed. Results from albacore tagging studies suggest that at least two proposed subgroups of fish constitute the North Pacific albacore population and that these subgroups have different migratory patterns, modal sizes in the U.S. fishery, growth rates, and peak spawning periods. While the subgroups are geographically separated and are differentiated by dissimilarities in biological or fishery statistic criteria, they are not believed to be genetically distinct.

Albacore make extensive movements during their lifetime. The degree of migration is geographically most expansive in the pre-adult ages between about two and five years. Fish of these ages may conduct trans-oceanic migrations in temperate and subtropical waters, following well-defined routes between the eastern and western or central Pacific. However, the spawning adults, above about six years, undertake relatively limited movements, mostly within the subtropical and tropical regions of either the western, central or eastern Pacific.

Results from extensive albacore tagging indicate that the northern subgroup of albacore is fished by the U.S. fishery north of about 40° N, the Japanese pole-and-line fishery in the western Pacific, and the Asian longline fishery. The southern subgroup appears to be fished by the U.S. fishery south of about 40° N, and the Asian longline fishery, but only to a limited extent by the Japanese pole-and-line fishery.

Based on physiological research findings, the normal habitat of albacore is within a temperature range of 50°-64° F, with dissolved oxygen saturation greater than about 60 percent. While individuals may temporarily move into waters outside of these values, thermoregulation and respiration functions will be adversely affected and operate marginally. The acoustic tracking of free-swimming albacore has demonstrated that albacore customarily live within the depths of the thermocline, rather than the upper mixed layer as has been generally presumed.

SMB-26873

The migration, distribution, availability, and vulnerability of albacore are strongly influenced by oceanographic conditions in the Pacific Ocean, notably oceanic fronts. The seasonal migration of albacore into North American coastal waters is associated with the North Pacific Transition Zone water and its frontal boundaries. In addition, oceanographic conditions also play an important role in the local concentrations and movements of albacore in coastal waters off North America. Albacore tend to aggregate on the warm side of upwelling fronts and move away from the fronts upon their disintegration in response to wind shifts unfavorable for upwelling. Satellite images of ocean color and sea surface temperature and concurrent albacore catch data clearly show that the distribution and availability of albacore off California are related to coastal upwelling fronts and that albacore are most abundant in warm, clear, blue oceanic waters near temperature and color fronts at the seaward edge of coastal water masses.

It is presumed that albacore aggregate in the vicinity of upwelling fronts to feed on small fishes, squids, and crustaceans that are plentiful in these areas. Yet it remains unclear what physical factors prevent albacore from crossing to the cooler side of these fronts in order to reach the highest potential forage biomass. Past beliefs have stressed confinement to a physiological optimum temperature range; however, explanations for environmental preferences of albacore are changing as new knowledge is acquired. The finding that albacore can regulate their body temperatures suggests that temperatures on the cool side of an upwelling front should not be limiting. Studies of free-swimming albacore in relation to ocean thermal structure, using acoustic telemetry and coincident oceanographic sampling, have shown that, while albacore would not cross from the warm side to the cool side of an upwelling front which had a horizontal sea surface temperature gradient of about a 4° F over a few miles, the fish would routinely swim through vertical temperature gradients up to about 18° F. The fish made extensive vertical excursions up to several hundred yards and crossed the thermocline in waters adjacent to the upwelling front. Recent research involving acoustic telemetry of freeswimming albacore, satellite measurements of ocean color and temperature, and oceanographic sampling of water optical and other characteristics, and potential forage abundance, indicates that water clarity as it affects the ability of albacore to detect prey is an important mechanism underlying the aggregation of albacore on the warm, clear sides of upwelling fronts.

Status of Population

Fishing effort and catch of albacore in the Japanese pole-and-line and the U.S. surface fisheries have declined, beginning in the early 1980's. In contrast, recent landings in the Japanese longline fishery have been relatively constant and there has been a rapid development of Asian gillnet fisheries that harvest large numbers of albacore in the North Pacific.

Several factors are associated with the decline in the traditional surface fisheries, but their relative importance is unknown. It appears that no single factor is responsible, but that the decline in catches is a result of complex interactions among factors, including (1) a reduction in overall fishing effort for albacore, (2) lack of fishing in areas of traditional high catch, (3) indications of population decline and (4) major anomaly patterns in oceanographic conditions across much of the North Pacific in the mid-1980's and early 1990's.

R. Michael Laurs and Ronald C. Dotson
National Marine Fisheries Service

References

Clemens, H.B. 1961. The migration, age, and growth of Pacific albacore (*Thunnus alalunga*), 1951-1958. Calif. Dept. Fish and Game, Fish Bull., 115, 128p.

Dotson, R.C. 1980. Fishing methods and equipment of the U.S. west coast albacore fleet. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-8, 126 p.

Laurs, R.M., P.C. Fiedler, and D.R. Montgomery. 1984. Albacore tuna catch distribution relative to environmental features observed from satellites. Deep-Sea Res., 31(9):1085-1099.

Laurs, R.M. and R.J. Lynn. 1977. Seasonal migration of North Pacific albacore, (*Thunnus alalunga*) into North American coastal waters: Distribution, relative abundance, and association with Transition Zone waters. Fish. Bull., U.S. 75(4):795-822.

Laurs, R.M. and J.A. Wetherall. 1981. Growth rates of North Pacific albacore, (*Thunnus alalunga*), based on tag returns. Fish. Bull., U.S. 79(2):293-302.

NORTHERN BLUEFIN TUNA

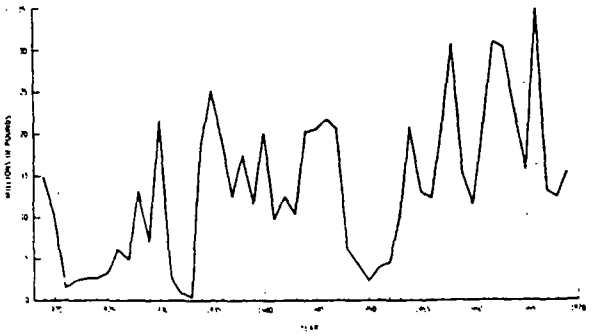
History of the Fishery

Fishing for northern bluefin tuna (*Thunnus thynnus*) began in California as a sport in 1898. Prior to World War I, many large fish were taken, particularly by vessels based at Catalina Island. The largest of these fish weighed 251 pounds. More recently, the average size of the sport-caught fish has been roughly 25 pounds, although large fish are still taken. Most of the sport-caught fish are taken by fishermen who are directing their efforts primarily toward albacore.

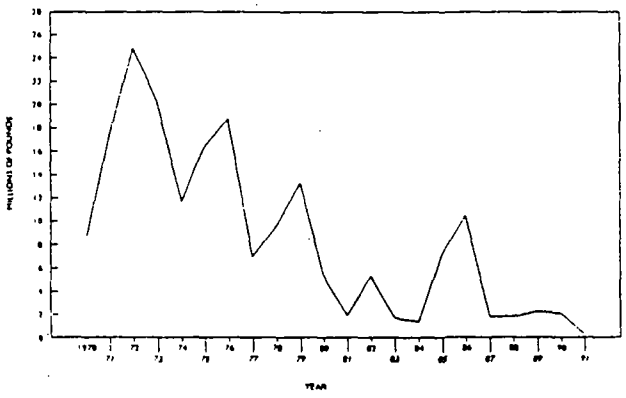
The commercial fishery for northern bluefin began in 1918. Since bluefin are rarely caught by the troll, baitboat, or gillnet fisheries, the catches by purse seiners have far exceeded those by any other type of gear. From 1918 until about 1960, most of the vessels were relatively small, with capacities less than about 200 short tons. None of them fished exclusively for bluefin. The smaller ones, sometimes referred to as wetfish vessels, fished chiefly for sardines, mackerel, and pelagic fish other than tropical tunas, and the larger ones fished mostly for yellowfin and skipjack. During 1959 and 1960, most of the larger tuna baitboats were converted to purse seiners and, during the ensuing years, many new purse seiners were built. During the 1960's, 1970's, and 1980's, many of the smaller, older vessels sank or dropped out of the fishery, and the new vessels which replaced them tended to be larger. As a result, there are now more larger purse seiners and fewer smaller ones than there were during the early 1960's. Bluefin are now taken by vessels of all sizes, but the smaller ones (capacities less than about 400 short tons) account for a proportionally larger share

SMB-26874

of the catch. The proportion of the bluefin catch made by the wetfish fleet is less now than it was during the early years of the fishery, because increased exploitation in the southern half of its range has shifted the center of abundance of the bluefin population southward beyond the area where these vessels normally fish. Most of the fish caught by purse seiners weigh less than about 50 pounds, but larger ones are sometimes caught, including one weighing 1,009 pounds.



California commercial landings of bluefin tuna, 1918-1969.

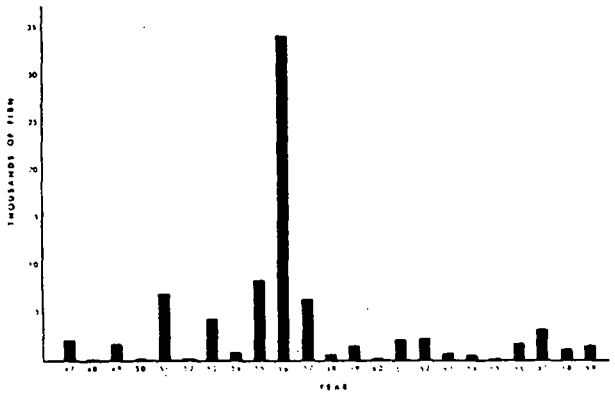


California commercial landings of bluefin tuna, 1970-1991.

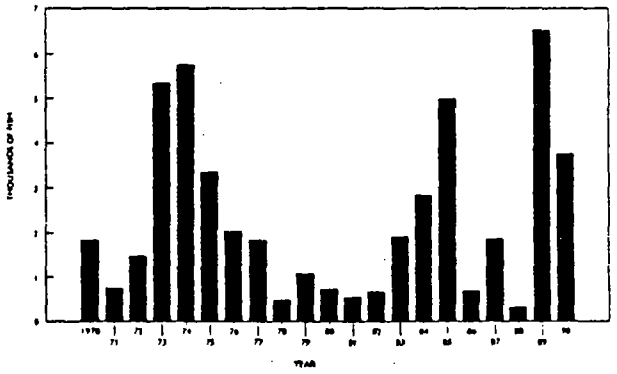
Most of the information regarding distribution of the catches of northern bluefin by tuna purse seiners has been obtained from the logbook records of these vessels. Bluefin are rarely encountered south of Cabo San Lucas, Baja California, or north of Point Conception, California. Within this area, a considerable change has taken place during the 20th century. Until 1930, fishing was conducted only off California. During that year, bluefin were discovered off Isla Guadalupe, Baja California, and about 40 percent of the catch was made in that area. From 1930 through 1947, fishing was conducted off California and Baja California, but in most years the majority of the catch came from off California. From 1948 to the present, however, most of the catch has been made off Baja California. The average annual catches made off California during the 1960's, 1970's, and 1980's have been considerably less than the average annual catches made in the same area during the 1918-1929 period. This may be because, during more recent years, the larger vessels fishing off Baja California have tended to intercept the fish before they reach the waters off California.

During January through April, there are typically only light and sporadic catches. Most of these are made off the coast of Baja California between 24° N and 26° N and in the vicinity of Isla Guadalupe. In May and June, the catches increase, and most of them are made between 24° N and 27° N. In July, the fishing area spreads to the north and is at its broadest distribution of the year; most of the catch is made between 25° N and 33° N. In August, there are usually only light catches at the southern end of the fishing area, most of the catch being made between 28° N and 33° N. In September, most of the catch is made in the same area as in August, but the amount of catch is usually considerably less. In October, the catches continue to decline, and most of them are made north of 30° N. In November and December, as in the first months of the year, the catches are light and sporadic.

Small amounts of northern bluefin are caught off the California coast by drift gillnets and further offshore by longline vessels. Extremely large bluefin are caught in some years off southern California, principally during November and December. Nearly 1,000 such fish were caught during the period from October 31, 1988 to January 3, 1989. Most of these were flown to Japan, where they brought high prices.



California commercial passenger-carrying fishing vessel landings of bluefin tuna, 1947-1969.

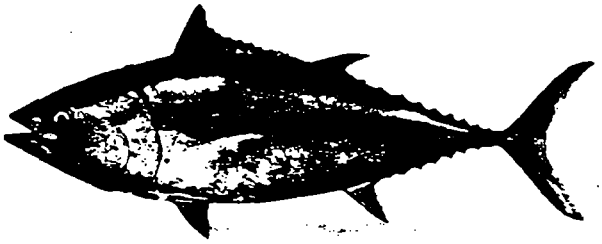


California commercial passenger-carrying fishing vessel landings of bluefin tuna, 1970-1990.

The total annual catches of northern bluefin by commercial and sport vessels in the eastern Pacific Ocean prior to 1918 were

SMB-26875

negligible. The data for 1918 through 1960 include only the catches landed in California, but it is believed that the catches landed elsewhere prior to 1961 were inconsequential. The subsurface catches are not included in the figure, but these are also believed to be inconsequential. The catches tended to be greater during the 1960's and 1970's than during the previous period, probably because of the conversion during 1959 and 1960 of most of the tuna baitboats to purse seiners, and the addition of many new purse seiners to the fleet.



Bluefin tuna, *Thunnus thynnus*.

Status of Biological Knowledge

Spawning of northern bluefin occurs between Japan and the Philippines in April, May, and June, off southern Honshu in July, and in the Sea of Japan in August. The larvae, postlarvae, and juveniles produced south of Japan are carried northward by the Kuroshio Current toward Japan. Fish in their first year of life, about six to 24 inches in length, are caught in the vicinity of Japan during the summer, fall, and winter. The results of tagging experiments indicate that some of these remain in the western Pacific Ocean and others depart for the eastern Pacific during the fall or winter of their first year of life or the summer, fall, or winter of their second year of life. The journey from the western to the eastern Pacific takes as little as seven months, or perhaps even less.

The fish which migrate from the western to the eastern Pacific form the basis for the fishery in the eastern Pacific. Most of the fish caught are in their second or third year of life, but some older, larger fish are also taken. After a sojourn in the eastern Pacific, which may or may not be interrupted by temporary visits to the central or western Pacific, the survivors return to the western Pacific, where they eventually spawn. Spawning first occurs at about five or six years of age.

The approximate length and weight attained by northern bluefin at various ages are: age 1, 23 inches and 10 pounds; age 2, 33 inches and 28 pounds; age 3, 43 inches and 60 pounds; age 4, 53 inches and 109 pounds; and age 5, 63 inches and 177 pounds.

Northern bluefin consume many species of fish and invertebrates in the eastern Pacific, including anchovies, red crabs, saurles, squid, and hake. Red crabs are a significant part of the diet only south of 29° N. "Boiling" and jumping schools of fish are much more common north of that latitude, where fish are the principal item of the diet. The differences in behavior in the two areas could be due to differences in the food, *i.e.*, filter feeding might be employed for feeding on red crabs, while pursuit of individual fish would be required for feeding on fish. Japanese scientists have reported that bluefin are heavily dependent upon sardines for food in the western Pacific. Albacore, yellowtail, barracuda, and mackerel compete with northern bluefin for food in the eastern Pacific.

Status of Population

There has been a decline in the catches of northern bluefin in the eastern Pacific in recent years. Catch data, length-frequency data, and data on fish tagged in the western Pacific and recaptured in the eastern Pacific suggest that this decline is due to a decrease in the availability of bluefin in the eastern Pacific (*i.e.*, a decrease in the proportion of the population which has migrated to the eastern Pacific).

William H. Bayliff
Inter-American Tropical Tuna Commission

References

Bayliff, William H. 1980. Synopsis of biological data on the northern bluefin tuna, *Thunnus thynnus* (Linnaeus, 1758), in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 2: 261-293.

Bayliff, William H. 1991. Status of northern bluefin tuna in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 7:29-88.

Bayliff, William H., Yoshio Ishizuka, and Richard B. Deriso. 1991. Growth, movement, and attrition of northern bluefin tuna, *Thunnus thynnus*, in the Pacific Ocean, as determined by tagging. Inter-Amer. Trop. Tuna Comm., Bull., 20(1):1-94.

Calkins, Thomas P. 1982. Observations on the purse-seine fishery for northern bluefin tuna (*Thunnus thynnus*) in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 18 (2): 121-225.

YELLOWFIN AND SKIPJACK TUNAS

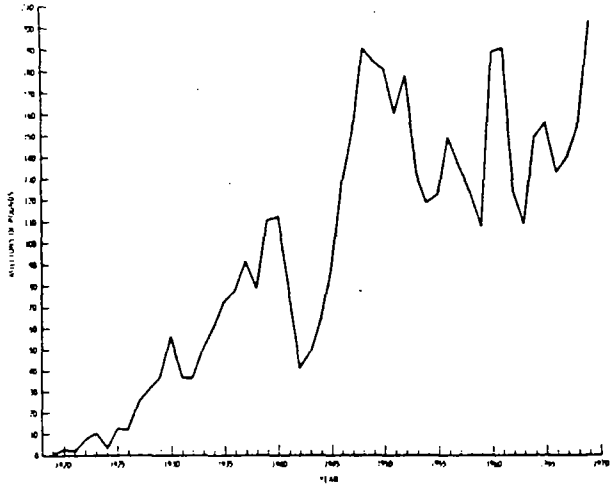
History of the Fishery

The failure of the historic sardine runs off southern California in 1903 reputedly led to the development of the tuna fisheries. Tuna was first canned in California in that year, and by 1907 the industry was well established. Initially, it depended on albacore for raw material and developed at a moderate rate until landings became erratic. As a result, the fishery expanded southward along the coast of Baja California and the Mexican mainland, turning toward yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) tunas in search of steady supplies to satisfy increasing demand. The spectacular decline of the albacore fishery in 1926, and its almost complete failure in 1928, caused the industry to rely more heavily on yellowfin and skipjack, and these two species became of major importance.

During the early days of the fishery, boats were small and catches were preserved on ice. With these limitations, the tuna caught from southern California south along the coast of Baja California and the mainland of Mexico were captured near shore and on outlying banks and islands. The bait used to attract the tuna was also caught near shore and carried alive aboard the baitboats for use in the pole-and-line fishery. In 1927, the first two tuna clippers, large baitboats over 100 feet in length, were constructed. In time, the larger boats began to explore further

SMB-26876

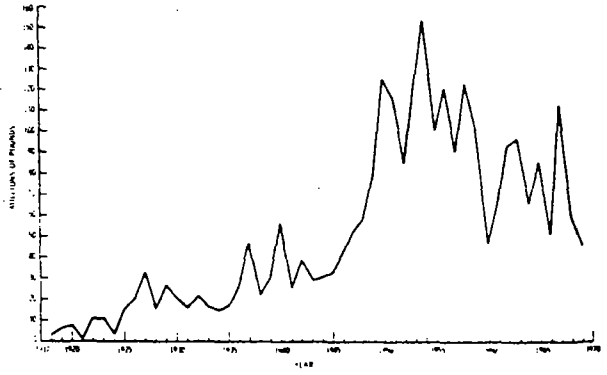
offshore. Fishing was conducted at the equator by 1931, and by 1934 some vessels expanded operations to the Gulf of Panama and Galapagos Islands; some went still farther south to Peru Bank by 1950.



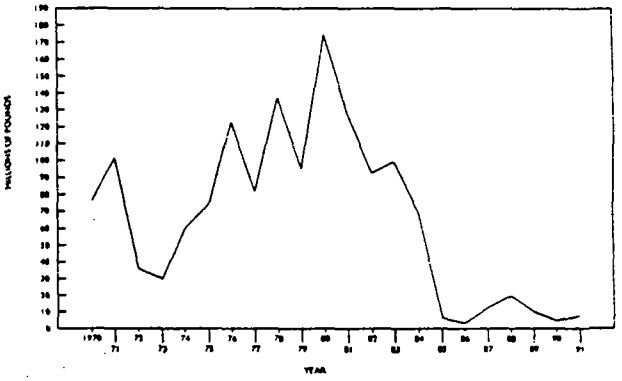
California commercial landings of yellowfin tuna, 1918-1969.

California commercial landings of yellowfin tuna, 1970-1991.

The development of brine refrigeration in the late 1930's contributed to the geographical expansion of the fishery by permitting vessels to increase in size and stay at sea for longer periods, thereby also increasing their range. Developments prior to 1957 that also helped fishing operations included radio telephones, depth meters, direction finders, and the periodic use of airplanes with floats. During the mid-1960's some of the larger vessels in the fleet also began using helicopters to search for fish. In 1957, however, the evolution of strong light-weight nylon netting and the introduction of the power block for rapidly hauling such large nets, set in motion the irreversible and rapid conversion of baitboats to purse seiners. This new gear, much more efficient than baitboats, relied on encircling fish schools with a vertical wall of suspended netting that could also be pursed at the bottom to prevent escape. The development of this gear also hastened the production of new vessels such that the ratio of purse seiners to baitboats that existed in 1961, 124 to 93, peaked in 1979 at 268 to 45. Since then, the number of surface vessels of all nations operating in the eastern Pacific Ocean has consolidated to the 1989 ratio of 172 seiners to 30 baitboats, with total capacities of 133,500 and 3,000 tons, respectively. The development of the purse seine eliminated the previous dependence on bait and liberated the tuna fleet to search for fish far offshore. By 1968, vessels had penetrated the eastern Pacific as far west as 115° W longitude, and continued fishing success stimulated further expansion to about 145° W by 1974. At present, and with the exception of the area around French Polynesia, the fishery for yellowfin and skipjack tunas in the eastern Pacific includes the tropical and subtropical regions between 150° W and the mainland of the Americas.



California commercial landings of skipjack tuna, 1918-1969.

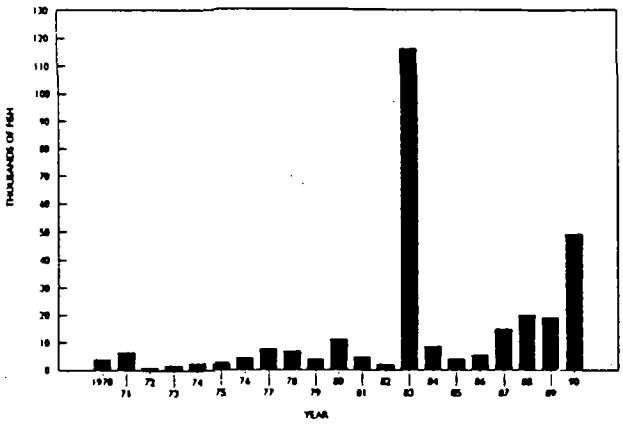


California commercial landings of skipjack tuna, 1970-1991.

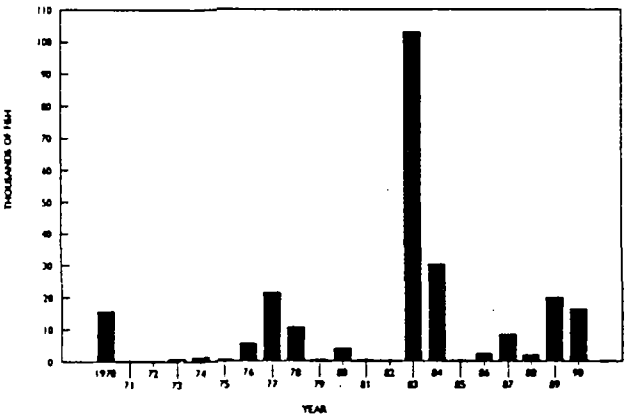
The U.S. Pacific tuna fleet based in southern California developed to legendary proportions through many decades of enterprise and innovation. As an integrated industry involving nearly 2,000 fishermen, about 6,000 additional employees were also engaged in canning, boat building and repair facilities. Over the brief span of two years, however, from 1982 through 1984, the major canneries in southern California relocated outside the continental U.S., and the presence of this major industry virtually disappeared from the area. The total number of U.S. baitboats and purse seiners fishing in the eastern Pacific also declined from the average values of 150 and 184 vessels in the 1960's and 1970's respectively, to an average of 74 during

SMB-26877

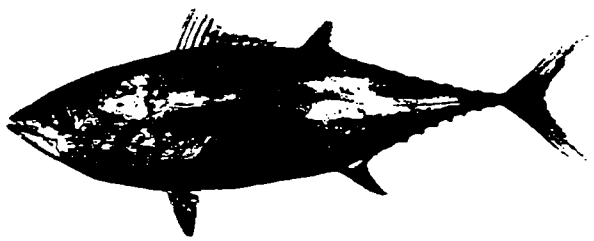
the 1984-1989 period. Approximately 75 percent of the purse seiners registered in California now fish in the western Pacific, and transship or unload their catches to canneries in Asia, American Samoa, various ports in Central and South America, and Puerto Rico.



California commercial passenger-carrying fishing vessel landings of yellowfin tuna, 1970-1990.



California commercial passenger-carrying fishing vessel landing of skipjack tuna, 1970-1990.



Yellowfin tuna, *Thunnus albacares*.

Status of Biological Knowledge

The distribution of adult yellowfin is widespread in the tropical Pacific, ranging north and south into temperate waters during warm months when sea-surface temperatures are in the mid-70's. In the eastern Pacific, individuals have been recorded from northern Chile to southern California. Skipjack tuna are cosmopolitan in distribution; they tolerate cooler water than yellowfin and range throughout the tropical and temperate seas. In the eastern Pacific individuals have been recorded from northern Chile to Cape Blanco, Oregon.

Tunas generally travel in schools varying in size from a few fish to several hundred tons. Individuals of similar size tend to school together; however, at times there is considerable variation in the sizes of tuna in a school. The yellowfin and skipjack in mixed schools tend to be similar in size, but the sizes of yellowfin in pure schools are more variable. Although yellowfin are found in association with dolphin during the daytime to some degree in all the world oceans, the relationship is particularly well developed in the eastern Pacific. In contrast, few skipjack associate with dolphins in any locality.

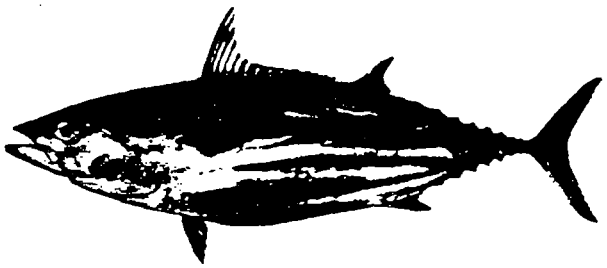
Experiments in which yellowfin have been tagged and recaptured at a later date indicate that there is a single population in the eastern Pacific. Seasonal migrations appear to be primarily along the coast, with some mixing offshore. There is no large-scale movement offshore, and to date no yellowfin tagged in the eastern Pacific has been recovered in the central or western Pacific. Skipjack represent a more complex situation in that the fishery in the eastern Pacific is supported by migration from the central Pacific. There appear to be two entry points, one group entering the eastern Pacific to the north near Baja California, and the other spreading southward toward Central and South America. Skipjack enter the fishery when they are about one to one and a half years old, and after several months most are thought to return to the central Pacific to spawn at the age of two to two and a half years. The skipjack in the northern group move north along the Baja California coast during spring and early summer, and southward in late summer and fall. The southern group that appears mostly off Panama also undergoes seasonal movements northwest to Central America and southward to Ecuador, Peru and northern Chile.

Yellowfin spawn across the Pacific in tropical and subtropical waters, generally at temperatures above 78° F, and the larvae are found year round near the equator. In the eastern Pacific, although spawning takes place all year, there are peaks that occur in different areas at different times. The spawning intensity off the coasts of Mexico and Central America results in two major seasons, but it is more evenly distributed farther offshore. The proportion of fish that are spawners also appears to be greater offshore than near the coast. On the other hand, although skipjack larvae are also more abundant in equatorial regions, their numbers increase from east to west across the eastern Pacific. During late winter and spring months some skipjack spawning takes place off Central America, and during April through November, off Baja California. Yellowfin larvae are known to migrate to the surface during the daytime, but skipjack larvae prefer to do so at night.

Several different methods have been used to estimate the ages of yellowfin and skipjack tunas. These have included tagging, the markings on hard parts, such as otoliths, vertebrae and scales, as well as the growth over time of recognizable size groups of fish. The estimated sizes of both sexes of yellowfin during the first five years are 19, 35, 50, 61, and 67 inches.

SMB-26878

respectively. After reaching maturity, female yellowfin tend to grow more slowly than males, and most females have also disappeared from the fishery by the time they are about three and a half years old. In the eastern Pacific, yellowfin females can begin to mature when they are nearly two years old, producing one million eggs at that age. Their fecundity increases rapidly, though, such that the average three-year old produces five million eggs. In the eastern Pacific, the estimated lengths of skipjack during the first four years are 17, 27, 33, and 36 inches, respectively. Skipjack females mature earlier than yellowfin, at about one year or older. Their fecundity also increases with size, a 24-inch female producing 400,000 eggs compared to about one million for a 29-inch fish.



Skipjack tuna, *Katsuwonus pelamis*.

Status of Population

During the mid-1960's, the increasing number of vessels and the efficiency of the emerging purse-seine fleet began to reduce the nearshore abundance of yellowfin in the eastern Pacific. The catch limits recommended by the international body conducting fisheries research in the region, the Inter-American Tropical Tuna Commission, were first implemented in 1966, and annual quotas were in effect thereafter until 1979. The fishery began to recover in the late 1960's as the fishery simultaneously expanded offshore, but during most of the 1970's the fishermen began to concentrate more on catching younger and smaller fish than larger adults. Although the offshore expansion helped to increase the tonnage caught, the net effect was a steady erosion of the overall number of fish. This situation came to a head in 1982 when the declining harvest was further reduced by adverse environmental conditions, and a substantial portion of the fleet moved to the western Pacific, where a number of vessels had been fishing successfully for several years. The absence of heavy fishing on the eastern Pacific stock, and successive years of exceptional survival of young fish, brought about the recovery of the stock. By 1985, as fishing activity in the eastern Pacific began to increase again, the fishermen also concentrated on catching the larger and older fish rather than the smaller fish that had not reached their full growth potential. As a result, the total catch during 1987 through 1989 averaged 315,000 tons per year, a quantity that exceeded all previous records.

Yellowfin is the principal tuna species harvested in the eastern Pacific, and the catches of skipjack are therefore frequently influenced by the amount of effort directed toward yellowfin. While this accounts for some of the annual variability in skipjack catches, the most important factor is that the catch is dependent upon the variable amount of immigration from the central Pacific. The catches in the southern fishery are generally about twice as large as those in the north, but frequently the improvement in one region is partially offset by a decline in the other. This may be due to the influx of young fish from the central Pacific favoring different regions. The relative abundance of skipjack declined during the early 1970's, as did that of yellowfin, but it recovered during the latter part of the 1980's. The average catch of 88,000 tons during 1987 through 1989 compares favorably with the average of 65,000 tons during the 1960's. Consequently, the historic levels of fishing intensity and past events do not seem to have a predictable influence on the future abundance of skipjack.

Alex Wild
Inter-American Tropical Tuna Commission

References

Bayliff, W.H. 1984. Migrations of yellowfin and skipjack tunas released in the central portion of the eastern Pacific Ocean, as estimated from tagging data. Inter-Amer. Trop. Tuna Comm., Internal Rep., 18:107p.

Joseph, J., and T.P. Calkins. 1969. Population dynamics of the skipjack tuna (*Katsuwonus pelamis*) of the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 13(1):1-273.

Matsumoto, W.M., R.A. Skillman and A.E. Dizon. 1984. Synopsis of biological data on skipjack tuna, *Katsuwonus pelamis*. NOAA Tech. Rep. NMFS Circular 451:92p.

Suzuki, Z., P.K. Tomlinson and M. Honma. 1978. Population structure of Pacific yellowfin tuna. Inter-Amer. Trop. Tuna Comm., Bull., 17(5):273-441.

Wild, A. 1986. Growth of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean based on otolith increments. Inter-Amer. Trop. Tuna Comm., Bull., 18(6):423-482

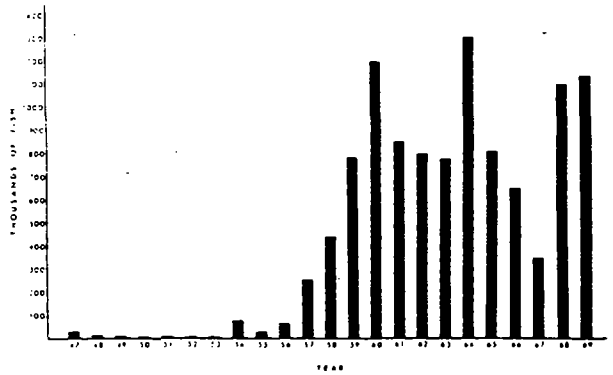
PACIFIC BONITO

History of the Fishery

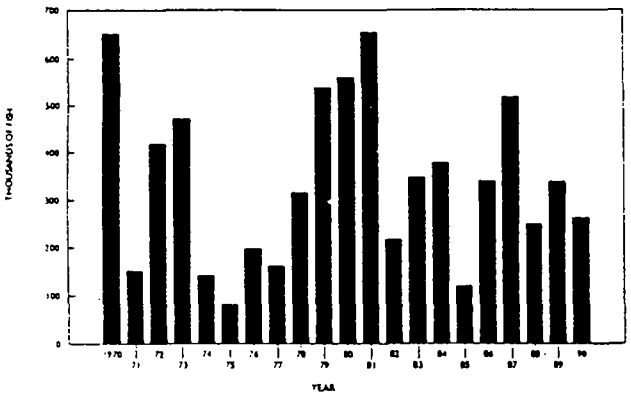
The Pacific bonito (*Sarda chiliensis*) has been ranked as one of the top 10 species sought by recreational fishermen in southern California. With the expansion of the commercial passenger fishing vessel (CPFV) industry after World War II, recreational fish catches increased from a few thousand in 1947 to over one million fish in 1960. Bonito, an important mainstay of that industry, was ranked fourth in importance among recreational fishes of southern California by CPFV landing operators.

During the 1980's, more than one-half of the bonito catch was made from private boats as this method of angling became increasingly popular. Recreational catches have ranged from 352,000 to 2.7 million bonito per year. Of these, annual CPFV landings ranged from 120,000 to 654,000 fish. The bulk of the catch consists of one-year-old bonito approximately 18 inches long. During fall and spring migrations, larger two-year-old

fish become available to anglers. About five to ten percent of the landings consists of fish larger than 24 inches.



California commercial passenger-carrying fishing vessel landings of Pacific bonito, 1947-1969.

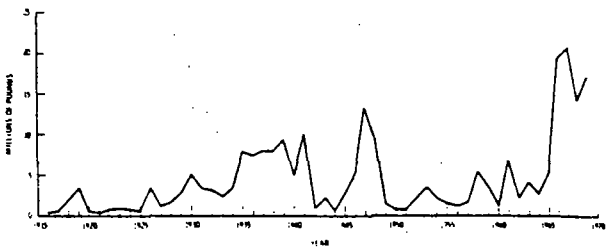


California commercial passenger-carrying fishing vessel landings of Pacific bonito, 1970-1990.

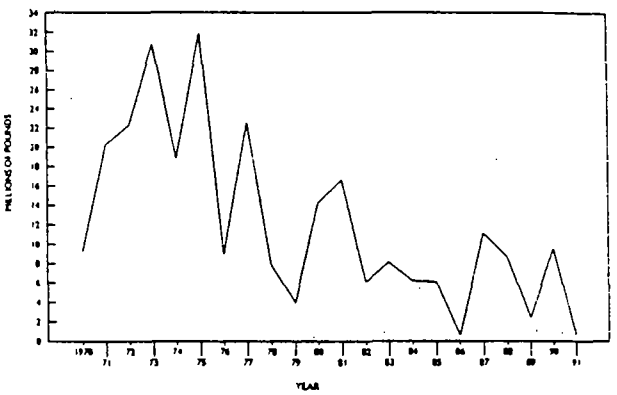
The concentration of angling effort off populous southern California probably accounts for over 75 percent of the catch being taken from coastal waters extending from Malibu Beach to the Coronado Islands. However, bonito extend their range northward with warming sea temperatures, and during the 1982-1983 El Niño an estimated 70,000 fish were caught off northern California. Significant catches were also made there in 1984 and 1986.

Bonito are well known for their fighting ability. They are taken by anglers using live anchovies or sardines for bait, or by casting or trolling with metal lures and feather jigs. The blood-rich muscle tissue of bonito degrades rapidly after capture, and some anglers do not keep them for food. Immediate bleeding and refrigeration will maintain bonito as a high quality food fish.

The major commercial fishing gear for bonito is the purse seine. The purse seine fleet consists of two general groups: the local "wetfish" vessels with fish load capacities of 30-100 tons, and the larger tuna seiners capable of carrying 150-500 tons. Wetfish boats harvest mackerel and sardines, but seasonally target bonito, squid, and bluefin tuna. Nearly all of these wetfish seiners are based in San Pedro and fish in the Santa Barbara and San Pedro channels. The large tuna seiners, now all but absent from California, operated primarily in the tropical waters off Mexico and Central and South America. Although the primary target was yellowfin tuna, these fishermen often took bonito while returning to the United States to help compensate for a poor tuna catch. Also, during the 1970's, seasonal closures were placed on the directed take of yellowfin tuna. Bonito were harvested by these vessels so that an incidentally allowed catch of the more valuable tuna could be landed.



California commercial landings of Pacific bonito, 1916-1969.



California commercial landings of Pacific bonito, 1970-1991.

Historically, commercial landings of bonito have fluctuated from 127,000 to over 30 million pounds per year. During the 1980's, landings varied between 533,000 and 16.6 million pounds. By total weight, bonito currently ranks among the top 20 species landed by California fisheries. Market demand or price, and the availability of other desirable species usually determine the amount of bonito landed. A trend of increasing prices, from $50 to $90 per ton in the 1960's, peaked at $550 per ton in 1981. The price then declined to $200 to $300 per ton in the mid 1980's. High availability of bluefin tuna with a value of $1,550 per ton resulted in the wet fish seiners shifting their effort toward that species; as a result, bonito landings were reduced to a low of 533,000 pounds in 1986.

Commercially-landed bonito are primarily canned for human consumption, but the offal may be utilized for pet food or for reduction to fish meal. Cannery orders are limited. Generally higher demand exists for yellowfin, skipjack, albacore, and bluefin tunas for human consumption; for Pacific mackerel and jack mackerel as pet food; and for northern anchovy as fish meal. Small amounts of bonito are processed by curing and smoking, and some are sold fresh or frozen.

Bonito are also taken commercially by troll gear, gill nets, and pole and line, but the landings of fish caught by these

SMB-26880

methods usually average less than two percent of the total. The local market for fresh bonito is supplied from these sources.

During the years 1943-1958 and 1975-1978, at least 50 percent, and often more than 90 percent, of the bonito landed were taken off Baja California, Mexico. More recently, Mexico has restricted access to foreign vessels fishing her nearshore waters, and California landings originating from Mexico have declined to less than 10 percent of total landings.

Typically, bonito off California are caught south of Point Conception from July through January, and north of Point Conception during the fall and early winter; many were caught as far north as Crescent City during the 1982-1983 El Niño.

Pacific bonito, *Sarda chiliensis*.

Status of Biological Knowledge

The Pacific bonito is an epipelagic schooling fish of the eastern Pacific Ocean. It has a discontinuous distribution. A southern population ranges from Panama to Chile, and a northern population ranges from southern Baja California to the Gulf of Alaska. Typically, however, the northern population centers between southern California and central Baja California and is uncommon north of the state except during El Niños.

Bonito grow rapidly during their first years of life. At one year they average 20 inches fork length and weigh about four pounds; at two years they average 25 inches and about 8 pounds. Growth slows in the latter half of life, and at six years they may reach a maximum of 32 inches and 17 pounds. Occasionally larger ones are reported; the California angling record was established by a 22-pound fish taken off Malibu Beach in 1978.

Pacific bonito broadcast their sexual products into the seawater where fertilization takes place. In aquarium-held fish, pairing occurred. During courtship, a ripe female displaying exaggerated wobbling swimming movement was followed closely by a male. The breeding pair then synchronized the release of gametes at the onset of a tight circle swim. Other males vied for position behind the ripe female. Threat displays between competing males consisted of vertical barring coloration changes, erected fins, and a lateral positioning of the body to the competitor.

The females begin to mature at two years and are fully mature at the minimum legal size limit of 24 inches. Males are more precocious; about 44 percent of the one-year-old males spawn, and all are mature when two years old and longer than 20 inches. Spawning begins in February or March and continues for a five-month period. Peak spawning occurs off central Baja California, but some takes place off southern California late in the season or during El Niño episodes. Some localized spawning may take place near the warm-water discharges from electrical generating stations in southern California. Individuals may spawn more than once during a season. No reliable estimate of fecundity, the number of eggs spawned by a female, has been made.

Bonito consume prey equalling about six percent of their body weight daily. When observed in a large aquarium, bonito abandoned their typical schooling pattern during feeding. The presumably aggressive vertical barring coloration seen in males competing to court females is also present while feeding. Northern anchovies are common prey, but market squid, highly vulnerable to predation while spawning, sometimes become a major part of the diet. Pacific sardines may also be a significant food.

Bonito swim continuously to maintain orientation and respiration. Swimming is powered by richly oxygenated red muscle tissues near the tail. As a fish grows, the proportion of red muscle tissue increases; hence larger fish become relatively more powerful swimmers. At the continuous-maintenance swimming speed, aquarium-held fish averaging 22 inches in length swam about 37 miles daily. While most of the fish in a tag and recapture study were recovered near the release site, a migration of about 600 miles was indicated by bonito that swam southward from southern California in the winter and northward from Baja California in the summer. Such migrations appear to be a response to changing sea temperatures. Individuals tagged and released at the warm- water discharges from electrical generating stations, appeared to forgo migration, as they were recaptured near the release site up to three years later.

Status of Population

An assessed decline in bonito abundance, and a drastic reduction in the size of the fish harvested commercially, brought about a reduced bag limit and minimum size regulation in 1982. The status of the population has not been reassessed since then, but warm water conditions in the 1980's have apparently provided good conditions for bonito survival, and large catches have been made.

Ken Miller and Marija Vojkovich
California Department of Fish and Game

References

Black, G. 1979. Maturity and spawning of the Pacific bonito, *Sarda chiliensis lineolata*, in the eastern north Pacific. Calif. Dept. Fish and Game, Mar. Resour. Tech. Rep. 41. 60 p.

Campbell, G. and R.A. Collins. 1975. The age and growth of Pacific bonito, *Sarda chiliensis*, in the eastern north Pacific. Calif. Fish and Game. 61:181-200.

Collins, R., D. Huppert, A. MacCall, G. Stauffer, and J. Radovich. 1978. Joint California Department of Fish and Game, National Marine Fisheries Service management information document for Pacific bonito (*Sarda chiliensis lineolata*). 89 p.

Magnuson, J.J. and J.H. Prescott. 1966. Courtship, locomotion, feeding, and miscellaneous behavior of Pacific bonito (*Sarda chiliensis*). Anim. Behav. 14:54-67.

Yoshida, H.O. 1980. Synopsis of biological data on bonitos of the genus Sarda. NOAA Tech. Rept. NMFS Circ. 432. 50p

SMB-26881

TUNAS AND BONITOS: DISCUSSION

Tunas and bonitos belong to the family Scombridae, as do seerfishes (wahoo and Spanish mackerels) and true mackerels. The tunas are muscular fishes which swim at great speeds for prolonged periods. Their high rates of metabolism obligate them to consume large amounts of food to stay alive. They are unique among bony fishes in that they maintain their body temperature at a level higher than that of the water in which they live. This is accomplished by countercurrent heat exchangers (*retia mirabilia*), networks of small arteries and veins in which the relatively cool arterial blood coming from the gills is warmed by the relatively warm venous blood coming from the muscles, brain, and eyes.

The eastern Pacific Ocean is one of the most important fishing areas in the world for tunas. For many years, most of the tunas caught in the eastern Pacific were taken by U.S.-flag vessels and landed and canned in California or Puerto Rico. The great majority of these were yellowfin and skipjack, caught off Latin America from Mexico to northern Chile. The weight and value of tunas landed in California exceeded those of any other fish.

Tuna seiners in San Diego.

During 1980 and 1981, the profitability of fishing in the eastern Pacific was reduced due to overfishing of yellowfin. Then there was a severe El Niño episode during 1982-1983, which reduced the vulnerability to capture of both yellowfin and skipjack. In response to this, many of the large California and Puerto Rico-based vessels transferred their operations to the western Pacific Ocean, landing their catches at American Samoa, to be canned, or at various Pacific islands, from which they are transhipped to canneries in Puerto Rico, Thailand, and elsewhere. Due principally to high labor costs, all but one of the major tuna canneries in California were closed during the early 1980's. Fishing conditions in the eastern Pacific Ocean improved during the mid-1980's, but two other factors induced most of the U.S.-flag vessels which were in the western Pacific to remain there and other vessels to go there for the first time. First, all the Latin American coastal states had by then extended their jurisdictions for fisheries to 200 miles, excluding U.S vessels from many of the best fishing areas. Second, legislation and other actions carried out to reduce the kill of dolphins have made it difficult to fish outside the 200-mile limits of the Latin American countries, as the catches of tunas in that area consist mostly of large yellowfin associated with dolphins.

The majority of vessels now participating in the fishery for yellowfin and skipjack in the eastern Pacific Ocean are based in Mexico, Ecuador, and Venezuela. Fish caught by these vessels are canned in various places, including Ecuador, Mexico, Puerto Rico, Venezuela, and Europe. Small amounts of yellowfin, skipjack, bluefin, and albacore caught by U.S.flag vessels are still canned in California. These fish are not caught in association with dolphins, as the major U.S. canneries do not accept such fish.

There are substantial sport fisheries for yellowfin, albacore, and bluefin in the eastern Pacific Ocean. Long-range vessels based in San Diego and Oceanside take passengers on fishing trips of one to three weeks to the Revillagigedo Islands, off Mexico, and to Clipperton Island, where many trophy-sized yellowfin are caught.

Research on yellowfin, skipjack, and bluefin in the eastern Pacific Ocean is conducted by the Inter-American Tropical Tuna Commission, and studies of albacore are carried out by the U.S. National Marine Fisheries Service.

William H. Bayliff
Inter-American Tropical Tuna Commission

References

Bayliff, William H. (editor). 1980. Synopses of biological data on eight species of scombrids. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 2: 530 pp.

Collette, Bruce B., and Cornelia E. Nauen. 1983. An annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to date. FAO Fish. Synop., 125 (2): vii, 137 pp.

Joseph, James. 1990. Status of the tuna fishery in the eastern Pacific Ocean with regard to management. *In*: Miles, Edward L. (editor), Management of World Fisheries: Implications of Extended Coastal State Jurisdiction, University of Washington Press, Seattle and London: 210-226.

Joseph, James. 1991. The conservation ethic and its impact on tuna fisheries. Tuna 91 Bali (Papers of the Second World Tuna Trade Conference, Bali, Indonesia, May 13-15, 1991): 12-18.

Joseph, James, Witold Klawe, and Pat Murphy. 1988. Tuna and Billfish - Fish without a Country, Fourth Edition. Inter-American Tropical Tuna Commission, La Jolla, California: ix, 69 pp.

BILLFISHES

STRIPED MARLIN

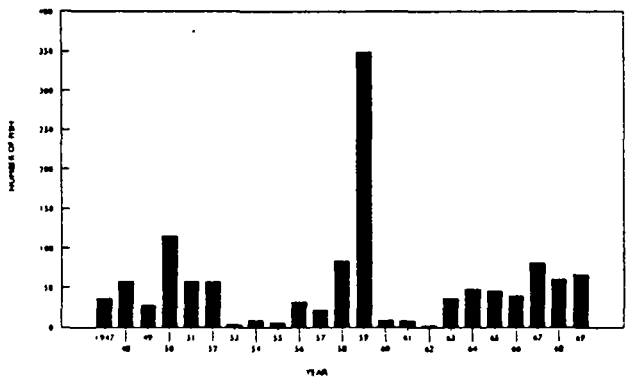
History of the Fishery

Striped marlin (*Tetrapturus audax*) have been fished off California since the early 1900's. The Avalon Tuna Club reported the first "marlin swordfish" landed by an angler in 1903. During the early years of the fishery, sport and commer-

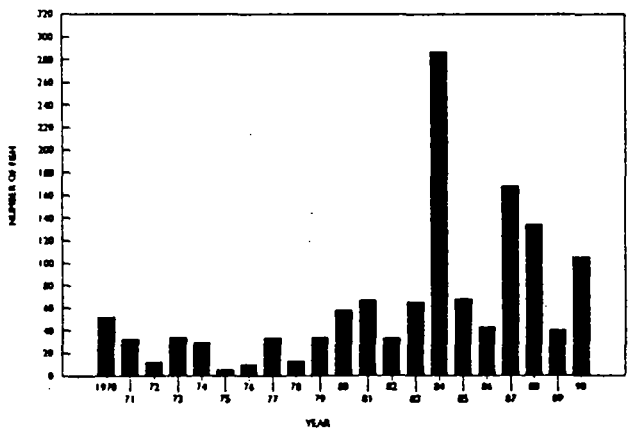
SMB-26882

cial landings were allowed. In 1935, the legislature prohibited the use of harpoons in the commercial harvesting of marlin, and landings dropped significantly. In 1937, the legislature eliminated the commercial fishery entirely by prohibiting the buying or selling of striped marlin in California. Since 1937, California sport fishermen have had the local fishery to themselves. Some commercial fishing by the Japanese takes place off lower Baja California, Mexico, as well as in the central and south Pacific Ocean. Longlines are used almost exclusively in this commercial fishery.

During the early years of the sport fishery, most striped marlin were landed by anglers using the services of a hired guide. The guide would supply the boat, tackle, and crew for a day's fishing. Very little fishing effort occurred from privately owned boats, because most people felt that a professional skipper was needed to catch marlin. This trend continued through the early 1950's but started to decline rapidly with the proliferation of small boats. Currently, most marlin are pursued by private boat anglers using vessels 20 to 60 feet in length. Some marlin are still taken by anglers chartering boats, but they amount to only 10-20 percent of the catch.



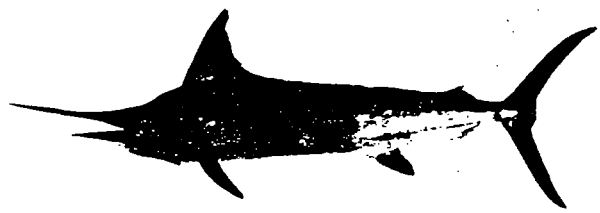
California commercial passenger-carrying fishing vessel landings of striped marlin, 1947-1969.



California commercial passenger-carrying fishing vessel landings of striped marlin, 1970-1990.

Striped marlin season in southern California generally runs from early July through October. However, during years when El Niños occur, the season may start as early as May and run through February of the following year. Striped marlin are usually found south of Point Conception. Excellent sport fishing can take place as far north as Morro Bay during an El Niño, and one fish was taken in Monterey Bay during such an event. Within southern California, marlin are usually taken from San Pedro southward and offshore to Catalina and San Clemente Islands. When marlin concentrate in this area, sport catches may exceed 2,000 fish per year because of the nearness of the fishery. Abnormally cool or warm waters tend to reduce marlin availability in southern California. During such times, the catch may slip to less than 100 fish per year because the fish do not enter the prime fishing area. Most marlin taken in California are intentionally caught while trolling artificial lures or casting live bait at fish on the surface. Occasionally, striped marlin may be taken incidentally to tuna fishing.

Recent catch figures reflect only the number of striped marlin caught (i.e., successfully brought to the boat), not the number kept and brought to port. There is a rapidly growing trend among marlin anglers to release or tag-and-release fish. In the past, anglers were encouraged to land their fish so that they could be weighed and photographed, and tourists would be attracted to the weigh station. Currently, approximately 30 percent of the catch is released, with about one-third of those fish being tagged. Greater recognition by fishing clubs and weigh stations of the value of releasing fish has helped to encourage the release of marlin.



Striped marlin, *Tetrapturus audax*.

Status of Biological Knowledge

Striped marlin occur mainly in tropical to temperate waters of the Pacific and Indian oceans. Occasionally, an individual may be taken in the Atlantic off the tip of South Africa. In the Pacific, they are found in a horseshoe-shaped band, with the tips of the horseshoe off Japan and Australia and the base located off the coast of Central America. Along the North American coast, striped marlin have been taken as far north as Oregon. The southern range for fish in the eastern Pacific is off Chile.

By using longline catch and tag recovery data, scientists have hypothesized that there are two stocks of striped marlin occurring in the Pacific. The stocks are separated by the equator, although mixing occurs off the coast of Central America. The northern stock, which contributes to the California fishery, is the larger of the two. Movement of fish within the northern stock appears to be correlated with seasonal changes in water temperatures. During the winter, marlin follow a general pattern of movement to the west. As spring approaches, fish in

SMB-26883

the central Pacific move east while those in the eastern Pacific move up the coast of central America. Throughout summer, fish along the Pacific coast are continually moving to the southeast, paralleling the coast. During the fall, there is further movement to the southeast with a return to the west in the winter. Striped marlin do not migrate around the Pacific on a yearly basis, as do albacore, but instead make the journey over several years.

While most fish taken off California are thought to be between three and six years old and weigh from 90 to 200 pounds, an occasional fish over 300 pounds is landed. During the early years of the fishery, a 405 pound striped marlin was taken. The current state record (the program started in 1930) is 339 pounds, while the world record, listed by the International Game Fish Association, is 494 pounds. Striped marlin as large as 570 pounds have been recorded by commercial fishermen.

Spawning occurs primarily in the central and western Pacific, with lesser activity occurring around the Rivella Gigedo Islands in the eastern Pacific. May and June are the months of greatest spawning activity for the northern stock. While mature females are found in the three spawning areas, larval fish are known from only the central and western Pacific.

Striped marlin are primarily piscivorous although they will consume invertebrates such as squid or pelagic red crabs. Off southern California, where they spend most of the time near the surface, fish make up most of their diet. Anchovies, sauries, flyingfish, and jack and Pacific mackerels are the most frequently found prey items when marlin stomachs are examined.

Status of Population

The North Pacific stock of striped marlin does not appear to be fully exploited. Data collected from Japanese longline fisheries show no correlation between catch and effort. Because of the large variation in catch per unit of effort, coupled with no trend towards decreasing total catch, the stock appears to be exploited below maximum sustainable yield. The current harvest rate of 9,000 to 11,000 tons per year appears to be at a safe level.

Steven J. Crooke
California Department of Fish and Game

References

Joseph, J., W. Klawe, and P. Murphy. 1980. Tuna and billfish - fish without a country. Inter-American Tropical Tuna Commission. La Jolla, CA. 46 p.

Macrate, A.E. 1948. History of the Tuna Club. The Tuna Club. Avalon, CA. 197 p.

Nakamura, I. 1985. Billfishes of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Fish. Synop. (125) Vol. 5. 65 p.

Stroud, R.H.(ed.). 1990. Planing the future of billfishes, research and management in the 90s and beyond. Proceedings of the second international billfish symposium, Kailua-Kona, Hawaii, August 1- 5, 1988, Part 2: contributed papers. National Coalition for Marine Conservation, Inc. Savanna, GA.

SWORDFISH

History of the Fishery

Swordfish (*Xiphias gladius*) support a valuable worldwide fishery which currently produces about 55,000 tons annually. The Pacific fishery lands about 40 percent of the world catch. The primary fishing areas in the Pacific coincide with fronts where major currents meet off Japan, southeast Australia, northeast New Zealand, Peru, and Ecuador, as well as California and Baja California. Most of the non-Californian Pacific landings are taken as an incidental catch in the large tuna longline fishery. Off California, swordfish are targeted directly by fishermen. Currently about 10 percent of the Pacific ocean's swordfish landings come from California.

Significant swordfish fish landings first occurred in 1927, when 130,000 pounds were caught. Since then, California landings have varied widely, between 23,000 pounds in 1954 and a 1985 high of 5.2 million pounds (worth $13.4 million). The large fluctuations in landings over the years are influenced by changes in swordfish availability and migratory patterns due to variations in oceanographic conditions, changes in swordfish markets, availability of alternative target species (such as albacore), and changes in fishing techniques.

Until the late 1970's, hand-thrown harpoon was the primary fishing method in California. Most vessels were 30 to 50 feet long with a 20 to 30 foot plank extending beyond the bow. The harpooner stands on the end of the plank as the vessel sneaks up on a fish that has been spotted sunning itself on the surface. After harpooning, an attached line, buoy and marker flag are thrown overboard. When the fish tires after several hours, it is landed, headed and gutted, fin-trimmed, and refrigerated.

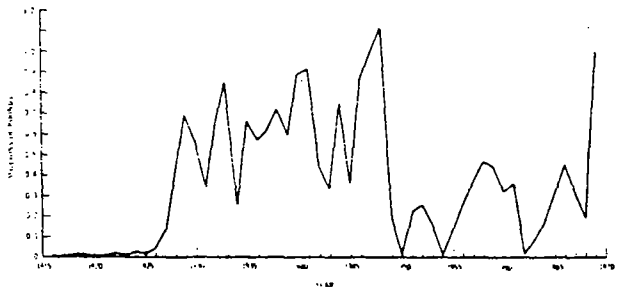
The swordfish fishery landings averaged about 400,000 pounds per year caught in the Pt. Conception to San Diego area, until 1970 when high mercury levels were detected in swordfish. In 1971, no swordfish with mercury levels over 0.5 parts per million were allowed to be imported. At first, the demand for swordfish dropped drastically but, by 1973, it started to recover. Increasing demand and reduced competition from imports led to rapid growth of the harpoon fishery from 150 permittees to 1,200 permittees by 1979. The intense competition in the fleet led to the use of aircraft to improve fish finding capabilities.

By 1978, the demand for swordfish had returned to previous levels and fishermen targeting thresher and mako sharks with large-meshed (8 to 20 inches) drift gill nets noticed that they could catch swordfish. The nets, usually to 120 feet deep and 6,000 feet long, are fished at night in surface waters. One end of the net is connected to the vessel as it drifts. By 1982, the drift gillnetters expanded the swordfish fishery northward and offshore, with sizeable catches off San Francisco. Many harpooners switched to the drift gillnet fleet, and in recent years about 95 percent of California's swordfish catch has been landed by gillnetters.

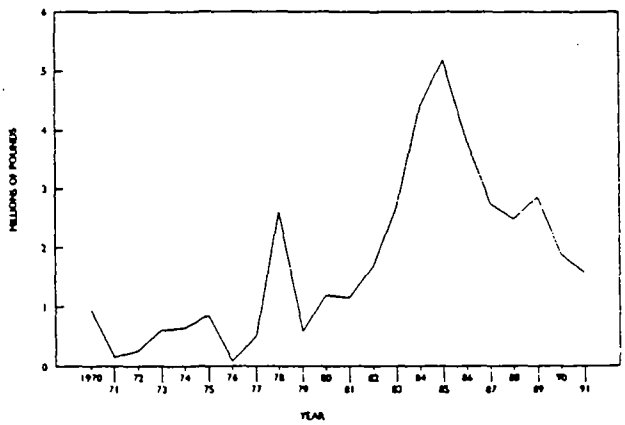
The expanded capability and range of the fleet, plus increasing worldwide demand for swordfish, contributed to large increases in the landings between 1980 and 1985. The catch peaked at 5.2 million pounds in 1985. While catches have

SMB-26884

declined about 50 percent since 1985, they remain well above the long-term historical average.

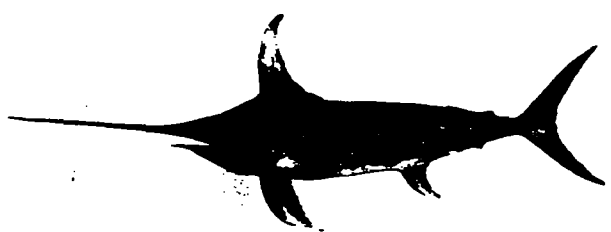


California commercial landings of swordfish, 1916-1969.



California commercial landings of swordfish, 1970-1991.

Swordfish are also a highly esteemed catch for recreational anglers. Only a few are caught by anglers each year. This could be due to swordfish feeding primarily at night when most anglers, in the words of U.C. Santa Barbara fish biologist R. M. Love, "are drinking lite beer and watching reruns of *Three's Company*."



Swordfish, *Xiphias gladius*.

Status of Biological Knowledge

Swordfish are found worldwide in tropical, subtropical and temperate seas (50° N to 50° S latitude). In the eastern Pacific, they occur in harvestable quantities from Chile to Oregon. Swordfish (family Xiphiidae) lack pelvic fins, have only one keel on their caudal peduncle, and have a flattened bill. These features distinguish them from other billfishes (family Istiophoridae). Swordfish grow to at least 1,200 pounds and 14 feet in length. Females grow larger than males, probably because of a faster growth rate. The limited data from tagging studies indicates that swordfish live at least nine years.

Spawning takes place in 68 to 75°F waters in the north Pacific, primarily from March through July. A mature female produces tens of millions of eggs and fertilization is external. Larvae and juveniles tend to concentrate near the 75° isotherm in areas with high productivity. Swordfish larvae feed primarily on fish larvae and zooplankton. Juveniles target squid and small fishes. Adult swordfish appear to be opportunistic feeders on squids, pelagic and demersal fishes and crustaceans. The thin, snake-like larvae and juveniles grow quickly and become bulkier as they mature. One-year old fish are 20 to 24 inches long. Two-year old fish begin to enter the fishery and the bulk of the swordfish landings appear to be 4 and 5 years old. One study indicated that they reached sexual maturity at five or six years old. Young swordfish are preyed on by billfishes, tunas and sharks. Only whales, large sharks, and humans appear able to prey on adult swordfish.

Limited data exist on swordfish migrations. Catch records off California indicate they move northward from Baja California in the Spring to California during the Summer and Fall. Then they move offshore for spawning. Swordfish tend to concentrate along food-rich temperature fronts between cold upwelled waters and warmer oceanic water masses. Fishermen use satellite images to help locate these thermal fronts.

The daily local movements of swordfish are of interest to fishermen and biologists. Swordfish rise to surface waters to feed at night and spend most of the day in deep water. This makes them susceptible to drift nets at night. In the temperate waters of the Atlantic and Pacific, swordfish will bask on the relatively warm surface. This is thought to aid digestion. California fishermen took advantage of this behavior to develop the earlier harpoon fishery for swordfish.

Swordfish are able to move from warm (60 to 75°) surface waters to depths up to 2,000 feet (41-50°) for feeding. They are also able to migrate across sharp thermal boundaries to feed near the surface. This is quite a physiological challenge. Biologists have found that swordfish have an extraordinary heater organ, made up of specialized skeletal muscle below the brain. This heater organ maintains elevated temperatures in the head region which may enable swordfish to function successfully (especially the eyes) at sharply reduced temperatures.

Status of Population

It is difficult to assess the status of the swordfish population in the Pacific because of a lack of consistent long-term data. Catch per unit effort (CPUE) in the fisheries has been the primary source of data. The most recent assessment used data from the Japanese longline fishery for 1952-1980, which are the best available data. After examining both the single Pacific-wide stock situation and the situation if three regional substocks exist, National Marine Fisheries Service researchers concluded that the exploitation through 1980 was not heavy enough to cause a noticeable decline in catch per unit effort. Generally, the

SMB-26885

Pacific-wide CPUE rose slowly from 1952-1962, dropped about one-third in 1963-1965, and remained level through 1980. In the eastern Pacific, the CPUE trend was level from 1966-1980.

Christopher M. Dewees
University of California, Davis
Sea Grant Extension Program

References

Bartoo, N.W. and A.L. Coan, Jr. 1989. An assessment of the Pacific swordfish resources. *In*: R.H. Stroud [ed.] Planning the future of billfishes: research and management in the 90's and beyond. Marine Recreational Fisheries 13. Proceedings of the Second International Billfish Symposium, Kailua-Kona, Hawaii, August 1-5, 1988. National Coalition for Marlin Conservation, Savannah, Georgia.

Bedford, D.W. and F.B. Hagerman. 1983. Billfish fishery resource of the California current. Ca/COFI Reports (24) 70-78.

Palko, R.J., G.L. Beardsley, and W.J. Richards. 1981. Synopsis of the biology of swordfish, *Xiphias gladius* Linnaeus. U. S. Dept. of Commerce NOAA Technical Report NMFS Circular 441.

Sakagawa, G.T. 1989. Trends in fisheries for swordfish in the Pacific ocean. *In*: Stroud, R.H. [ed.] Planning the future of billfishes: research and management in the 90's and beyond. Marine Recreational Fisheries 13. Proceedings of the Second International Billfish Symposium, Kailua-Kona, Hawaii, August 1-5, 1988. National Coalition for Marlin Conservation, Savannah, Georgia.

Shomura, R.S. 1980. Summary report of the billfish assessment workshop, Pacific resources. U. S. Dept. of Commerce, NOAA Technical Memo, NOAA-TM-NMFS-SWFC-5.

Shomura, R.S., and F. Williams, eds. 1974. Proceedings of the International Billfish Symposium, Kailua-Kona, Hawaii, 9-12 August, 1972. U.S. Dept. of Commerce, NOAA Technical Report, NMFS SSRF-675.

NEARSHORE FISHES

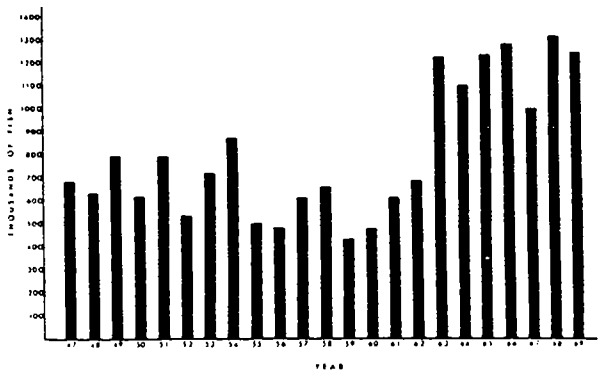
KELP BASS

History of the Fishery

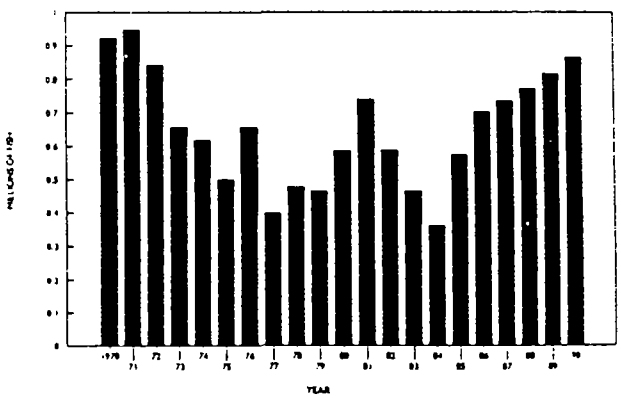
The kelp bass (*Paralabrax clathratus*) has been the target of southern California anglers and commercial fishermen since the early 1900's. For many years, catch statistics grouped kelp bass and the two other *Paralabrax* species, barred sand bass and spotted sand bass, into a single "rockbass" category. It is safe to assume kelp bass comprised most of this catch category.

The largest commercial landings of rockbass occurred during the 1920's and 1930's; annual landings averaged 500,000 pounds. During and after World War II, there was a sharp decline in fishing activity and landings never exceeded 150,000 pounds from 1941 through 1953. Rockbass imported from Mexico contributed to the landings, sometimes in amounts greater than the California catch. The decline of the rockbass resource prompted conservation measures which, in 1953, made commercial fishing for rockbass illegal in California waters. Legally sold fish imported from Mexico have dwindled to insignificant levels since the late 1950's.

Sport anglers using light hook-and-line tackle catch kelp bass while fishing from piers, beaches, private boats, and commercial passenger fishing vessels (CPFVs). There are few catch records for anglers fishing from piers, beaches, and private boats. Sport catch records for rockbass taken by CPFVs have been available since 1935, but only since 1975 have CPFV records reliably differentiated kelp bass catches from the other rockbass. Early sport anglers considered the kelp bass a nuisance when attempting to catch more desirable gamefish. Only the largest "bull bass" were sought. In 1939, a limit on sport fish catches in California, 15 total fish in an aggregate of several species, was the first management attempt at preventing depletion of popular sport fish populations.



California commercial passenger-carrying fishing vessel landings of kelp and sand bass, 1947-1969.



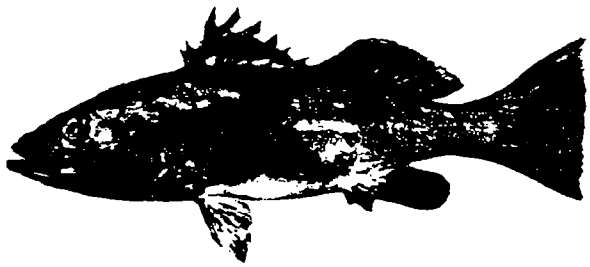
California commercial passenger-carrying fishing vessel landings of kelp and sand bass, 1970-1990.

Intense fishing immediately after the war caused a progressive decrease in the size of landed bass, and some areas were fished out. The popular kelp bass fishery was deteriorating. The California Department of Fish and Game (CDFG) instituted comprehensive studies in 1950 that resulted in size and bag limits for sport caught kelp and sand bass combined. The new size limit began at 10.5 inches and was increased several times until the 12 inch limit was reached in 1959.

SMB-26886

The kelp bass catch has fluctuated greatly since the 1960's. The largest CPFV catches occurred during the mid-1960's, estimated at over 1,000,000 fish annually. Since 1975, the CPFV kelp bass catch has ranged from 220,000 to 496,000 fish. The recent Federal Marine Recreational Fishery Statistics Survey estimated that the catch from shore, pier, and private boat anglers approaches that of CPFV fishermen and exceeds it in some years. This means that 1,000,000 or more kelp bass, on average, are caught annually by southern California anglers.

The most productive fishing areas in recent years have been off the Coronado Islands, Baja California, Mexico; Point Loma and La Jolla in San Diego County; Dana Point and Huntington Beach in Orange County; Santa Catalina Island and Horseshoe Kelp in Los Angeles County; and around the Channel Islands in Santa Barbara and Ventura Counties.



Kelp bass, *Paralabrax clathratus*.

Status of Biological Knowledge

Kelp bass range from the Columbia River to Magdalena Bay, Baja California, although they are infrequently caught north of Point Conception. They are generally found associated with kelp beds, rocks, and seaweeds. Large adults often inhabit rocky areas with little or no seaweed in depths to 150 feet. Kelp bass range throughout the water column, but concentrate between 8 and 70 feet. In general, they live solitary lives but form assemblies to spawn and to feed on small schooling fish.

Tag and release studies have shown little movement for the majority of kelp bass. If they move at all, it is to nearby rocky reefs or short distances to gather into breeding assemblies.

Kelp bass have the broad diet of a generalized carnivore. They prefer to feed in deep calm areas of reefs or clear water areas of kelp bed margins. Occasional bottom feeders, they forage primarily at mid-water. Young kelp bass feed on small crabs, copepods, and plankton. Large kelp bass eat larger and more motile prey: small fish (anchovies), squid, octopus, and various bottom dwelling crabs, shrimps, and amphipods. They feed lightly in the winter and most heavily during May through September.

Kelp bass spawn from April through the fall months. Females release pelagic eggs 0.04 inches in diameter. Spawning occurs in and around kelp forests or over rocky reefs, generally, in depths down to 150 feet. Several hundred ripe adults may aggregate in a small area during spawning. Some kelp bass are mature at seven to eight inches and two to three years of age. Other individuals of the same size and age may require another year or more to reach maturity. Larger females may spawn more than once if they mature early in the season.

Growth is slow and a large size may ultimately be attained. The largest angler-caught kelp bass weighed 14 pounds 7 ounces. Maximum length is 27 to 28 inches. Kelp bass are believed to live long lives; one individual was estimated to be 32 years old.

Status of Population

Throughout the 1980's, kelp bass have consistently ranked among the top five fishes caught by CPFV anglers. CDFG surveys indicate the estimated total catches of kelp bass have increased since the mid-1970's. Low periods of kelp bass landings in the mid-1970's and early-1980's are attributed to El Niño events that provide anglers with alternative species to catch. Peak landings have followed each El Niño event. CDFG surveys of the CPFV industry indicate a stable spawning population is being maintained because of the large number of age classes that are caught and kept by anglers. Approximately 85 percent of the kelp bass kept by CPFV anglers measure between 11.4 to 15.9 inches, representing up to seven age classes. A number of years with conditions unfavorable to the survival of immature kelp bass would have to occur before a population decline could reduce angler catches.

Robert Read
California Department of Fish and Game

References

Ally, J.R.R., D.S. Ono, R.B. Read, and M. Wallace. 1991. Status of major southern California marine sport fish species with management recommendations, based on analyses of catch and size composition data collected on board commercial passenger fishing vessels from 1985 through 1987. Calif. Dept. Fish and Game, Mar. Resour. Div. Admin. Rept. 90-2: May, 1991.

Love, M.S. and A.W. Ebeling. 1978. Food and habitat of three switch-feeding fishes in the kelp forests off Santa Barbara, California. Fish. Bull., U.S. 76:257-271.

Quast, J.C. 1968. Observations on the food and biology of the kelp bass, (*Paralabrax clathratus*), with notes on its sportfishery at San Diego, California. Pages 81-105. *In*: W.J. North and C.L. Hubbs (eds.). Utilization of kelp-bed resources in southern California. Calif. Dept. Fish and Game, Fish. Bull. 139.

Smith, C.L. and P.H. Young. 1967. Gonad structure and the reproductive cycle of the kelp bass, *Paralabrax clathratus*, with comments on the relationships of the serranid genus *Paralabrax*. Calif. Dept. Fish and Game 52(4):283-292.

Young, P.H. 1963. The kelp bass (*Paralabrax clathratus*) and its fishery, 1947-1958. Calif. Dept. Fish and Game, Fish. Bull. 122. 67 p.

SAND BASSES

History of the Fishery

Two sand bass species are commonly caught by anglers in California, barred sand bass (*Paralabrax nebulifer*) and spotted

SMB-26887

sand bass (*P. maculatofasciatus*). Of the two, barred sand bass is the more abundant and widely distributed species and, since the late seventies, has consistently ranked among the top 10 species in the southern California marine sport fish catch. The major barred sand bass fishing sites include the Huntington Flats area off Orange County, the inshore portion of northern Santa Monica Bay off Pacific Palisades and Santa Monica in Los Angeles County, and the Ventura Flats area off northern Ventura County.

Spotted sand bass are of lesser importance to sport anglers, because their distribution is limited to a few bay, estuary, and harbor habitats. San Diego Bay, Mission Bay, and Newport Bay are the primary spotted sand bass fishing sites in southern California.

Both sand bass species are targeted exclusively by sport anglers; the commercial harvest of these species has been illegal since 1953. Throughout the 1930's and early 1940's, the sand basses, as well as the kelp bass, were not considered to be quality angling fare but gained tremendously in popularity as game fishes by the mid-1950's. At that time, concern about the resource by sport fishermen and fishery managers resulted in the initiation of life history studies and the formulation of conservation measures. By 1959, a 10-fish bag limit and a 12-inch minimum size limit had been imposed on all three kelp and sand bass species, measures designed to counteract the declining numbers and shrinking size composition of the bass catches. The commercial passenger fishing vessel (CPFV) bass fishery responded positively to this management regime, and landings of kelp and sand bass increased substantially through the 1960's and early 1970's. From 1975 through 1989, the CPFV barred sand bass catch expanded threefold to a peak of 400,000 fish in 1988.

Although lacking some of the sporting qualities of kelp bass, barred sand bass are much more susceptible to hook and line gear and are somewhat easier to catch. When CPFV skippers target barred sand bass schools, they can usually produce substantial catches for their passengers, even for novice anglers possessing minimal fishing skills. In 1985, 1987 and 1988, barred sand bass was the leading bass species in the CPFV catch, exceeding kelp bass landings for the first time since 1961 when kelp bass and sand bass landings were first reported separately. Estimates of annual barred sand bass landings from all sport fishing activity (shore, pier, private boat, CPFV's, etc.) ranged as high as 2,100,000 during the 1980's.

Spotted sand bass landings are greatest from private boats and rental skiffs fishing the bays and estuaries of southern California. A skiff survey conducted by the California Department of Fish and Game (CDFG) estimated that the southern California annual catch ranged from 12,790 to 23,933 fish between 1976 and 1981. Other estimates of the annual sport catch of spotted sand bass, including both boat and shore fishing effort, ranged from 53,000 to 170,000 between 1980 and 1989.

Status of Biological Knowledge

Barred sand bass range from Magdalena Bay, Baja California to Santa Cruz, California, although they are infrequently taken north of Point Conception. They inhabit sandy bottom areas from shallow water depths to 600 feet, but the greatest concentrations are found between 60 to 90 feet. They feed on small fishes and invertebrates such as crabs, clams, and squid. The largest barred sand bass on record measured 26 inches in length, and the maximum recorded weight was 11.1 pounds.

Barred sand bass spawn during the late spring and summer months and form large aggregations at this time. Pelagic eggs are released and juvenile young of the year appear in nearshore areas during the fall and winter. A juvenile barred sand bass is approximately seven inches long after one year, and reaches sexual maturity at 10 inches in three to four years. The maximum verified age for barred sand bass is 24 years.

Spotted sand bass range from Mazatlan, Mexico to Monterey, California and are present throughout the Gulf of California. They inhabit sandy or mud bottoms in bays or harbors at depths ranging from the intertidal zone to 200 feet. They are diurnally active, seeking shelter near eel grass beds, rocks, or other structures, and feeding on small fishes, cephalopods, and crustaceans. Maximum recorded size is 22 inches, and the maximum recorded weight is 5.8 pounds. They are known to reach an age of over 20 years.

Spotted sand bass, unlike the other two *Paralabrax* species, are protogynous hermaphrodites; that is, all spotted sand bass start out as females and after a period of time transform into males. This transformation may begin in fish as small as five inches long, although female spotted sand bass up to 10 inches long have been noted. Spawning occurs during the spring and early summer, during which time they release pelagic eggs. Young of the year begin appearing in the intertidal zone the following winter.

Spotted sand bass can tolerate an extremely wide range of water temperatures, from 90° F in the Gulf of California to 45° F in experimental situations. This attribute is a physiological adaptation to the temperature extremes occurring in the shallow-water, bay environment preferred by spotted sand bass.

Status of Populations

While there are no current population estimates for either barred sand bass or spotted sand bass, examining the sport catch trends gives an indication of the health of both stocks.

The barred sand bass catch has risen steadily since 1975, challenging kelp bass as the premier bass species in the southern California sport fishery. Several factors seem to account for the upward trend. Most significantly, CPFVs, which account for the greatest portion of the barred sand bass catch, have begun to target them more frequently, especially during the summer spawning period. The fish are concentrated at that time, usually in well defined areas along the coast. Also, new barred sand bass spawning sites have been discovered over the last 10 years and are now being exploited by CPFV's and private boats.

As fishing effort targeting barred sand bass has increased, there has been concern that the stock may become overexploited. Recent studies have indicated that the CPFV sand

SMB-26888

bass fishery is supported by multiple year classes, and that most sublegal (<12 inches) fish are released. This is indicative of a healthy sport fishery operating on a sustained yield basis.

More data are needed to define barred sand bass growth rates, maturation, spawning, and migration. A tagging study initiated in 1989 by the CDFG and a group of southern California CPFV owner-operators should help define the growth and migration parameters for the species. An earlier CDFG tagging study revealed barred sand bass movements of from five to 40 miles.

Poor water quality may have an adverse affect on barred sand bass. There is evidence that tumors, deformities, and other anomalies found in barred sand bass may result from industrial and domestic wastes discharged into the nearshore environment. Survival of egg, larvae, and juvenile stages is also diminished by waste discharges.

Probably the greatest threat to spotted sand bass stocks is the degradation and destruction of bay and estuarine habitats. Encroaching development, landfills, and the degradation of water quality all negatively impact the spotted sand bass population. The maintenance of the quality and quantity of suitable habitat is key to the reproduction, growth, and survival of spotted sand bass in southern California waters.

David S. Ono
California Department of Fish and Game

References

Feder, H.M., C.H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Dept. Fish and Game, Fish Bull. 160, 144 p.

Fitch, J.E. and R.E. Lavenberg. 1975. Tidepool and nearshore fishes of California. Univ. Of Calif. Press. 156p.

Hastings, P.H. 1989. Protogynous hermaphroditism in *Paralabrax maculatofasciatus* (Pisces: Serranidae). Copeia. 1989:184-188.

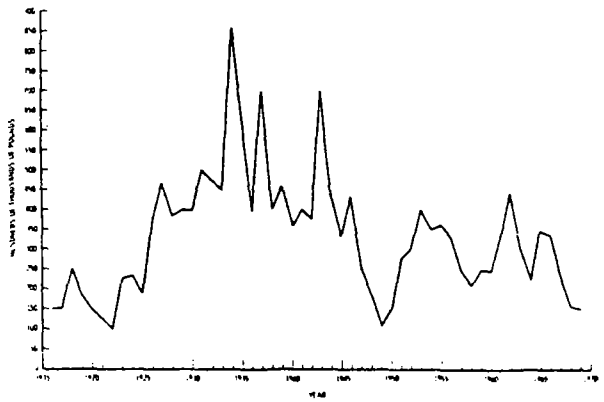
Valentine, D.W. and K.W. Bridges. 1969. High incidence of deformities in the serranid fish, *Paralabrax nebulifer*, from southern California. Copeia. 1969:637-638.

GIANT SEA BASS

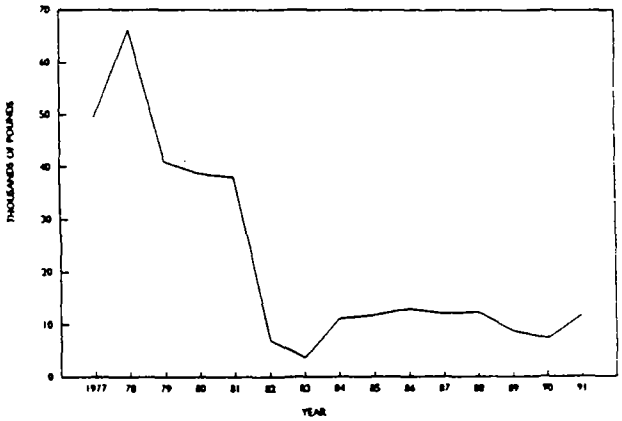
History of the Fishery

Commercial fishing for giant sea bass (*Stereolepis gigas*) in California has occurred since 1870 and a sport fishery has existed since 1895. In 1982, the California State Legislature banned commercial fishing for giant sea bass (except for the current one fish per trip tolerance for gill net boats), while the California Fish and Game Commission has banned sport landings from California waters. However, the Commission has allowed anglers fishing in Mexico to land two fish per trip.

The commercial fishery for giant sea bass initially targeted southern California fish but moved south into Mexico as local populations declined. Off Mexico, the fishery occurred along the coast between Cape Colnett and Magdalena Bay as well as on the offshore banks of lower Baja California. Early commercial fishermen relied on handlines to catch fish, but later shifted to gill nets as the resource declined. Landings have ranged from a high of 861,498 pounds in 1934 to a low of 3,666 pounds in 1983. During 1931, over 254,000 pounds were caught in California waters, the highest year on record for the local fishery. Mexican production reached 807,746 pounds in 1934, the highest year for foreign-caught landings. Landing weights are for "cleaned" fish, since commercial fishermen behead and eviscerate the fish immediately after capture.



California commercial landings of giant sea bass, 1916-1969.

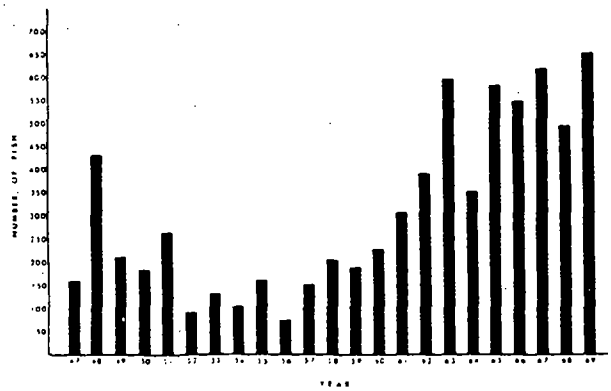


California commercial landings of giant sea bass, 1977-1991.

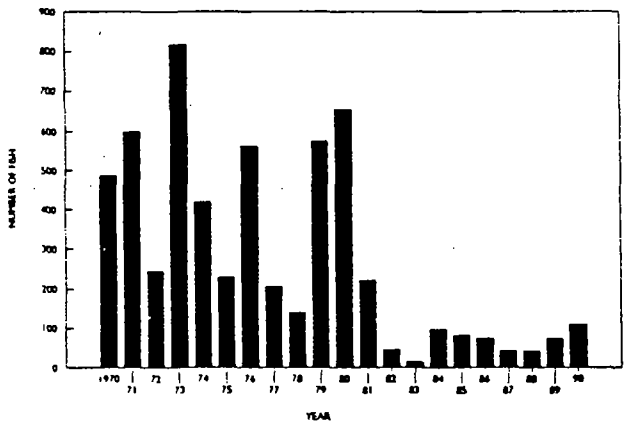
During the early years of the sport fishery, most activity took place at Santa Catalina Island. Anglers generally fished from small charter vessels, but some fish were landed by beach fishermen. Most fish were taken incidentally in directed fisheries for other species, although some anglers did target giant sea bass. Fishing for giant sea bass was considered boring because bites were infrequent. Since this outweighed the excitement of an anticipated hook-up, directed effort on giant sea bass was small.

With the expansion of the commercial passenger fishing vessel (CPFV) fleet following World War II, sport fishing for giant sea bass expanded to include all the offshore islands and banks, as well as most of the mainland coast south of Point Conception. Most fish were still taken incidentally to other species, although some directed effort occurred during summer when giant sea bass formed spawning aggregations.

With the advent of long range CPFV trips to Mexico, the sport fishery moved south, much as the commercial fishery had done earlier. During the late 1960's and early 1970's, long range boats advertised summer "black sea bass specials" to Mexico. They were very successful (50-100 fish per trip) until the local stocks were reduced to a level where anglers no longer found it worthwhile to fish for them.



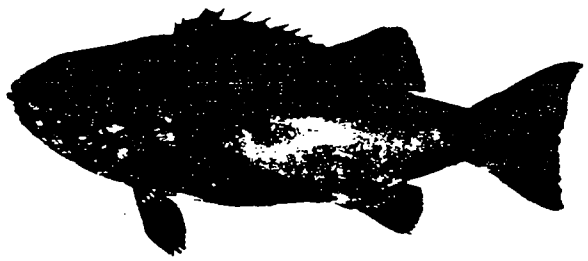
California commercial passenger-carrying fishing vessel landings of giant sea bass, 1947-1969.



California commercial passenger-carrying fishing vessel landings of giant sea bass, 1970-1990.

Landings of giant sea bass from Mexican and California waters reported to the California Department of Fish and Game (CDFG) on CPFV logs have varied between 13 and 816 fish per year. The highest figure was recorded in 1973 during the "black sea bass special" era, while the lowest landings were recorded during 1983, the first full year of the moratorium. Most fish landed on CPFV's weighed less than 80 pounds, although fish over 500 pounds have been taken. Within California, the vast majority of fish weighed less than 30 pounds, while those taken in Mexico are in the 60 to 80 pound range.

Divers have played an active role in the giant sea bass fishery. Originally, they would free dive, but switched to SCUBA diving after World War II. They were especially adept at exploiting spawning aggregations, since skilled divers had no trouble approaching the fish. Additionally, once they found a spawning aggregation, some tended to return on a daily basis until most of the fish had been taken.



Giant sea bass, *Stereolepis gigas*.

Status of Biological Knowledge

Limited information exists about giant sea bass, as the species has never been the subject of a directed study. The data that exist have been collected in conjunction with other investigations. One individual, the late John E. Fitch, is responsible for most of the current biological knowledge.

Giant sea bass range from Humboldt Bay on the north to the tip of Baja California on the south. They are also found in the Gulf of California, more often in the northern half. Within California, fish are commonly taken between Point Conception and the Mexican border. Catches north of Point Conception are rare. Adults tend to prefer rocky bottom habitats located next to kelp beds. They are also commonly found in 110 to 150 feet of water adjacent to areas where the bottom drops away quickly. Juveniles are usually found in and around kelp beds as well as sandy bottom areas, generally at depths of 40 to 70 feet.

Giant sea bass are the largest resident marine bony fish in California. They grow to seven feet five inches in length. Fish up to 563 pounds have been recorded from the sport fishery, and commercial fishermen believe that 600-pound fish exist. They have been reliably aged to 75 years old (a 435-pound specimen). The age of the 563 pound fish was not determined, but may have been 90 to 100 years old.

Spawning takes place between June and September. Females start to mature at seven to eight years of age and all are spawning by the time they are 11 years old. Large females are capable of producing enormous numbers of eggs. The ovaries of a 320-pound fish contained an estimated 60 million eggs. While spawning, large fish will form spawning aggregations and remain together for one or two months. During this time they are especially vulnerable to skin divers and less so to hook-and-line fishermen.

Small fish feed primarily on inshore species such as anchovies, sardines, and squid. Larger fish also feed on these species but their diet consists primarily of larger food organisms. Pacific mackerel, bonito, ocean whitefish, midshipmen, stingrays, white croaker, small sharks, crabs, spiny lobsters, and mantis shrimp all have appeared in the stomachs of adult fish. Predation on giant sea bass is confined to man, marine mammals, and some of the larger sharks. Older fish usually are heavily parasitized.

SMB-26890

Status of Population

Giant sea bass populations off California, and probably those off central and northern Baja California, appear to be depressed. Because of this, giant sea bass cannot be taken off California by recreational anglers. Commercial fishermen are limited to one fish per trip if taken incidentally in gill or trammel net operations. However, fish are still landed by sport anglers fishing south of the border. Mexico has expressed an interest in protecting giant sea bass. Legislation by Mexico could offer total protection by the fall of 1992.

Since 1983, sport anglers have reported catching and releasing increasing numbers of giant sea bass. The trend appears to indicate that juvenile fish are increasing in abundance and it may soon be possible to reopen the fishery. Should the sport fishery be reopened, strict size and catch limits would be necessary to prevent overfishing. The minimum size limit for giant sea bass should be 48 inches (60 pounds), the size at which all females are spawning. Spear fishing for giant sea bass should also be prohibited during the spawning season (June through August).

Young giant sea bass in the 30 to 60 pound range have proven to be particularly vulnerable to capture in nearshore gill and trammel nets. Passage of a recent State Constitutional amendment prohibiting these nets in southern California nearshore waters after 1993 should help to conserve the subadult population and may hasten the recovery of the giant sea bass stock.

Steven J. Crooke
California Department of Fish and Game

References

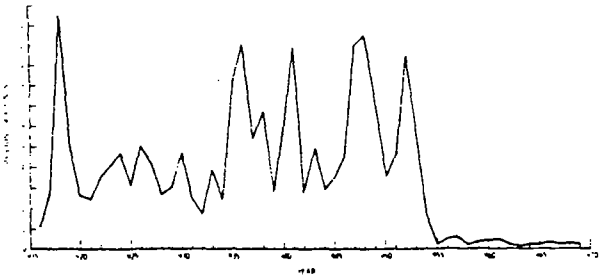
Fitch, J.E. 1961. Black sea bass. Pages 48-49. *In*: California ocean fisheries resources to the year 1960. Calif. Dept. Fish and Game. 79 p.

Fitch, J.E. and R.J. Lavenberg. 1971. Marine food and game fishes of California. University of California Press, Berkeley. 179 p.

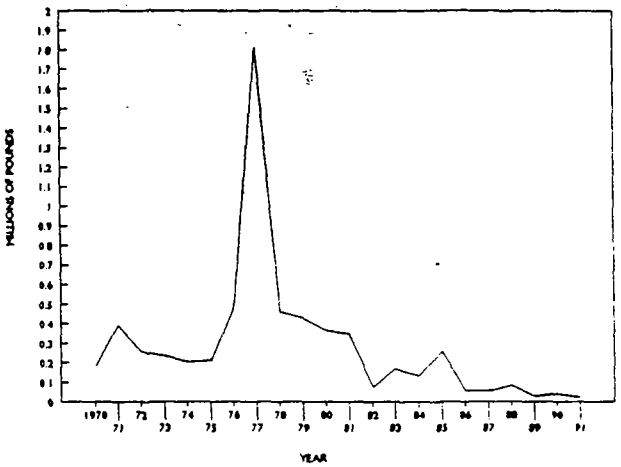
YELLOWTAIL

History of the Fishery

Sport and commercial fisheries for yellowtail (*Seriola lalandi*) have existed off California since the late 1800's. Commercial or subsistence fishing is the older of the two, with modern hook-and-line sport fishing getting its start in 1898 at Santa Catalina Island. Prior to 1898, sportsmen used handlines, a practice which faded with the advent of hickory rods, functional reels, and linen line. Both the sport and commercial fisheries in California are confined to the area south of Point Conception. The fishery usually occurs in nearshore areas, often adjacent to kelp beds. During the summer, fish may be found offshore under floating mats of kelp.



California commercial landings of yellowtail, 1916-1969.



California commercial landings of yellowtail, 1970-1991.

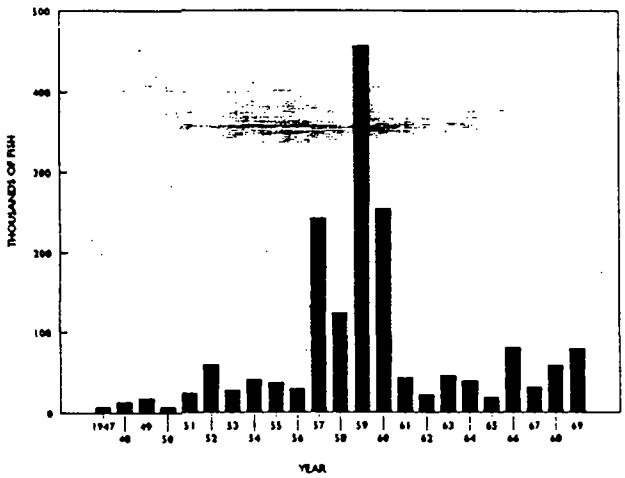
Commercial landings of yellowtail have fluctuated greatly in the past, ranging from a high of 11.5 million pounds in 1918 to a low of 28,000 pounds in 1989. Market conditions appear to dictate landings more than does the health of the resource. When market demand for fresh yellowtail was high or the canneries needed fish because tuna were unavailable, the price to the fisherman was great enough to encourage trips for the fish.

The commercial fishery for yellowtail was restricted to small live bait boats working off southern California or the Coronado Islands, Baja California, Mexico, until 1933. At that time, purse seiners began fishing in Mexican waters, as the supply of yellowtail off California had decreased and it was illegal to seine them north of the international border. Gill net boats also started landing yellowtail taken incidentally to white seabass fishing. Currently, the gill net fleet catches most of the yellowtail landed commercially in California. However, nearshore gill net fishing will be banned beginning in 1994. This should virtually eliminate the commercial fishery, as hook-and-line fishermen land few yellowtail.

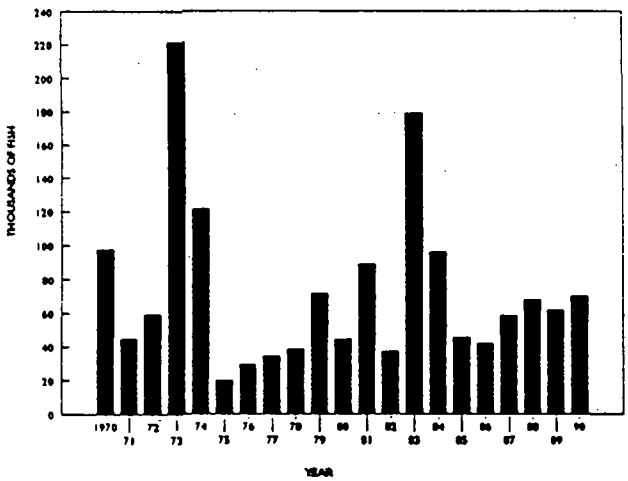
Data from commercial passenger fishing vessel (CPFV) logs provide a general indication of the magnitude of the sport fishery for yellowtail in southern California. During years when the water was warm, CPFVs landed over 450,000 fish. When the water was cold, yellowtail catches were sometimes less than 10,000 fish. Prior to the early 1950's, CPFVs were responsible for most of the sport catch. However, in the 1950's private boaters began taking a significant number of fish. During some

SMB-26891

years, private boaters land more yellowtail than do CPFV anglers. For instance, during 1984, private boat anglers landed 105,000 fish compared to 96,000 recorded by CPFV anglers. The increase of private boat anglers may impact the yellowtail resource more than continued effort by CPFV anglers or commercial fishermen.



California commercial passenger-carrying fishing vessel landings of yellowtail, 1947-1969.

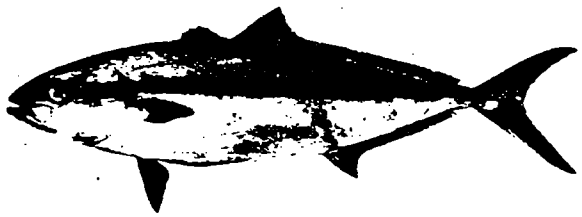


California commercial passenger-carrying fishing vessel landings of yellowtail, 1970-1990.

Major fishing areas for CPFV and private boat anglers include the Channel Islands, Santa Monica Bay, Dana Point to Oceanside, La Jolla, San Clemente Island, Santa Catalina Island, and the Coronado Islands. Long-range CPFVs fish primarily from Cedros Island south. They often concentrate on the offshore banks, especially in the Magdalena Bay area. The commercial fishery is conducted in the same areas as the sport fishery.

Status of Biological Knowledge

Yellowtail are found from British Columbia, Canada to Mazatlan, Mexico. They are present in the Gulf of California, occurring as far north as the Bay of Los Angeles.



Yellowtail, *Seriola lalandi.*

Most yellowtail spawn during the summer months, June through September. During this period, adults move offshore and form spawning aggregations. Some two-year-old females may spawn, but all females over three years of age are capable of spawning. Young fish spawn only once during the season, while those seven years of age (20 pounds) and older are capable of multiple spawnings. A 20-pound fish is capable of producing 940,000 eggs during a single season.

Yellowtail are opportunistic daytime feeders. Off southern California, yellowtail stomachs contain sardines, anchovies, jack mackerel, Pacific mackerel, and squid. Fish taken off Mexico frequently are full of pelagic red crabs.

Age and growth studies conducted on yellowtail indicate the fish are relatively slow growing. They gain approximately three to four pounds a year during most of their lives, although very large individuals may gain only one to two pounds per year. Growth can vary considerably from year to year and also between and within geographical areas. The largest recorded individual weighed 80 pounds. The average sizes at selected ages are: age 1, 20 inches and 3.8 pounds; age 2, 25 inches and 7.4 pounds; age 3, 28 inches and 9.9 pounds; age 4, 31 inches and 13.2 pounds; age 5, 33 inches and 15.9 pounds; age 10, 44 inches and 35 pounds.

Within southern California and at the Coronado Islands, sport anglers generally land yellowtail that weigh 8 to 12 pounds. Long-range CPFV anglers fishing off central Baja California usually catch 12 to 18 pound fish. Commercial fishermen generally land 10 to 20 pound yellowtail, because of the selective nature of gill nets.

Results of a tagging study conducted by the California Department of Fish and Game indicate there are two stocks of yellowtail off Baja and southern California. One group occurs south of Cedros Island, Baja California, while the second group occupies the area from Cedros Island northward. There is some interchange of fish between the two groups around Cedros Island. Because of limited mixing between the two stocks, the southern California fishery is wholly dependent on fish recruited from the northern population.

The number of yellowtail available to southern California fishermen in any given year is dependent on whether warm water conditions exist off northern Baja California. Excellent yellowtail catches have occurred during years when water temperatures were at least three to five degrees F. above normal

SMB-26892

in the spring. Conversely, periods of cool water produce low catches. When fish are available, they usually are found nearshore in the spring and fall but offshore during the summer months.

Status of Population

While no population estimate is available for the northern stock of yellowtail, the resource appears to be healthy. The stock is probably not as large as it was in the early 1950's but can support significant sport and commercial fisheries when oceanic conditions are favorable.

Data collected during the 1970's and early 1980's indicate that the northern population has undergone a shift in fish size. Two and three year olds now dominate the catch, whereas six to nine year olds made up the majority of the catch in the past. The shift in size could be an indicator of either population stress or good recruitment.

Because more of the northern stock is available to sport anglers during warm water conditions, CPFV catches during El Niño events should provide an indication of the health of the resource. Three major El Niño events have taken place in recent years: 1959, 1973, and 1983. While CPFV activity has remained relatively stable, catches have declined from 457,000 fish in 1959 to 221,000 fish in 1973 and 179,000 in 1983. The decline is probably reflective of a reduced but still viable yellowtail population off northern Baja California.

Steven J. Crooke
California Department of Fish and Game

References

Baxter, J.L. 1960. A study of the yellowtail *Seriola dorsalis* (Gill). Calif. Dept. Fish and Game, Fish Bull. 110. 96 p.

Crooke, S.J. 1983. Yellowtail, *Seriola lalandei* Valenciennes. Calif. Coop. Oceanic Fish. Invest. Rep. 24:84-87.

Radovich, J. 1961. Relationship of water temperature to marine organisms of the northeast Pacific, particularly during 1957 through 1959. Calif. Dept. Fish and Game, Fish Bull. 112. 62 p.

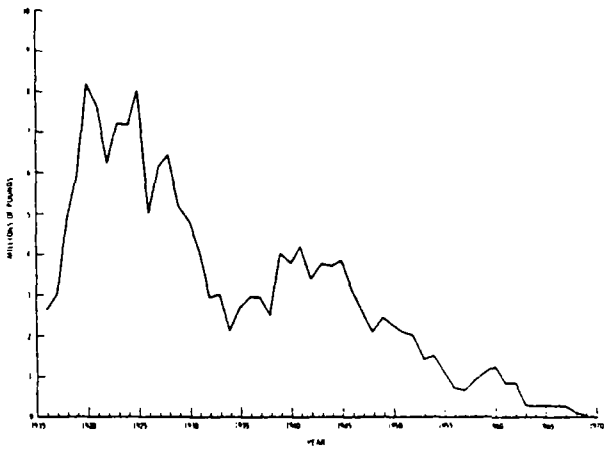
CALIFORNIA BARRACUDA

History of the Fishery

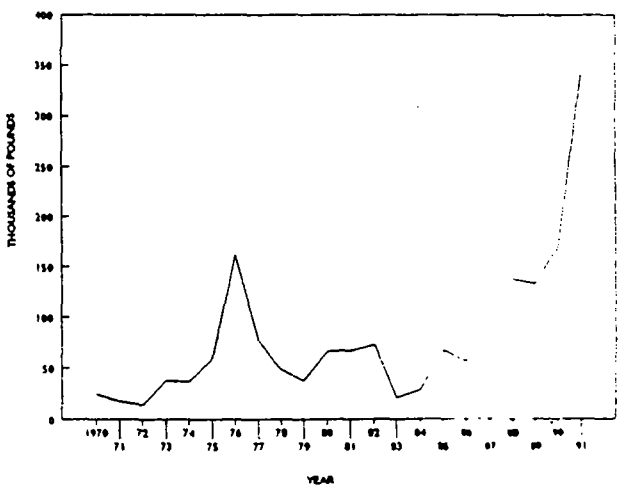
The California barracuda (*Sphyraena argentea*), also known as the Pacific barracuda, has played a significant role in the growth and development of California's commercial and sport fishing industries. Taken primarily off southern California and northern Baja California, Mexico, barracuda figured prominently in the development of the purse seine fishery. Additionally, they have long been a major component of the southern California sport fish catch.

Annual records of commercial barracuda landings date back to 1889, but only nine years of intermittent records exist through 1915, and these are not specific as to catch areas. Since 1916, landing records have differentiated barracuda caught in California waters (essentially off southern California) from those caught "south of state" (northern Baja California waters). Commercial landings for 1889 were 0.5 million pounds, and by 1915 they were 3.6 million pounds. A purse seiner was operating off southern California as early as 1893, and its landings may have contained barracuda. By 1916, the purse seine fleet had at least seven vessels. Influenced by the economic impetus of World War I, the commercial barracuda fishery grew concurrently with the rapid development of the purse seine fleet.

Attempts to manage the barracuda fishery began in 1915 with a minimum size limit of 18 inches for hook-and-line caught barracuda. Since then, many commercial and sport regulations on gear, seasons, weight, size, and bag limits have been enacted, modified, or repealed. Today, most barracuda are taken by gill nets with 3.5-inch mesh, although some are taken by hook and line. The minimum size limit is 28 inches. May and June are usually the peak months of commercial fishing activity for barracuda.



California commercial landings of California barracuda, 1916-1969.

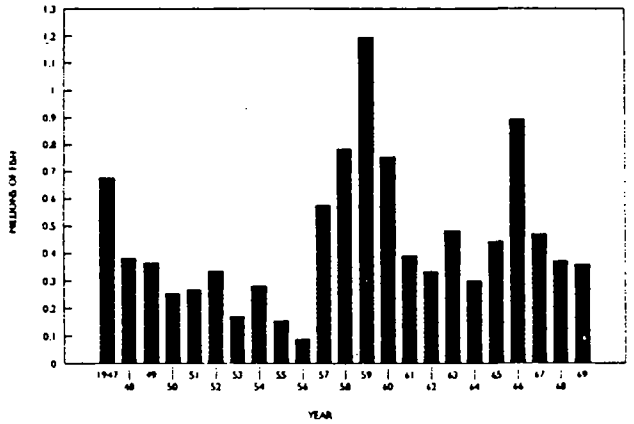


California commercial landings of California barracuda, 1970-1991.

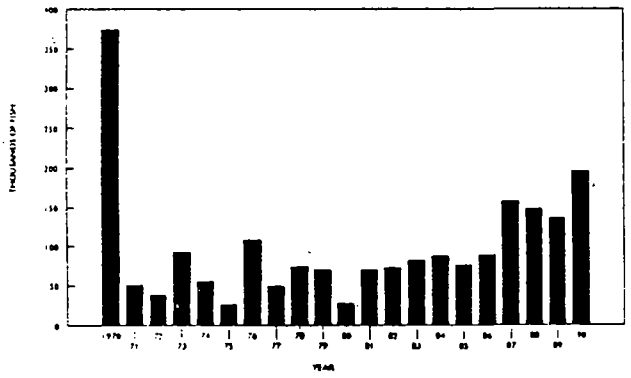
SMB-26893

Annual commercial landings of barracuda taken in California waters averaged 3.1 million pounds from 1916 through 1948, but only about 290,000 pounds from 1949 through 1991. Landings taken "south of state" averaged 1.1 million pounds annually from 1916 through 1968, but only 440 pounds from 1969 through 1989. The major reason for the decline was the imposition of commercial fishing regulations by Mexico which became increasingly restrictive to California fishermen over the years. From 1916 through 1989, annual commercial landings of barracuda taken in southern California waters have exceeded California landings of barracuda taken "south of state" in all but 10 years.

In general, commercial barracuda prices are a function of supply and demand. Historically, the price paid to fishermen has been low. In 1989, commercial fishermen received an average $0.71 per pound.



California commercial passenger-carrying vessel landings of California barracuda, 1947-1969.



California commercial passenger-carrying fishing vessel landings of California barracuda, 1970-1990.

The popularity of California barracuda as a game fish goes back to at least the mid-1920's, as is evident from photographs and newspaper accounts. However, the California Department of Fish and Game (CDFG) did not begin collecting records of commercial passenger fishing vessel (CPFV) sport fish landings until 1936. Records from 1936 through 1940 reveal that CPFV barracuda landings (in numbers of fish) exceeded those of other sport fishes, and that they often equaled or exceeded commercial landings (in weight) for barracuda taken in California waters. Annual landings for these five years averaged roughly 630,000 fish. Records were not kept from 1941 through the first half of 1946. As interest in marine sport fishing grew in the post-World War II era, the sport take of barracuda greatly exceeded that of the commercial fleet in California waters. From 1947 through 1970, the average annual CPFV landings were nearly 450,000 fish. In 1971, the current 28-inch minimum size limit for all sport-caught barracuda became effective, causing an 87 percent decline in CPFV barracuda landings from the previous year. From 1971 through 1990, barracuda CPFV landings fluctuated between 26,289 fish and 157,913 fish and averaged about 79,500 fish annually.

The Marine Recreational Fisheries Statistics Survey has shown that, on average, 54 percent of the total barracuda catch is from CPFVs, 45 percent is from private and rental boats, and 1 percent is from shore. A recent CDFG study has determined that roughly 60 percent of CPFV-caught barracuda are released (almost all of which are less than 28 inches). Los Angeles County accounts for 58 percent of the CPFV barracuda landings.

Sport anglers, especially aboard CPFVs, usually use live anchovies to fish for barracuda. Anchovies are also used to chum and hold barracuda schools close to the boat. Metal or plastic artificial lures in a variety of shapes and colors are also popular. Sport-caught barracuda are taken mainly near the surface. Most fishing activity occurs from May through September, when surface water temperatures range between 62° and 70° F.

California barracuda, *Sphyraena argentea*.

Status of Biological Knowledge

The California barracuda is a nearshore, epipelagic, schooling fish found from Cabo San Lucas, Baja California to Kodiak Island, Alaska. Catch origins indicate the population is centered between San Quentin, Baja California and Point Conception, California. During warm water oceanic events, such as El Niños, a portion of the population may shift northward into central California. Frequently seen at the surface, barracuda have been taken at depths of 120 feet.

Growth in length is most rapid during the first year of life. Barracuda reach a total length of 14 inches at one year. At two years they have grown to 20 inches and weigh about one pound. However, the maximum growth by weight of nearly one pound per year is achieved by four- and five-year-old fish. The minimum size limit of 28 inches, approximately a three-pound fish, is near the average size for a four-year old. At this age, females are about 0.75 inches larger than males, and the difference increases to about 2.5 inches in fish over six years old. The oldest fish aged was an 11-year old measuring 41 inches

SMB-26894

and weighing about nine pounds. Larger and presumably older fish include the state angling record of 15 pounds 15 ounces and a 17-pound fish caught off Carpenteria in 1958 that measured 46.5 inches.

California barracuda produce pelagic eggs and larvae. Fertilization takes place externally as the sexes simultaneously release their gametes. At two years, almost all males and 75 percent of females are sexually mature. All are mature at three years of age. Full sexual maturity occurs in males at a length of 20 inches and in females at 22 inches. In a single spawning, a two-year-old female may produce 50,000 eggs, increasing to about 400,000 by age six. Individuals may spawn more than once during a spawning season. Off southern California, spawning takes place from April to September, peaking in June.

Feeding habits of California barracuda are not well documented, but some potential prey species can be mentioned. During pelagic schooling movements, barracuda may feed on other open water schooling fishes such as northern anchovy, Pacific sardine, Pacific mackerel, jack mackerel, and Pacific saury. In association with kelp beds or shallow water habitats, they may feed on topsmelt and California grunion. Opportunistic feeding on market squid made vulnerable during their spawning activity is likely.

Previous references to the predators that feed on California barracuda have listed sea lions, seals, porpoises, and giant sea bass. Analyses of the gut contents and scat from marine mammals have failed to discover barracuda remains. Observations of California sea lions and harbor seals opportunistically feeding on barracuda injured or entrapped by fishing gear are common, but these animals more typically feed on the same size prey as adult barracuda. Giant sea bass are more likely predators on juveniles and adult barracuda.

California barracuda have an inshore distribution during their early life history. Fish a few inches long are observed in protected bays and marinas. Larger young-of-the-year fish school below the canopy of semiprotected kelp-bed habitats. Older juveniles and adults form large schools that disperse widely in the open-water environment.

Movements of California barracuda have been studied by tagging. Fish tagged during May 1959 at locations off northern Baja California and off southern California were recovered at intermixed locations, indicating a single population. Movements of up to 100 miles north and south occurred during the summer, but a portion of the recoveries were at the release sites. However, a general migration pattern that was distinctly northward during the summer and less distinctly southward during the fall was indicated. Movements are presumably a response to sea temperature, and warm overwintering temperatures off southern California reduce the southward return. High catch success during spring and summer off southern California has been correlated with warm sea temperatures the preceding winter.

Status of Population

The status of the California barracuda population is unknown, because data concerning catch, fishing effort, and age composition are scarce. Barracuda catches off California are variable for many reasons, one of which is that barracuda are migratory with a preference for warmer waters. During an El Niño event, when warmer than normal water masses move up the coast, barracuda are caught far north of their normal range and in greater than average numbers off southern California, suggesting a higher population level. This was apparent during the 1957-1959 El Niño event, one of the most intense on record. However, during the similarly intense 1982-1983 El Niño event, barracuda catches did not increase appreciably. Assuming fishing effort and the percentage of the population migrating northward were similar, the difference suggests that the barracuda population was depressed during the latter El Niño period. Catches in the late 1980's have increased above those of recent previous years, indicating a possible resurgence in population level. Only during one three-year period, 1958-1960, has the number of barracuda off southern California been estimated by the CDFG. Estimates ranged from 1.6 to 2.9 million fish.

Angler placing a California barracuda in an experimental refrigeration system.

Because of uncontrollable factors such as migration, water temperature, and Mexico's management policies, the CDFG's management policies for this species probably have a limited effect on its population level. Nevertheless, the regulations are intended to reduce the likelihood of overfishing this valuable resource.

J.R. Raymond Ally and Ken Miller
California Department of Fish and Game

References

Ally, J.R.R., D.S. Ono, R.B. Read, and M. Wallace. 1991. Status of major southern California marine sport fish species with management recommendations, based on analyses of catch and size composition data collected on board commercial passenger fishing vessels from 1985 through 1987. Calif. Dept. Fish and Game, Mar. Resour. Div., Admin. Rep. 90-2. 376 p.

Orton, G.L. 1955. Early developmental stages of the California barracuda, *Sphyraena argentea* Girard. Calif. Fish and Game. 41:167-176.

Pinkas, L. 1966. A management study of the California barracuda *Sphyraena argentea* Girard. Calif. Dept. Fish and Game, Fish Bull. 134. 58 p.

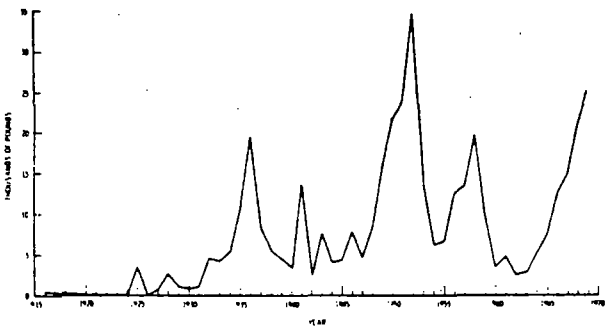
SMB-26895

Schultze, D.L. 1983. California barracuda life history, fisheries, and management. Calif. Coop. Oceanic Fish. Invest. Rep. 24:88-96.
Walford, L.A. 1932. The California barracuda (*Sphyraena argentea*). Calif. Div. Fish and Game, Fish Bull. 37. 122 p.

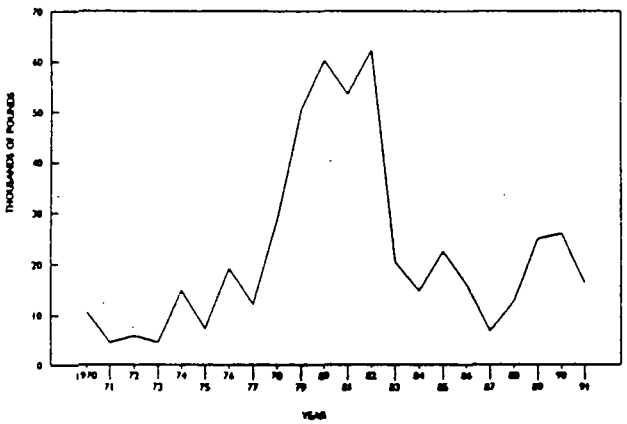
CABEZON

History of the Fishery

As game fish, cabezon (*Scorpaenichthys marmoratus*) are prized by sport divers for edibility, size, and ease of capture. The recreational take by persons aboard commercial passenger fishing vessels (CPFVs) does not comprise a large proportion of the catch, but those that are taken are usually of a good size, averaging around 3.5 pounds. Santa Barbara generally has the highest landings by CPFVs in the state.



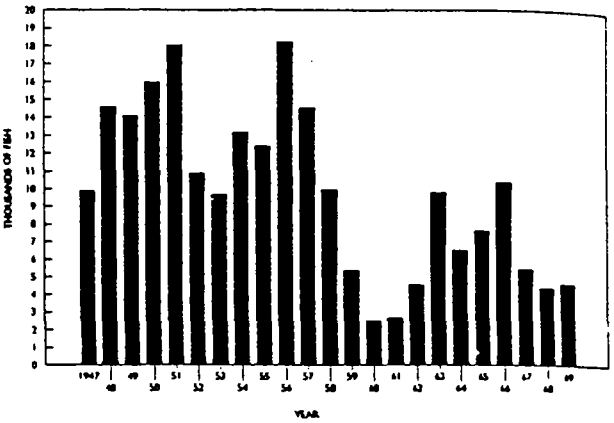
California commercial landings of cabezon, 1916-1969.



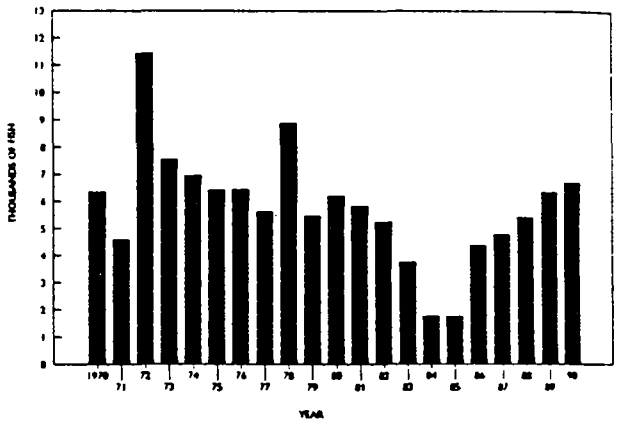
California commercial landings of cabezon, 1970-1991.

Cabezon are taken incidentally in commercial catches by boats fishing for rockfishes using hook and line or gill nets. Although the meat is tasty, the greenish or turquoise color of the flesh renders it undesirable to some fish market customers. Cabezon make up a minor proportion of the total catch; the majority of fish are landed in Monterey.

Sport and commercial landings both peaked during the period 1950-1958. Since that time, sport fish catches have never come close to the 18,000 fish taken in 1956. Since 1970, the catch has averaged under 6,000 fish a year. Commercial landings peaked again between 1979 and 1982 at over 62,000 pounds. This topped the previous peak of 35,000 pounds in 1951. Sport landings have generally been higher than commercial landings, although between 1979 and 1985 this trend apparently reversed. Overall, total landings have fluctuated greatly over the years.



California commercial passenger-carrying fishing vessel landings of cabezon, 1947-1969.



California commercial passenger-carrying fishing vessel landings of cabezon, 1970-1990.

Status of Biological Knowledge

The cabezon is the largest member of the cottid family. In Spanish *cabezon* means big-headed or stubborn, and, proportionally, the massive head is definitely the largest feature of this fish. The specific name *marmoratus* refers to the marbled or mottled appearance of the body, which can be reddish, greenish, or bronze. Generally the belly is a pale turquoise or white, and there are no scales on the body.

Populations range along the eastern Pacific coast from Point Abreojos, Baja California to Sitka, Alaska. They are found on hard bottoms in shallow water from intertidal pools to depths of 250 feet. Fish frequent subtidal habitats in or around rocky reef areas and under kelp beds.

Cabezon may reach an age in excess of 20 years. The largest recorded size is 39 inches in length and over 25 pounds.

SMB-26896

Juveniles can reach a size of nearly eight inches in two years, at which time males may become sexually mature; by three years of age all males have matured. Some females begin to mature in their third year between 10 and 19 inches in length, and by the fifth year all females are sexually mature.

Cabezon, *Scorpaenichthys marmoratus*.

In California, spawning commences in late October, peaks in January and continues until March, while, in Washington, the spawning season begins in November and extends to September with a peak in March and April. There is some evidence that, at least in Washington, females may spawn more than once in a season. Females spawn their eggs on subtidal, algae-free rocky surfaces, which can be horizontal or vertical in orientation. Up to 152,000 eggs can be expected from a large female (30 inches, 23 pounds). Masses of the pale green or reddish eggs are up to 18 inches in diameter and up to two to four inches thick. As the eggs develop they change to an olive green color.

There have been several reports on the toxicity of cabezon roe. In the 1950's, the well-known ichthyologist Carl Hubbs published a personal account from 1923 of eating cabezon roe. As part of an ongoing search for another caviar, Hubbs and his wife consumed the roe and flesh of a cabezon for dinner. Four hours later they "... awoke in misery ... and were violently ill throughout the rest of the night." Both were very weak the following day, but there were no lingering symptoms. Laboratory evidence indicates that the roe is lethal to mice, rats, and guinea pigs. Anecdotal information on egg masses exposed at low tide suggests they are not preyed upon by natural predators such as raccoons, mink, or birds. Observations of captive cabezon have documented a female eating her own eggs with no resulting ill effects.

Males fertilize the eggs after they are spawned by the female, and the male guards the nest. Apparently the same nest sites are used from year to year. Fish are very protective of the nests for the two to three weeks it takes the eggs to develop and hatch.

Pelagic juveniles are silvery when small, spending their first three to four months in the open ocean feeding on tiny crustaceans and other zooplankton. At a size of about 1.5 inches, juveniles leave the open water and assume a demersal existence. They appear in kelp canopies, tide pools, and other shallow rocky habitats such as breakwaters from April to June in California.

Cabezon can be aptly described as "sit and wait" predators. Their mottled coloration lets them blend in with the surroundings as they sit motionless to wait for their next meal. With large, robust pectoral fins set low on the body and a powerful tail, they quickly lunge after unwary prey, engulfing it in their large mouth.

Their diet consists mainly of crustaceans, although large and small cabezon have different diets. Adult fish eat crabs, small lobsters, mollusks (abalone, squid, octopus), small fish, and fish eggs. Small juveniles depend mainly on amphipods, shrimp, crabs, and other small crustaceans.

Juveniles are taken by rockfishes and larger cabezon, as well as by lingcod and other sculpins. Large cabezon may be taken by harbor seals or sea lions, as well as by humans.

Cabezon normally occur nearshore, except as larvae. Usually solitary, juveniles and adults both are common on any rocky bottom area with dense algal growth. They are often in the vicinity of kelp beds, jetties, isolated rocky reefs or pinnacles, and in shallow tide pools.

Most of their time is spent sitting in holes, on reefs, in pools, or on kelp blades beneath the canopy, but not actively swimming. As fish get older and larger they tend to migrate to deeper water. In shallower water they migrate in and out with the tide to feed. Their habit of sitting makes them an easy target for sport divers.

Status of Population

Limited information is available on population biology or changes in biomass over time. As sport diving and spear fishing become more popular, it is possible populations living in popular fishing spots will begin to decline.

Deborah Wilson-Vandenberg
California Department of Fish and Game

References

Fuhrman, F.A., G.J. Fuhrman, D.L. Dull, and H.S. Moser. 1969. Toxins from eggs of fishes and amphibians. J. Agric. Food and Chem. 17:417-424.

Hubbs, C.L. and A.N. Wick. 1951. Toxicity of the roe of the cabezon Scorpaenichthys marmoratus. Calif. Fish and Game 37:195-196.

Lauth, R.R. 1989. Seasonal spawning cycle, spawning frequency, and batch fecundity of the cabezon, *Scorpaenichthys marmoratus*, in Puget Sound, Washington. Fish. Bull., U.S. 87:145-154.

O'Connell, C.P. 1953. The life history of the cabezon *Scorpaenichthys marmoratus* (Ayres). Calif. Dept. Fish and Game, Fish Bull. 93. 76 p.

Pillsbury, J.B. 1957. Avoidance of poisonous eggs of the marine fish *Scorpaenichthys marmoratus* by predators. Copeia 1957:251-252.

LINGCOD

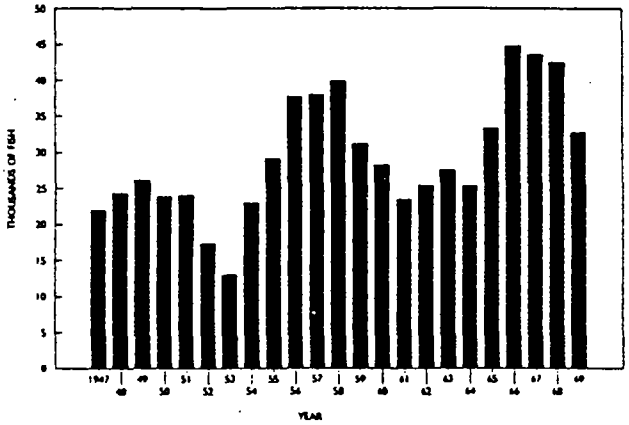
History of the Fishery

The lingcod (*Ophiodon elongatus*) is one of the largest northern California sport fishes. It is an aggressive predator that readily takes either a baited hook or an artificial lure, and it is a prized food fish. Although the raw flesh sometimes has a blue or green color, the flesh when cooked is white and of a mild flavor. From 1981 to 1986, lingcod provided more pounds of fish to

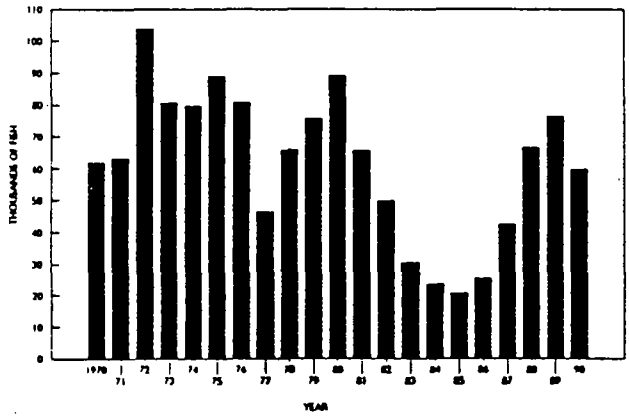
SMB-26897

central and northern California recreational fishermen than any other species, including salmon. Only the rockfish group provides more pounds of fish to northern California recreational fishermen.

Annual landings averaged 51,250 lingcod from 1957 to 1961. At an average weight of eight pounds each, the annual yield was 410,000 pounds. The recreational fishery produced 20 to 25 percent by weight of all lingcod landed in those years. Twenty years later recreational fishermen were landing five times as many lingcod, but they were 20 percent smaller. From 1980 through 1986, annual landings averaged 254,000 fish per year. These fish averaged 6.2 pounds each yielding 1,575,000 pounds per year. The recreational fishermen's share has increased from a quarter to half of all lingcod landings.



California commercial passenger fishing vessel landings of lingcod, 1947-1969.

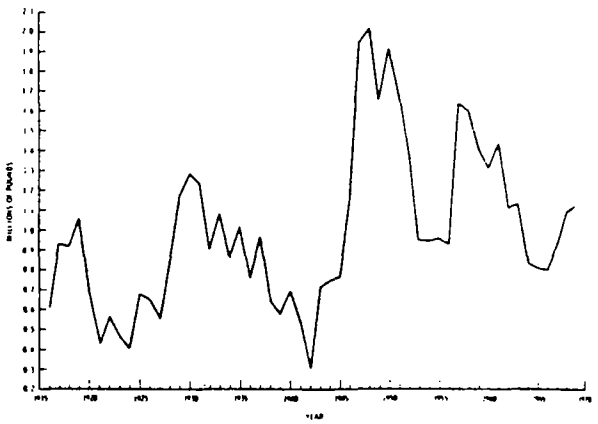


California commercial passenger-carrying fishing vessel landings of lingcod, 1970-1990.

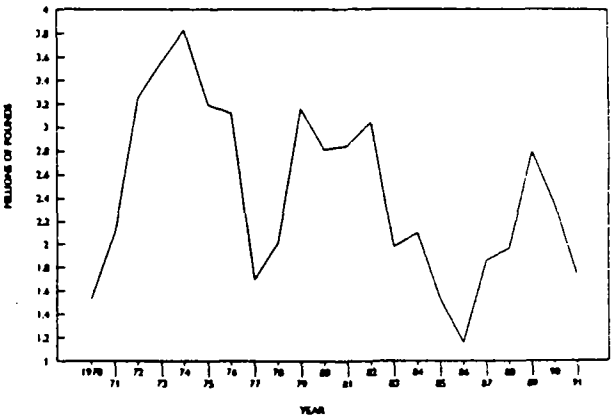
Lingcod are most abundant north of Santa Barbara county, with eighty to ninety percent of the recreational landings being made north of San Luis Obispo County. Divers and recreational anglers both take lingcod. Divers use spears, and anglers use several styles of hook-and-line gear from a variety of fishing platforms. They may use either live or dead bait or artificial lures. Anchovies, squid, sanddabs, small rockfishes, kelp greenlings, and white croakers are used as live bait, while squid is the most common dead bait. Chrome plated jigs are the most popular artificial lures.

Recreational anglers catch lingcod while fishing from commercial passenger fishing vessels (CPFVs), privately owned boats (skiffs), piers, and the shore. In the late 1950's, 61 percent of the lingcod caught by recreational anglers were taken aboard CPFVs. However, the CPFV share of the landings declined to 33 percent in the early 1980's. Skiffs picked up the difference, increasing their share of lingcod landings from 32 to 58 percent. Shore and pier anglers and divers take a relatively small portion of lingcod landings; there appears to have been little change in their share.

Several steps have been taken to halt the decline in size of lingcod available to anglers. A 22-inch size limit was established in 1981, and the bag limit was reduced from ten to five fish one year later. These measures have slowed the decline but have not stopped it entirely.



California commercial landings of lingcod, 1916-1969.



California commercial landings of lingcod, 1970-1991.

The lingcod is also a valuable species in the fresh-fish market trade and is caught primarily north of Santa Barbara. It is frequently sold whole when landed in small quantities. A large lingcod makes an impressive addition to a display of fresh fish on a bed of ice. Hook-and-line caught lingcod are preferred for these displays, and fishermen receive a premium price for such fish because the fish's skin is not marred when they are

SMB-26898

caught. Large catches of lingcod are usually filleted. Boneless portions can be cut from large fillets, and the flesh is slow to develop strong odors. These qualities contribute to the lingcod's commercial value. Commercial fishermen received $1,020,000 for the lingcod they sold in 1989.

Recorded commercial landings in California have ranged from a low of 400,000 pounds in 1924 to a high of 3.8 million pounds in 1974. Larger quantities are taken off Oregon, Washington, British Columbia, and Alaska. Most of the landings preceding World War II were caught by hook-and-line fishermen. Before 1946, commercial landings fluctuated between 1,288,000 pounds in 1930 and 314,000 pounds in 1942, averaging 758,000 pounds per year.

With the introduction of the balloon trawl during World War II, trawl gear became the most important source of lingcod landings. Landings increased to 2,056,000 pounds in 1948, and then declined to 800,000 pounds in 1966. Landings began to recover in the late 1960's, and climbed sharply in the early 1970's reaching a new high of 3,824,000 pounds in 1974. This increase in landings during the 1970's had at least two causes. Lingcod experienced exceptional reproductive success during the late 1960's, and gill nets became an important means of catching rockfish and lingcod at Monterey. Since 1970, a large portion of the commercial lingcod catches south of San Francisco have been taken in gill nets.

During the 1980's, two-thirds of the commercial lingcod landings were taken by trawlers. Eighteen percent were taken with unknown gear and at least 13 percent were taken with gill nets. On average only 2.7 percent of the lingcod sold in the 1980's were caught on hook and line. However, as salmon populations declined and gillnetting was restricted, many fishermen converted to fishing for rockfish and lingcod with hook and line. Hook-and-line landings of lingcod increased seven fold from 1985 to 1989, producing 30 percent of the commercial lingcod landings in 1989.

Trawling is generally prohibited within three miles of shore. Most of the adult males and many of the adult females and juveniles feed in these nearshore areas. Gillnetting for rockfish has recently been prohibited in state waters, further protecting both juvenile and adult lingcod.

Lingcod, *Ophiodon elongatus*.

Status of Biological Knowledge

Lingcod are found only off the west coast of North America. They are distributed in nearshore waters from northern Baja California to the Shumagin Islands along the Alaska Peninsula. Their center of abundance is off British Columbia, and they become less common toward the southern end of their range. Lingcod are found over a wide range of substrates at depths from 10 to 1,300 feet, but most occur in rocky areas from 30 to 330 feet.

Adult lingcod are strongly residential, tending to remain near the reefs or rocky area where they live. Large-scale tagging studies in Canadian waters have found that the vast majority of mature lingcod are recaptured within six miles of where they were tagged. Individual fish do make long movements, however, and one fish that was tagged at Cordell Bank was recaptured nine months later at Coquille Bank, Oregon, over 430 miles away. Juveniles tend to disperse and travel over a wider range than adults.

Lingcod growth follows a typical pattern of rapid increases in length during the first years of life, followed by progressively smaller increases. Although there is large variation in length at age, the average one-year-old fish is 13 inches, and a two-year-old is 17 inches. After age two, females begin to grow faster than males. The average four-year-old female is 24 inches, an eight-year-old is 32 inches, and a 12-year-old is 35 inches. The average four-year-old male is 22 inches, an eight-year-old is 29 inches, and a 12-year-old is 32 inches. In California, the oldest lingcod on record is a 14-year-old, 37-inch female, while the longest is 43 inches. The maximum age recorded anywhere is 20 years, and a 59-inch British Columbia lingcod weighed 70 pounds.

Both sexes mature over a wide size range. In California, some females mature at 20 inches, half are mature at 23 inches, and all are mature by 28 inches. Some males mature at 14 inches, half are mature at 16 inches, and all are mature by 22 inches. Size at maturity is larger for lingcod in more northerly latitudes because these fish grow faster.

Lingcod have a unique form of reproduction which includes spawning migrations into nearshore habitats, reproductive territoriality by males, spawning of an egg mass to form the nest, and the presence of a guardian male at the nest until the eggs hatch. In California waters, spawning begins by November and continues until March, with a peak in December and January. Males move into the spawning grounds first to establish territories, and it appears that larger males select the most suitable nesting sites. Preferred nest sites are rocky areas in shallow water (low tide line to 100 feet) where there are strong currents. A relatively strong current is necessary to oxygenate the egg mass and prevent death of the embryos. Often, egg masses are located on rocky ledges with an opening directly behind the eggs to allow water to pass over the nest. Laboratory studies show that a current with a velocity of four to six inches per second is necessary to provide adequate oxygen levels throughout the egg mass.

Lingcod probably spawn at night. After a female chooses a male and a nesting site, she swims over the site and deposits a layer of several eggs. The male then swims over the site and fertilizes the eggs. This process is repeated until spawning is completed, after which the female immediately leaves the spawning grounds. The eggs become firmly cemented to each other within the gelatinous mass in 24 to 48 hours. A 24-inch female can produce 50,000 eggs, a 32-inch female 124,000 eggs, and a 36-inch female 170,000 eggs. Egg masses of three to 68 quarts have been reported.

After spawning, males remain to guard the nests from predation until hatching is complete. Males position them-

SMB-26899

selves within three feet of the nest and drive away potential predators. On occasion, males have been found guarding two nests if they were close together. If the male is removed, a new male will sometimes assume the guardian role. Males have very aggressive behavior during nest guarding and, therefore, are particularly vulnerable to fishing at this time. An unguarded egg mass is invariably eaten by predators. The eggs generally hatch about seven weeks after they are laid, but incubation can last from five to 11 weeks. Eggs on the outside of the egg mass hatch first. Hatching may continue for 24 to 48 hours, after which the guardian male leaves.

Newly hatched larvae (0.25-0.5 inch) occur in January and February in Humboldt Bay and San Francisco Bay. In Canadian waters, the first appearance of these larvae is in early March. From March until June, lingcod grow about 0.04 inch per day, transforming into pelagic juveniles. Juvenile lingcod may be caught off central California from April (at two inches in length) to June (at three inches) in pelagic trawls in the upper 100 feet of the surface waters. After June, these juveniles disappear from surface waters and migrate to bottom habitats, frequently around kelp and eelgrass beds. Lingcod appear in typically adult habitats at about 12 inches.

Larval lingcod feed primarily on various life stages of copepods. During the pelagic juvenile stage, there is a gradual transition from a diet of small copepods to one of larger copepods, crab larvae, amphipods, euphausiids, and herring larvae. As small benthic juveniles, lingcod feed on herring, flatfishes, shiner perch, and other fishes. Even young lingcod have a very large mouth for their body size, allowing them to feed on prey much larger than other fish of their age and size.

For large juvenile and adult lingcod, fish is the dominant prey, accounting for about 80 percent (by volume) of the stomach contents. In California waters, juvenile rockfishes are the most important prey. When the stomachs of nest-guarding males are examined, they are invariably found to be empty.

Most predation on lingcod occurs during the egg stage, and predation becomes less common with age. The presence of a nest- guarding male prevents fish predators, often other greenlings and surfperches, from consuming the entire egg mass; when the guardian male is removed, the entire egg mass is lost. Invertebrate predators such as predatory snails commonly feed on egg masses and are not repulsed by guardian males. On rare occasions, pelagic juvenile lingcod (1.5 to 2.6 inches) are found in the stomachs of chinook salmon from the Gulf of the Farallones. It can be assumed that other predators of juvenile fish, such as seabirds, particularly the common murre, and marine mammals, prey on juvenile lingcod at a similar rate. Small benthic lingcod are not usual prey of nearshore predators. Because of their large size, large juvenile and adult lingcod escape all but the occasional predator.

Status of Population

Fishing success is currently our only long-term indicator of changes in the abundance of lingcod. Commercial and recreational landings exhibit regular fluctuations with a periodicity of about ten years; commercial landings having peaked seven times in the past 73 years.

Recreational fishing success has exhibited regular fluctuations over the past 40 years, with each peak falling within two years of a peak in commercial landings. Peak landings of lingcod have been preceded by reports of sightings of small lingcod. SCUBA divers occasionally see large numbers of small lingcod less than one year old. Sightings were reported three to five years before each of the last three peaks. The years of exceptional lingcod abundance are probably the result of especially good survival of lingcod larvae. Although divers saw some small lingcod in 1988 and 1990, they were much less abundant than the 1984 cohort that produced the peak sport and commercial landings of 1989.

The population is still strong and is still providing landings of a size similar to those made early in this century. There is no long term trend in commercial landings. There has, however, been a five-fold increase in recreational landings in the past two decades and a 20 percent decline in the average weight of recreationally-caught lingcod. The decline in average weight is accompanied by a considerable reduction in longevity of lingcod. This trend must be stopped to ensure the existence of a spawning biomass large enough to produce an abundance of larvae when oceanic conditions are conducive to their survival.

Peter B. Adams
National Marine Fisheries Service

James E. Hardwick
California Department of Fish and Game

References

Adams, P. 1990. Status of lingcod (*Ophiodon elongatus*) stocks off the coast of Washington, Oregon and California. Appendix F. *In*: Status of the Pacific coast groundfish fishery through 1986 and recommended acceptable biological catches for 1987. Pacific Fishery Management Council, Portland.

Cass, A.J., R.J. Beamish, and G.A. McFarlane. 1990. Lingcod (*Ophiodon elongatus*). Can. Sp. Pub., Fish. and Aquat. Sci. 109. 30 p.

Fitch, J.E. 1958. Offshore fishes of California. Calif. Dept. Fish Game. 80 p.

LaRiviere, M.G., D.D. Jessup, and S.B. Mathews. 1981. Lingcod, *Ophiodon elongatus*, spawning and nesting in San Juan Channel, Washington. Calif. Fish and Game 67:231-239.

Miller, D.J. and J.J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Calif. Dept. Fish and Game, Fish Bull. 158. 137 p.

KELP GREENLING

History of the Fishery

Kelp greenling (*Hexagrammos decagrammus*) are fished primarily for sport, but there is a small commercial fishery based largely on catch incidental to the lingcod or inshore rockfish fisheries. Because of their abundance in nearshore rocky areas, they are frequently caught by people fishing from shore or small boats and are a common target for spear fishermen underwater. Sport fishing surveys made from 1958 to

SMB-26900

1961 showed that kelp greenling were the most frequent catch of shore fishermen north of San Francisco, where in some areas they made up more than 30 percent of the total catch. In each of those years in California, an average of 54,000 kelp greenling were caught by hook-and-line fishermen and another 2,000 by spear fishermen. In later surveys from 1979 to 1986, the estimated sport catch averaged 116,000 fish per year, with 109,000 of these taken between Monterey County and the Oregon border. It should be noted that the two sport fishing surveys used different sampling designs, and so results may not be comparable. By comparison, the commercial catch reported from 1987 to 1989 averaged about 5,000 fish per year. Most of these were sold in the fresh-fish market. Though fillets from kelp greenling are not as large as those from their more popular relative the lingcod, texture and taste are comparable.

Kelp greenling, *Hexagrammos decagrammus*.

Status of Biological Knowledge

Kelp greenling range from San Diego to the Aleutian Islands, but are common only north of Morro Bay. Here they are one of the most conspicuous fishes in rocky nearshore habitats often in and around kelp beds. The male and female look so different that they were first described as separate species. The body color is variable in both sexes, ranging from light gray to brown. Males, however, have large irregular blue patches anteriorly, while females are uniformly covered with smaller dark spots.

These solitary fish are common at depths between 10 and 60 feet, and range down to 150 feet. Sport catches indicate that larger fish live in deeper water. For example, fish caught at 80 to 100 feet range from 12 to 18 inches long while those caught at 20 to 40 feet tend to be eight to 13 inches long. Kelp greenling grow faster than most nearshore fishes during their first three years. After the third year, growth slows, especially in males (as it does in lingcod), so that by the fifth or sixth year males are smaller than females. The maximum reported age and size is 16 years and 21 inches. At age 3, males average 10.6 inches and females 9.1 inches. By age 5, the males average 12.6 inches while females are 14.7 inches. Ten year olds average 15.5 and 16.4 inches, respectively. These studies were done in Puget Sound, Washington.

The reproductive behavior of greenling is similar to that of the lingcod. Females are mature by their fourth year and spawn adhesive egg masses on the seabed and encrusting biota within the territories of courting males. In Puget Sound, females deposit egg masses that range from golf-ball to tennis-ball size, with an average of about 4,000 eggs per cluster. Males fertilize the eggs and guard them until larvae about one third of an inch long emerge four to five weeks later. Often, males guard more than one egg mass at a time, each possibly produced by a different female. Hatching occurs from December through February in northern California and gets progressively earlier to the north, November through January in Puget Sound and August through September in Alaska. Larvae and early juveniles feed on small copepods and spend about one year in the pelagic environment before entering the nearshore benthic community.

After they settle in the nearshore environment, kelp greenling have flexible food habits. During most of the year, they consume a variety of prey that is consistently available in the habitat, including crabs, amphipods, polychaetes and ascidians. There are brief periods when organisms such as juvenile fishes or herring spawn become exceptionally abundant, and kelp greenling shift their food habits to take advantage of these opportunities.

The primary predators of adult greenling are lingcod, and the harbor seal. As juveniles they probably are prey of many nearshore predators.

Status of Population

There are no estimates of abundance for kelp greenling in California. The yearly sport catch remained relatively constant during the eight years (1979-1986) it was surveyed. Since decline in catch is one symptom of overfishing, there is no indication that current levels of fishing are having adverse effects on the population. Spear fishermen may overfish local populations, however, because they can select individual targets, and greenling are particularly vulnerable to spears when guarding their nests. Other data that could reveal changes in the population structure are not available.

Dan Howard
National Marine Fisheries Service

References

Barker, M. W. 1979. Population and fishery dynamics of recreationally exploited marine bottomfish of northern Puget Sound. Ph.D. Dissertation, University of Washington, Seattle, 152p.

Demartini, E. E. 1986. Reproductive colorations, paternal behavior, and egg masses of kelp greenling, *Hexagrammos decagrammus*, and whitespotted greenling, *H. stelleri*. Northwest Science 60(1):32-35.

Gorbunova, N. N. 1970. Spawning and development of greenlings (family Hexigrammidae). *In*: Rass, T. S. (ed.), Greenlings: taxonomy, biology, interoceanic transplantation. (Trans. from Russian) Isr. Progr. Sci. Transl. No. 5553, p. 121-185.

Rothrock, G. C. 1982. Age-length, weight, fecundity, and meristics of the kelp greenling (*Hexagrammos decagrammus*) off California. Masters Thesis, University of California of Davis. 95 p.

WHITE SEABASS

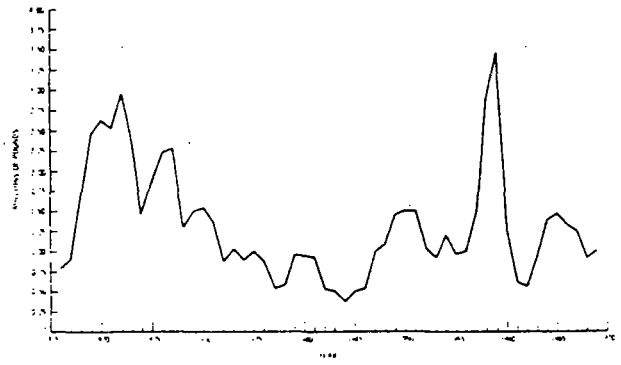
History of the Fishery

White seabass (*Atractoscion nobilis*) have been favored by California anglers and consumers for at least a century. Coastal

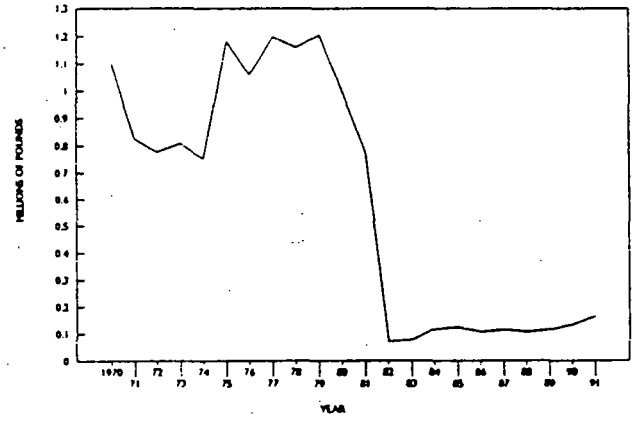
Indian middens have yielded many seabass ear bones (otoliths) suggesting that this fish was highly regarded for food and possibly used for ceremonial purposes.

Commercial landings of white seabass have fluctuated widely over the nearly 75 years of record keeping. Almost three million pounds were reported in 1922, 599,000 in 1937, 3.5 million in 1959, and 70,000 in 1982. Since 1959 the trend has been one of decline, although landings have been over 100,000 pounds for the last eight years (1984-1991). Although there was a commercial fishery in the San Francisco area from the late 1800's to the mid-1920's, landings of fish caught north of Point Conception rarely exceeded 20 percent of the total California catch.

Today, catches of white seabass are concentrated along the coast from Point Conception to San Diego and around the Channel Islands. Before 1982, California commercial fishermen landed thousands of pounds of white seabass taken in Mexico. Often these landings comprised more than 80 percent of the annual catch. Since then, the Mexican government has denied access permits to U.S. fishermen and the fishery is concentrated in California.



California commercial landings of white seabass, 1916-1969.

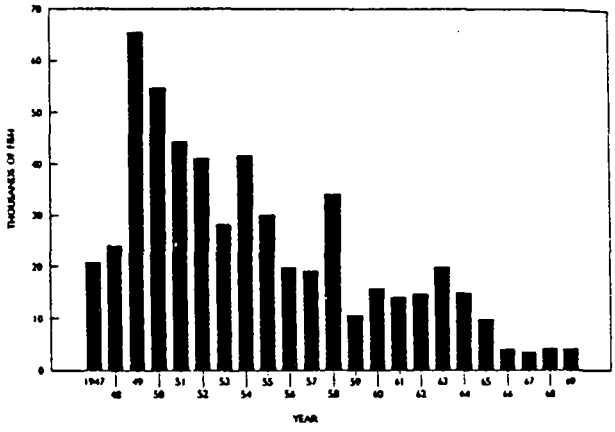


California commercial landings of white seabass, 1970-1991.

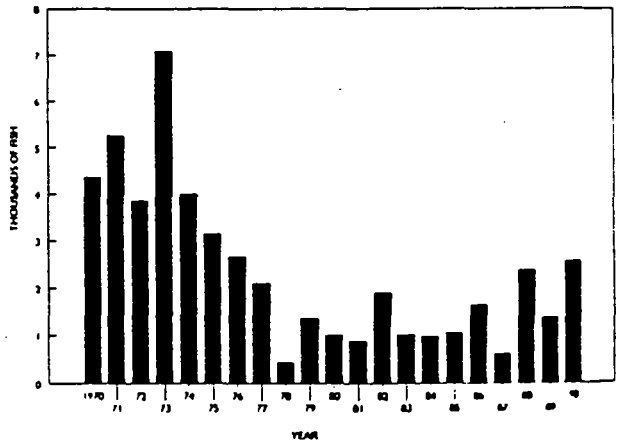
During the early years of the fishery, commercial catches were made by gill nets, hook and line, and round-haul nets such as lamparas and purse seines. Purse seining was curtailed in the late 1920's because decreasing catches made it uneconomical. Since all round haul nets were prohibited in the early 1940's, gill nets have been the major commercial fishing gear. Technological changes in gill nets have occurred, but basically the nets of today are constructed and fished as in the past. Some commercial hook-and-line fishing takes place during the early spring, when large seabass are available.

Although the legal size limit for white seabass is 28 inches (about seven pounds), the average commercially caught fish is nearly 40 inches (about 20 pounds). Because of consumer demand, seabass has always commanded relatively high prices. In 1991, commercial fishermen were paid about $2.25 per pound for whole fish. At the retail level the fish are sold fresh, primarily as fillets and steaks.

Recreational fishing for white seabass began around the turn of the century. Because of their size and elusive nature, seabass are popular with anglers. Historical records show that anglers on commercial passenger fishing vessels (CPFVs) landed an average of 44,600 fish annually during the period 1947-59. The catch steadily declined to an average of 11,000 fish in the 1960's, 4,300 fish in the 1970's, and 1,400 fish in the 1980's. These figures are somewhat misleading, as additional seabass are caught by anglers aboard private boats, for which accurate catches are difficult to estimate.



California commercial passenger-carrying fishing vessel landings of white seabass, 1947-1969.



California commercial passenger-carrying fishing vessel landings of white seabass, 1970-1990.

SMB-26902

Today, anglers catch mostly small white seabass, and they have difficulty locating and catching large ones. While the 28-inch size limit also applies to recreational anglers, most of the catch (kept and released) is between 20 and 24 inches. In a survey of private boaters at launch ramp facilities during 1978-1982, biologists found that only 6 to 16 percent of the white seabass kept were of legal size. In a similar survey aboard CPFVs during 1985-1987, biologists reported that 16 to 25 percent of the seabass caught were legal. However, during short periods in spring, large seabass are caught. These fish can range in size from 35 to 55 inches (15 to 45 pounds).

White seabass are more often caught with live bait than with dead bait or lures, but all are effective when the fish are actively feeding. Seabass can sometimes be brought to the surface by heavy chumming with live bait. Anglers fishing around Santa Catalina Island have reported consistently good catches using blacksmith and silversides as bait. However, when available, live squid and Pacific sardines are popular baits. Spearfishing for large seabass by free-divers (without SCUBA) is successful in kelp beds.

Regulations covering white seabass have been in effect since 1931 and have included a minimum size limit, closed seasons, bag limits, and fishing gear restrictions. Such regulations are in effect today, with slight variations.

White seabass, *Atractoscion nobilis*.

Status of Biological Knowledge

White seabass is the largest member of the croaker family (Sciaenidae) in California. Fish weighing nearly 90 pounds with lengths of five feet have been recorded, but individuals larger than 60 pounds are seldom seen. White seabass range from Magdelena Bay, Baja California, Mexico to the San Francisco area. They are also found in the northern Gulf of California. During the strong El Niño of 1957-1959, seabass were reported as far north as Juneau, Alaska and British Columbia, Canada.

The center of the white seabass population presently appears to be off central Baja California. Recent genetic research of seabass populations shows a definite mingling of fish from California and Mexico. However, there may be local subpopulations of fish that do not mix regularly. While the question of population continuity remains unresolved, there is evidence that each summer the fish move northward with warming ocean temperatures (as demonstrated by catches). Biologists believe the movement is probably spawning-related.

Spawning occurs from April to August, with a peak in the late spring to early summer. Fecundity (egg productivity) for this species has not been determined, but a maturity study in the late 1920's reported that females begin maturing when four years old (nearly 24 inches), and some males were sexually mature at three years (20 inches). All white seabass have probably spawned at least once by age six (nearly 32 inches).

The eggs, which are the largest of any croaker on the west coast, are planktonic. The larvae, which are hardy and darkly colored, have been collected from Santa Rosa Island, California to Magdelena Bay. Most are found in the inshore areas of Sebastian Viscaino and San Juanico Bays, Baja California, indicating that major spawning occurs off central Baja California.

Young-of-the-year white seabass, ranging in length from 0.25 inch to 2.25 inches, inhabit the open coast in waters 12-30 feet deep. They associate with bits and pieces of drifting algae in areas of sandy ocean bottom. By the time they are two or three years old, they move into protected bays where they utilize eelgrass communities for cover and forage. Older juveniles are caught off piers and jetties and around beds of giant kelp. Adult seabass occupy a wide range of habitats including kelp beds, reefs, offshore banks, and the open ocean. Adult white seabass eat Pacific mackerel, Pacific sardines, squid, pelagic red crabs, and Pacific herring.

Laboratory spawning of white seabass was first induced in 1982. Shortly thereafter, a pilot program was begun to test the feasibility of raising seabass for population enhancement. By 1991, more than 100,000 juvenile white seabass had been released off San Diego. Additionally, valuable life history information has been gathered during this program. More work is necessary to determine if artificial propagation is successful in enhancing the seabass population.

Status of Population

The range of the white seabass population has contracted since the early part of this century, and few are found north of Point Conception. Few data are available concerning the status of seabass in Mexico, and it is difficult to determine whether the decline in California waters indicates problems for the entire population.

Population estimates have not been made. Fishery biologists have been concerned about the decline in landings since the late 1920's. Today, this concern still exists within the scientific community, commercial fishing industry, and with the angling public. Human-induced changes, such as pollution, overfishing, and habitat destruction have probably contributed to this long-term population decline. However, natural environmental changes can also influence the population. The large numbers of small seabass caught in recent years suggests that the 1982-1983 El Niño helped to increase young fish survival. It is unknown whether this will subsequently enhance the adult spawning population.

Marija Vojkovich
California Department of Fish and Game

References

Allen, L.G. and M.P. Franklin. 1988. Distribution and abundance of young-of-the-year white seabass, *Atractoscion nobilis*, in the

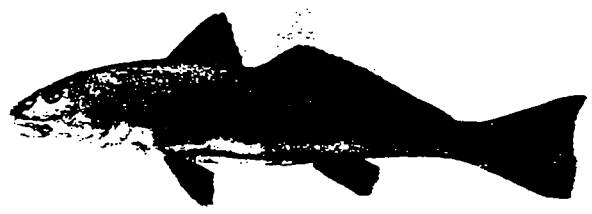
vicinity of Long Beach Harbor, California in 1984-1987. Calif. Fish and Game 74:245-248.
Clark, F.N. 1930. Size at first maturity of the white seabass (*Cynoscion nobilis*). Calif. Fish and Game 16:319-323.
Moser H.G., D.A. Ambrose, M.S. Busby, J.L. Butler, E.M. Sandknop, B.Y. Sumida, and E.G. Stevens. 1983. Description of early stages of white seabass, *Atractoscion nobilis*, with notes on distribution. Calif. Coop. Oceanic Fish. Invest. Rep. 24:182-193.
Skogsberg, T. 1939. The fishes of the family Sciaenidae (croakers) of California. Calif. Div. Fish and Game, Fish Bull. 54. 62 p.
Thomas, J.C. 1968. Management of the white seabass (*Cynoscion nobilis*) in California waters. Calif. Dept. Fish and Game, Fish Bull. 142. 34 p.
Vojkovich, M. and R.J. Reed. 1983. White seabass, *Atractoscion nobilis*, in California-Mexican waters: status of the fishery. Calif. Coop. Oceanic Fish. Invest. Rep. 24:79-83.

CALIFORNIA CORBINA

History of the Fishery

The California corbina (*Menticirrhus undulatus*) is reserved as a recreational resource. It has been illegal to take corbina with nets since 1909 and illegal to sell or buy them since 1915. This wary species is a real challenge to anglers. Sometimes corbina can be seen in small scattered schools, swimming slowly along the bottom seeking sand crabs. While feeding in this manner, they seldom take bait. The corbina is considered one of the most difficult fish to catch in southern California, although on occasion it throws caution to the wind and takes fishermen's bait without hesitation. Its temperamental behavior and fine fighting qualities make corbina a popular surf fish, accounting for about 15 percent of the surf fisherman's bag in southern California. Corbina can be taken throughout the year, but summer and early fall provide the best fishing.

A 1963-1966 survey estimated that 38,000 corbina were taken by southern California anglers, making it the third ranked species in the surf fisherman's creel. Marine Recreational Fishery Statistics Survey estimates for 1979 through 1989 ranged between 30,000 and 96,000 fish caught; the eleven year average was 55,700.



California corbina, *Menticirrhus undulatus*.

Status of Biological Knowledge

Corbina, which grow to at least 28 inches, are found along sandy beaches and shallow bays to depths of 45 feet, from Point Conception, California, south to the Gulf of California. A verified specimen weighing seven pounds, four ounces was caught in 1955 at San Onofre. Males mature at an age of two years (10 inches) and females at age three (12 inches). A 20-inch corbina was eight years old.

The spawning season is from June through September and is heaviest in July and August. Spawning apparently takes place offshore, since running-ripe fish are not often found in the surf zone. Eggs are pelagic. Young about one inch long have been observed outside the surf in four to eight feet of water.

The diet of juveniles is small crustaceans. As they grow, they gradually progress to clam siphons, and then primarily sand crabs by the time they reach a length of about eight inches. Adults may be seen feeding in the surf, at times in water so shallow their backs are exposed. They scoop up mouthfuls of sand and separate out the food by pumping sand through the gill openings.

Tagging studies indicate that movement is limited, and that corbina have no discernible migratory patterns. The greatest distance traveled was 51 miles.

Status of Population

Population size, recruitment, and mortality are unknown; however, given the fairly stable catch estimates, the population appears to be sustaining itself under the present level of recreational harvest.

Malcolm S. Oliphant
California Department of Fish and Game

References

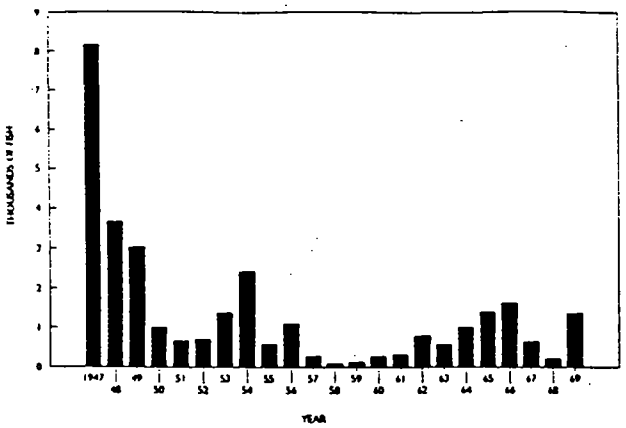
Carlisle, J.G., Jr. 1961. California corbina. Page 28 in California ocean fisheries resources to the year 1960. Calif. Dept. Fish and Game. 79 p.
Joseph, D.C. 1962. Growth characteristics of two southern California surffishes, the California corbina and spotfin croaker, family Sciaenidae. Calif. Dept. Fish and Game, Fish Bull. 119. 54 p.
Skogsberg, T. 1939. The fishes of the family Sciaenide (croakers) of California. Calif. Div. Fish and Game, Fish Bull. 54. 62 p.
Starks, E.C. 1919. The fishes of the croaker family (Sciaenidae) of California. Calif. Fish and Game. 5:13-20.

SPOTFIN AND YELLOWFIN CROAKERS

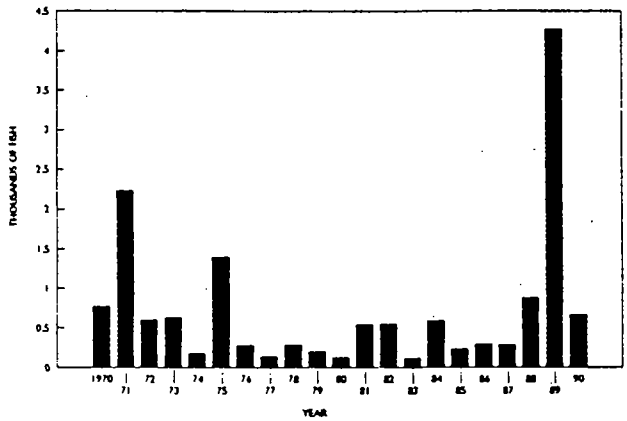
History of the Fishery

Spotfin croaker (*Roncador stearnsi*) and yellowfin croaker (*Umbrina roncador*) are reserved for sport fishing only. In 1909, it became illegal to take them with nets and, in 1915, illegal to sell them. The two species together make up about 10 percent of the southern California surf fishermen's catch. A 1963 survey estimated that anglers fishing from piers, jetties, and the shoreline caught 29,000 spotfin and 17,000 yellowfin croakers between Point Conception and the U.S.-Mexico border. Some can be caught year-round, but late summer is the best time for spotfin croaker fishing. Good fishing depends on runs, and when "croaker holes" are found, all present can enjoy the bonanza, whether in a bay, on a pier, or in the surf.

SMB-26904



California commercial passenger-carrying fishing vessel landings of yellowfin croaker, 1947-1969.



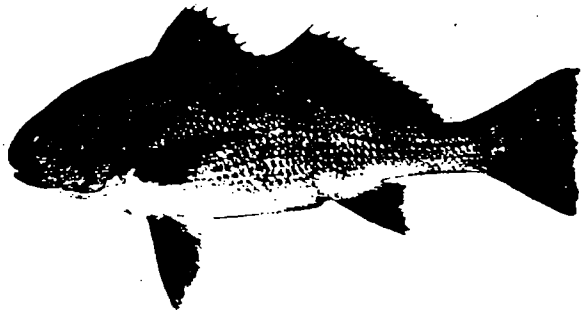
California commercial passenger-carrying fishing vessel landings of yellowfin croaker, 1970-1990.

Most of the spotfin croaker catch consists of small- to medium-size fish. There is an offshore reserve of larger fish that rarely is exploited. In a study by the California Department of Fish and Game, several hundred of these offshore fish were tagged, but only about one percent of them were subsequently caught by surf fishermen. The small- and medium-size fish tagged onshore had a return of over six percent. The tagging program also showed that spotfin croaker move around considerably without a discernible pattern. Fish tagged in Los Angeles Harbor were later taken off Oceanside. Surf fishermen use conventional and spinning gear. Preferred baits are marine worms, clams, and mussels. Their fighting spirit and delicate taste make spotfin croaker a prized catch.

Yellowfin croaker are caught by the commercial passenger fishing vessel (CPFV) fleet, as well as from piers, jetties, private vessels, and the shoreline. Annual CPFV catches of yellowfin croaker have varied widely, ranging from just under 100 fish to a high of just over 8,000 in 1947.

Status of Biological Knowledge

Spotfin croakers range from Point Conception to San Juanico Bay in southern Baja California, while yellowfin croakers occur from San Francisco southward into the Gulf of California. In California, these two species are most common south of Los Angeles Harbor. They live along beaches, in bays, and in shallow sloughs over bottoms varying from course sand to heavy mud at depths from four feet to 50 feet.



Spotfin croaker, *Roncador stearnsi*.

Spotfin croakers prefer depressions and holes near shore. Many "croaker holes" are well known to surf anglers. Spotfin croaker aggregate in small groups or schools of 50 or fewer fish; however, schools containing several hundred fish are occasionally encountered.

Spotfin croakers may reach a weight of 10 or more pounds. A fish weighing 10.5 pounds was eight or nine years old, while one large male 26.5 inches long was at least 15 years of age. Large males are a golden color and commonly are called golden croaker. Males first spawn at two years of age, when they are about nine inches long. Most females spawn at three years and average about 12.5 inches. All are mature at four years, when they measure about 14.5 inches. Spawning occurs from June to September, probably offshore, since no ripe fish have been captured in the surf zone. One-inch juveniles appear in the surf zone in the fall.

Yellowfin croakers are smaller, a medium size fish being about 16 inches long. A 10-inch fish is four years old, while a 15-inch fish is about age 10. A few fish have been caught which weighed over five pounds, but most are three pounds or less. Indications are that spawning occurs during summer months.

Status of Population

Population size, recruitment, and extent of fishing pressure on these species are unknown. California is on the northern fringe of the populations, and the stock size has not been determined for either species. From 1947 to 1958, there was a downward trend in CPFV landings of yellowfin croaker. Since 1958, catches have been highly variable, with the 4,300 fish reported in 1989 being the highest since 1947. Modifications of the inshore environment, including development, land fills, and dredging, have had an adverse effect on the habitats of both species.

Malcolm S. Oliphant
California Department of Fish and Game

References

Carlisle, J.G., Jr. 1961. Spotfin croaker. Pages 28-29 in California ocean fisheries resources to the year 1960. Calif. Dept. Fish and Game. 79 p.

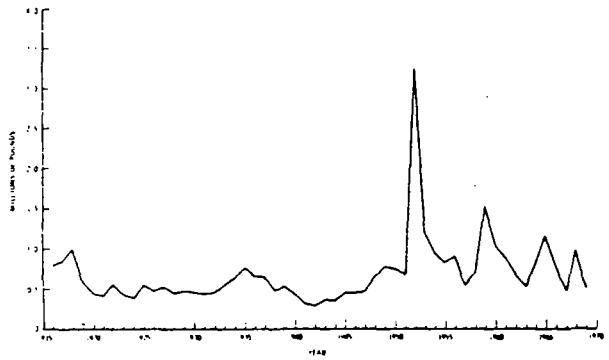
SMB-26905

Joseph, D.C. 1962. Growth characteristics of two southern California surffishes, the California corbina and spotfin croaker, family Sciaenidae. Calif. Dept. Fish and Game, Fish Bull. 119. 54 p.
Skogsberg, T. 1939. The fishes of the family Sciaenide (croakers) of California. Calif. Div. Fish and Game, Fish Bull. 54. 62 p.
Starks, E.C. 1919. The fishes of the croaker family (Sciaenidae) of California. Calif. Fish and Game. 5:13-20.

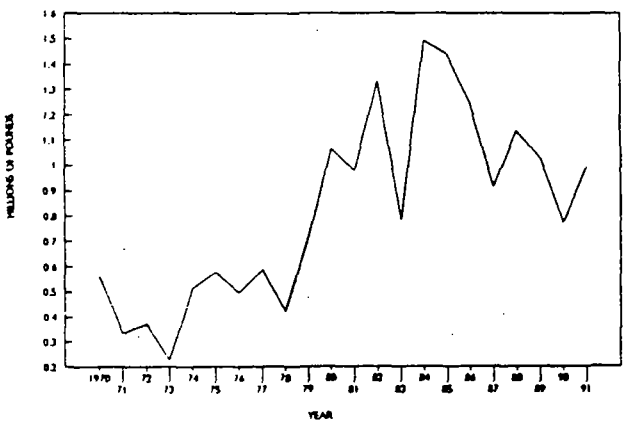
WHITE CROAKER

History of the Fishery

Although not a highly-prized species, the white croaker (*Genyonemus lineatus*) is an important constituent of commercial and sport fisheries in California. Before 1980, the commercial catch of white croakers was primarily by roundhaul net (mainly lampara), although some were taken by trawl, gill net, and hook and line. Since 1980, most white croakers have been taken by gill net, and some are still taken by the other gears.



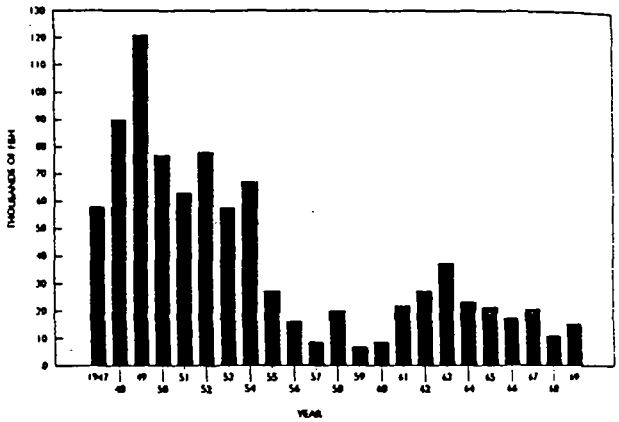
California commercial landings of white croaker, 1916-1969.



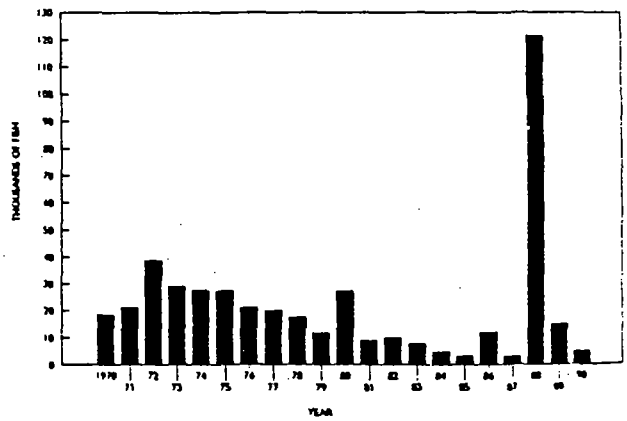
California commercial landings of white croaker, 1970-1991.

Pre-1980 white croaker landings averaged 658,000 pounds annually and exceeded one million pounds in several years. Peak landings in 1952 (88 percent in southern California) were probably in response to the total collapse of the sardine fishery that year. Since 1980, total landings have averaged 1.1 million pounds and were above one million pounds in all but four years. Before 1980, 73 percent of the catch was in southern California. Since 1980, 58 percent of the catch has been in central California. The changes in fishing methodology and area of greatest landings since 1980 are due primarily to the entrance of southeast Asian refugees (mainly Vietnamese) into this fishery. Many of these refugees who settled in California's coastal areas were gillnet fishermen in their homelands and sought to earn their living here by that method of fishing. The underutilized white croaker resource (especially in central California) and moderate start-up costs required for gillnetting (small to medium-size boats and moderate gear costs) offered many of them an opportunity to enter the commercial fishing business.

Most of the commercial catch is sold in the fresh fish market, although a small amount is used for live bait. In the past, the species was sold under the name "kingfish," and a number of markets still use that name. Also, small quantities of another croaker, the queenfish (*Seriphus politus*), are included in the commercial landing records, mostly for southern California.



California commercial passenger-carrying fishing vessel landings of white croaker, 1947-1969.



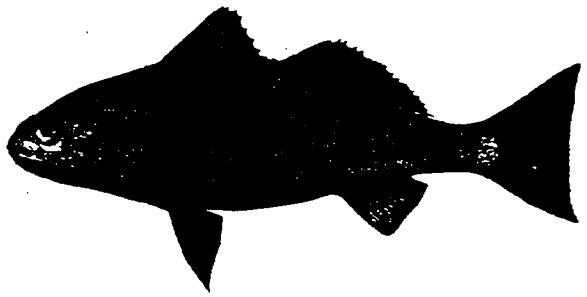
California commercial passenger-carrying fishing vessel landings of white croaker, 1970-1990.

Federal recreational fisheries statistics estimate that about two to three million white croakers were taken each year in California's sport fishery from 1980 through 1986. At an average weight of about 0.4 pounds per fish, the average annual

SMB-26906

weight of the estimated white croaker sport catch was about one million pounds, nearly equaling the commercial catch.

Over 80 percent of the sport catch is in southern California. Anglers fishing from piers, breakwaters, and private boats account for about 90 percent of the catch. Anglers aboard commercial passenger fishing vessels often consider white croakers a nuisance.



White croaker, *Genyonemus lineatus*.

Status of Biological Knowledge

The white croaker is an abundant, nearshore species in California, usually found near the bottom over sandy substrates. They range from Vancouver Island, British Columbia to Magdalena Bay, Baja California, but are not abundant north of Point Reyes, California. They usually swim in loose schools, and are found from the surf zone to depths as great as 600 feet and in shallow bays, sloughs, and lagoons. Most of the time, they occupy offshore areas at depths of 10 to 100 feet, but sometimes are fairly abundant to a depth of 300 feet.

White croakers up to four pounds have been reported, but those weighing over two pounds are extremely rare. They live to about 12 years and reach a length of up to 16.25 inches. Females grow slightly faster than males. By one year (about 5.5 inches for males, 6 inches for females), over 50 percent of both sexes are sexually mature. By three or four years of age and 7.5 inches in length, all white croakers are mature.

In southern California, white croakers spawn mainly from November through April, with peak months being January through March. In central California, they spawn all year and may have winter and summer spawning peaks (ovary weights were found to be highest in January and September and lowest in May). Females may spawn about once every five days and about 18 to 24 times each season, depending upon their size and age. Batches of eggs ranged from an estimated 800 eggs in a 6-inch female to 37,200 in a 10-inch female. The fertilized eggs are pelagic and occur where ocean depth ranges from about 25 to 120 feet. The larvae initially are pelagic and most abundant where ocean depth ranges from about 50 to 75 feet. As the larvae grow, they descend toward the bottom and migrate towards shore. Juveniles occur near the bottom where ocean depth is about 10 to 20 feet. As they mature, they migrate to deeper water.

The diet of white croakers includes a variety of small fishes, shrimps, crabs, squid, octopi, clams, worms, and other items, living or dead. They are preyed upon by seals, sea lions, halibut, giant sea bass, bluefin tuna, and other fishes.

White croakers which live near marine waste discharges may concentrate toxic materials in their bodies at levels that are considered hazardous for human consumption. These materials build up in the food chain and accumulate at high levels in predators such as the white croaker. Included are pesticides (DDT, DDE, etc.), polychlorinated biphenyls (PCB's), metals (zinc, selenium, mercury, etc.), and petroleum products. Some white croakers in these areas are diseased and malformed and some develop tumorous growths. Current health guidelines advise against human consumption of white croakers from southern California waters in Santa Monica Bay, off the Palos Verdes Peninsula, and the Los Angeles-Long Beach Harbor area.

Status of Population

The size of the white croaker population is not known. However, increasing catches with greater fishing effort, the species' fecundity, and age and size at sexual maturity relative to harvest sizes indicate that the overall population is healthy and is sustaining itself under current fishing pressure.

Paul W. Wild
California Department of Fish and Game

References

Love, M.S., G.E. McGowen, W. Westphal, R.J. Lavenberg, and L. Martin. 1984. Aspects of the life history and fishery of the white croaker, *Genyonemus lineatus* (Sciaenidae), off California. Fish. Bull., U.S. 82:179-198.

Puffer, H.W., M.J. Duda, and S.P. Azen. 1982. Potential health hazards from consumption of fish caught in polluted coastal waters of Los Angeles County. No. Amer. Jour. Fish. Mgmnt. 2:74-79.

Watson, W. 1982. Development of eggs and larvae of the white croaker *Genyonemus lineatus* Ayres (Pices: Sciaenidae), off the southern California coast. Fish. Bull., U.S. 80:403-417.

SURFPERCHES

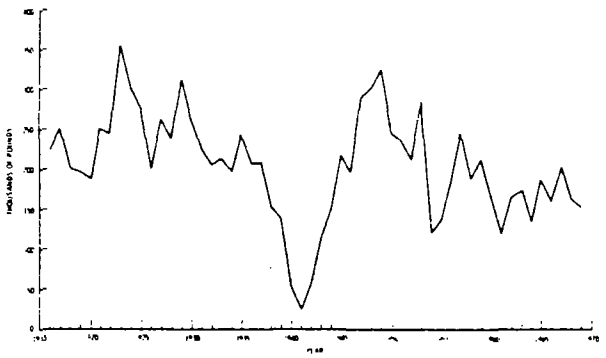
General

The surfperches, family Embiotocidae, are a small abundant assemblage of 23 species found predominantly in temperate eastern North Pacific waters. Nineteen of the 20 species found in California occur in inshore coastal waters. Tuleperch (*Hysterocarpus traski*) occupies freshwater and estuarine habitats. Collectively, the nineteen marine species are found in a variety of habitats, including beaches, rocky substrate, intertidal and subtidal kelp beds. A few species inhabit several of the habitat types. Included in this group are the island seaperch (*Cymatogaster gracilis*), pile perch (*Rhacochilus vacca*), rubberlip seaperch (*Rhacochilus toxotes*), shiner perch (*Cymatogaster aggregata*), walleye surfperch (*Hyperprosopon argenteum*), and the white seaperch (*Phanerodon furcatus*). The majority of surfperches occupy only one type of habitat. Species most commonly found along beaches include the barred surfperch (*Amphistichus argenteus*), calico surfperch (*Amphistichus koelzi*), redtail surfperch (*Amphistichus*

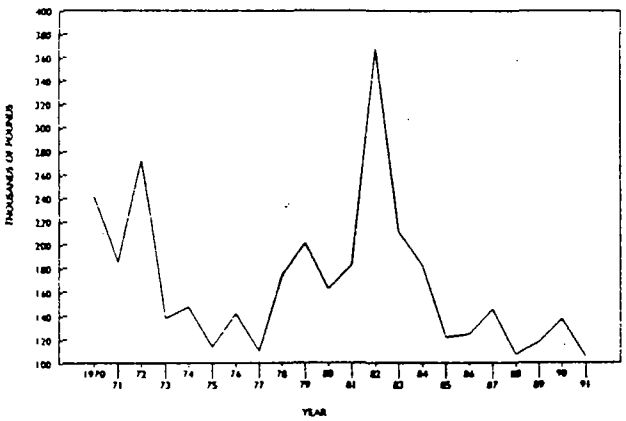
rhodoterus), silver surfperch (*Hyperprosopon ellipticum*), and the spotfin surfperch (*Hyperprosopon anale*). Black perch (*Embiotoca jacksoni*), dwarf perch (*Micrometrus minimus*), kelp perch (*Brachyistius frenatus*), rainbow perch (*Hypsurus caryi*), reef perch (*Micrometrus aurora*), sharpnose seaperch (*Phanerodon atripes*), and striped seaperch (*Embiotoca lateralis*) tend to be associated with rocky substrate and kelp beds. The pink seaperch (*Zalembius rosaceus*) inhabits deep water and is seldom taken in the sport catch.

The surfperch fishery in California includes both sport and commercial components. The sport fishery is enjoyed by anglers of all ages who fish for surfperch from piers, jetties, sandy beaches, and boats. The recreational catch of surfperch for 1986 totaled 2,538,000 fish, with the majority being caught in northern California.

Surfperch are easy to catch, which makes them highly sought. They can be caught using light gear and a variety of baits such as clams, tube worms, or sand crabs. A spinning or casting outfit using 10 to 15 pound test monofilament line, and a standard two-hook surf leader with size six hooks, is ideal for shore based surfperch fishing.



California commercial landings of surfperches, 1916-1969.



California commercial landings of surfperches, 1970-1991.

Annual commercial landings of surfperches have also been highly variable. While the market for fresh "perch" fillets is relatively small, the total catch for the fishery was 129,749 pounds in 1989. The California Department of Fish and Game did distinguish between species in their statistics until 1987, simply listing the category as surfperch. Currently, there is a large commercial fishery for various surfperches in the southern part of the state and a moderate fishery focusing on redtail surfperch in northern California.

Surfperches can be identified by their elliptical, compressed body form and forked tail. Most are marked with bars or stripes. They have a continuous dorsal fin with 9-11 spines and 19-28 soft rays. The anal fin has three spines with 15-35 soft rays.

The diet of surfperches consists of isopods (*e.g.*, rock lice) of all sizes, and gastropod mollusks (*e.g.*, snails); various amphipods (*e.g.*, skeleton shrimp), polychaete worms, brittle stars, and small crabs, also are included. Surfperches are usually bottom grazers, but apparently will feed mid-water when competitors are absent.

Surfperch reproduction is viviparous, their young being highly developed and free swimming at birth. Newborn males of a few species are reproductively mature.

Much information is lacking on this group. Although the taxonomy has been recently refined, life history and habitat requirements are areas in need of more research.

BARRED SURFPERCH

History of the Fishery

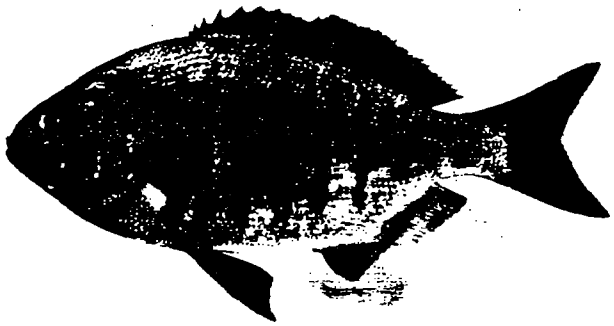
The commercial fishery for barred surfperch is minor compared to the sport fishery. Its popularity as a sport fish stems from abundant numbers and accessibility. In 1986, the southern California sport fishery for barred surfperch reached over 530,000 fish, with 99 percent being caught from beaches and jetties. Similarly, 99 percent of northern California's catch also came from shore, but only 178,000 fish were landed. The best months for fishing are December, January, and February with the majority of large individuals being gravid females. Sand crabs are the best bait for barred surfperch, especially female sand crabs carrying orange colored eggs. Small jigs and spinners also work well. Although barred surfperch are excellent sport fish for the light tackle angler, they are sometimes considered a pest to anglers pursuing other fish such as California halibut or corbina.

Status of Biological Knowledge

Barred surfperch have eight to 10 rust-colored, irregular bars on their sides with spots in between. The background color is usually silver or white, and the back can take on a blue or grayish coloration. Similar species are the calico surfperch and the redtail surfperch, but the barred surfperch can be distinguished from the redtail and calico because it lacks red coloration in its fins.

Barred surfperch are found in small schools along sandy beaches and near jetties, piers, and other sources of food and cover. They range from Bodega Bay in northern California to north central Baja California. While the majority are found in the surf zone, some have been caught in water as deep as 240 feet. The largest individual ever taken was a female that weighed 4.5 pounds and was 17 inches in length. Most fish are in the one- to two-pound range and are highly prized by anglers.

SMB-26908



Barred surfperch, *Amphistichus argenteus*.

Calico surfperch, *Amphistichus koelzi*.

Barred surfperch mate during the fall and winter months, and young are released during spring and summer. Males and females both darken considerably during courtship, and males make "figure-eights" around females before mating. A female can produce from four to 113 young, depending on her size. Females undergo a five month gestation period, and juveniles are born at about 1.75 inches in length. Juveniles are miniature replicas of the parents and are independent at birth. The young usually live relatively close to where they were born.

Status of Population

The sport fishery in southern California has yielded up to 600,000 pounds of barred surfperch (1981), while northern California may produce upwards of 250,000 pounds annually, but no estimates have been made of the size or current status of the barred surfperch population.

CALICO SURFPERCH

History of the Fishery

The calico surfperch is of moderate sport value along the California coast. Due to its striking similarity and frequent misidentification with the redtail surfperch, calico surfperch, until recently, have been considered of minor importance in the sport catch. The calico fishery has historically included fishing from piers, sandy shores, and skiffs.

Status of Biological Knowledge

The calico surfperch can be identified by its silvery surface, which is covered by olive-green mottling and broken bars down each side. The calico reaches a length of 12 inches and rarely weighs more than one pound.

The range of the calico surfperch is from north central Washington to northern Baja California. The primary habitat of the calico is sandy beaches, although they can occasionally be found over rocky substrate. The vertical distribution of the calico includes depths from the surface down to 30 feet.

Status of Population

At this time, little information is available on the population status of the calico surfperch.

PILE PERCH

History of the Fishery

Pile perch sustain a limited commercial fishery in Del Mar, California, and Papalote Bay, Baja California, but do not contribute substantially to annual commercial landings in the state.

They are of interest as a sport fish throughout the state, but are of more importance in the southern part of the state. Many are caught from piers, jetties, beaches, or skiffs. Pile perch may be caught year-round on any number of popular baits, including clams, sand shrimps, and worms.

Status of Biological Knowledge

Pile perch can be identified by the silvery sides with a dark vertical bar about midbody, and a unique dorsal fin with the first few soft dorsal rays longer than any of the others, giving the fin a peaked appearance. They are equipped with strong, well developed teeth, enabling them to feed on hard shelled mollusks, crabs, and other crustaceans. Their specialized dentation differs enough from rubberlip surfperch to convince some ichthyologists to place them in their own genus (*Damalichthys*).

Pile perch are found between southeastern Alaska and northern Baja California, including Guadalupe Island. They usually live along rocky shores, from the surface down to 150 feet, and may grow to around 17.5 inches in length.

Fecundity increases with age and size of the females. Average fecundity at first reproduction is 11.7 young, and sometimes exceeds 60 in older females. Adult longevity of pile surfperch is seven to 10 years.

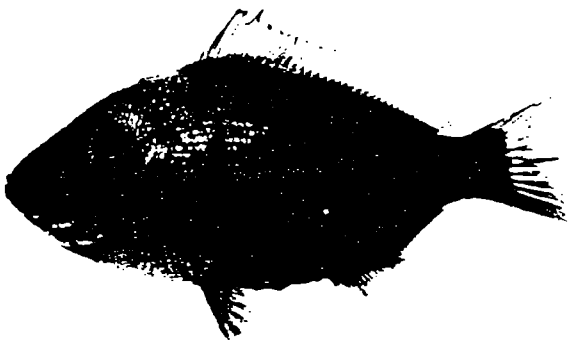
Status of Population

Because accurate landings data for pile perch are lacking, little can be concluded about the current population status in California.

REDTAIL SURFPERCH

History of the Fishery

Redtail surfperch sustain a sport fishery from central California to Vancouver Island, British Columbia. They support a commercial fishery only in northern California, especially in the inshore waters of the Eureka area. These fish are taken primarily from sandy beaches or the mouths of rivers and streams entering the sea, but also can be caught from jetties and piers inside harbors and bays. Humboldt Bay in northern California is the primary location of the winter redtail commercial fishery. Fishing is mostly from open beaches using seine, or hook and line. The best catches are in March and April when the fish are concentrated for spawning. Commercial fishing is closed from May 1 to July 15. The annual commercial harvest averages about 25,000 pounds, with a high catch in 1985 in excess of 35,000 pounds and a low catch of 21,200 pounds in 1988.



Redtail surfperch, *Amphistichus rhodoterus*.

Sport fishing for redtails occurs in the same areas where they are commercially taken. They are taken year round by hook and line, but are usually targeted during the spawning season. No recent information is available on sport catch.

Status of Biological Knowledge

Redtail surfperch are distinguished by the nine or ten vertical, orange-to-brassy bars alternating at the lateral line and the light red pelvic, anal, and caudal fins. The body is moderately deep and laterally compressed, with a light green back and silver sides and belly. Adult redtail average 10 to 12 inches and weigh about 1.8 pounds. The largest recorded individual was 16.5 inches long and weighed 3.7 pounds. Females produce eight to 45 young about one year after fertilization, sometime between May and August.

Redtail surfperch are found from Vancouver Island, Canada, to Monterey Bay, California, but the fishery is centered north of the San Francisco Bay area.

Status of Population

There are no estimates of the size of the redtail surfperch stocks in California coastal waters. Based on the consistent commercial harvest, it appears probable that the population is being adequately maintained. The Eureka area, where about 95 percent of the commercial redtail fishery occurs, has consistently produced between 20,000 and 30,000 pounds annually.

RUBBERLIP SEAPERCH

History of the Fishery

The rubberlip seaperch is one of the many important surfperch sport fish along the California coast. It is caught along jetties and piers, and also taken by skiff anglers nearshore or in kelp beds. There is no current information on sport and commercial landings of rubberlip seaperch.

Status of Biological Knowledge

The large, thick lips of the rubberlip distinguish it from other surfperches. Its coloration varies from olive- to brassy-brown on the sides, with one or two dusky bars on adult fish. The pectoral fins are yellow to orange, and the pelvic fins are usually black. The maximum length of rubberlip seaperch is 18.5 inches, making the rubberlip the largest of the surfperches.

Rubberlip surfperch are found from Russian Gulch State Beach (Mendocino County), California, to central Baja California, including Guadalupe Island. These fish range from inshore waters to depths of 150 feet.

Although no data have been collected on age at sexual maturity, gravid rubberlip surfperch have been caught from April to June. Time of birth is estimated to be midsummer.

Status of Population

No recent estimates have been made of the rubberlip perch population its size is unknown at this time.

STRIPED SEAPERCH

History of the Fishery

Striped seaperch is one of the eight to ten species that make up the small commercial "perch" fishery. However, it is a minor component when compared to such species as the barred surfperch. Conversely, striped seaperch do comprise a substantial portion of the state's sport fishery. These perch are easily taken from piers, jetties, beaches, and skiffs, and are favorites of anglers due to their beautiful coloration.

Status of Biological Knowledge

Striped seaperch can be easily identified by the red, blue, and yellow lines which run laterally along the length of the body. Maximum length is 15 inches. These fish are sexually mature in their third year of life and produce about 18 young per female. At age seven, the average number of young produced per female is 32. The maximum life expectancy for this fish is approximately 10 years.

Striped seaperch are found from southeastern Alaska to northern Baja California.

SMB-26910

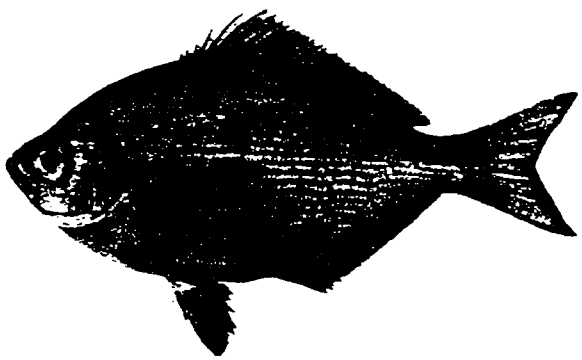
Status of Population

Population estimates of striped seaperch have not been made, but recent landing figures indicate that this species is able to sustain an estimated annual sport catch of 123,000 pounds.

WALLEYE SURFPERCH

History of the Fishery

The walleye surfperch is an important commercial species. Although generally small in size, it is found in dense schools that measure up to eight feet across and contain several thousand individuals. Such large schools make an easy target for seines and gillnets. Sport anglers also enjoy fishing for walleyes. In 1986, anglers caught 171,000 individuals, well over 90 percent being caught from shore, jetties, and piers. Walleyes can be taken on sand crabs and other invertebrates, as well as on small spinners and jigs. They are excellent eating.



Walleye surfperch, *Hyperprosopon argenteum.*

Status of Biological Knowledge

Walleye surfperch are silver to bluish above, with very faint pink bars that fade quickly after death. Most notable are the large eyes and black tipped pelvic fins. Similar species are the spotfin surfperch and the silver surfperch. However, the spotfin has black spots on its dorsal and anal fins, while the silver lacks any black coloration.

Walleye surfperch are found in large schools along sandy beaches, jetties, kelp beds and other habitats with rich invertebrate life. They range from Vancouver Island, British Columbia, to central Baja California, including Guadalupe Island. They reach a length of 12 inches and are found to depth of 60 feet.

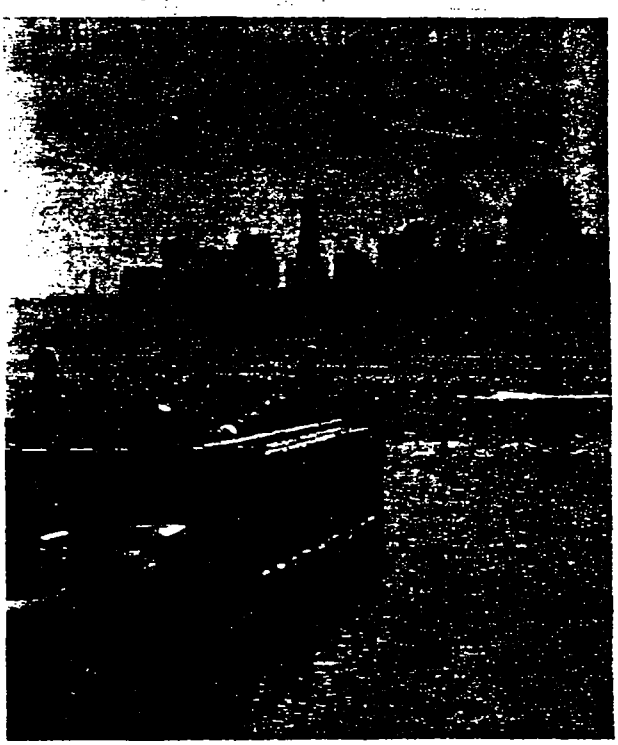
Walleye surfperch mate from November to December and, after a five month gestation period, give birth in mid-April. Males engage in an aggressive "swooping" courtship before mating. Females, depending on size, will have five to 12 young which are about 1.5 inches at birth. The young are miniature replicas of the parent and mature the fall or winter following their birth.

Status of Population

The recent combined sport and commercial harvest has exceeded 500,000 pounds. However, the total stock size is unknown at this time.

SURFPERCH : DISCUSSION

Surfperches are important both commercially and as sport fish. Most of the California coastal species are taken in the sport catch. The redtail, pile, and barred surfperches are the most notable in the commercial catch and may be important to local economies.



Fishing for surfperch in San Francisco Bay.

Surfperch habitats have been, and will continue to be, areas of conflict. As humans develop the shoreline, areas inhabited by surfperches may become polluted or destroyed. Although surfperches may adapt to structures such as jetties and piers, it should not be assumed that they can continue to adapt to all the changes that are forced upon them.

Ronald A. Fritzsche, Glenn Harkleroad, Phil D. Lam, Scott Kennedy, Tom Cady, David Slama, and Mike Farmer
Humboldt State University

References

Fritzsche, R.A. and T.J. Hassler. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) - pile perch, striped seaperch, and rubberlip seaperch. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.103) U. S. Army Corps of Engineers, TR EL-82-4. 15pp.

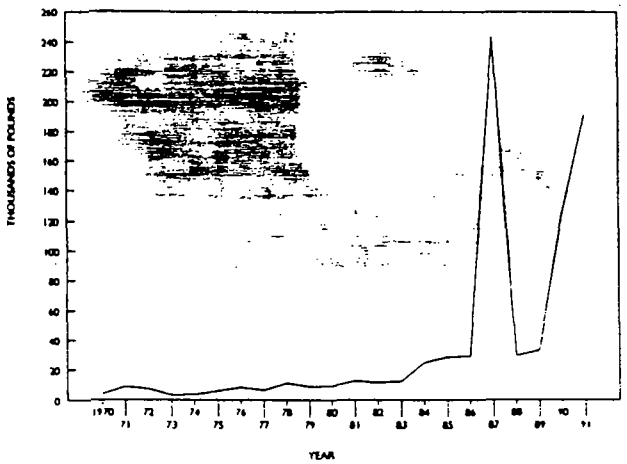
Tarp, F.H. 1952. A revision of the family Embiotocidae (the surfperches). Calif. Fish and Game Fish Bull. 88:1-99.

SMB-26911

CALIFORNIA SHEEPHEAD

History of the Fishery

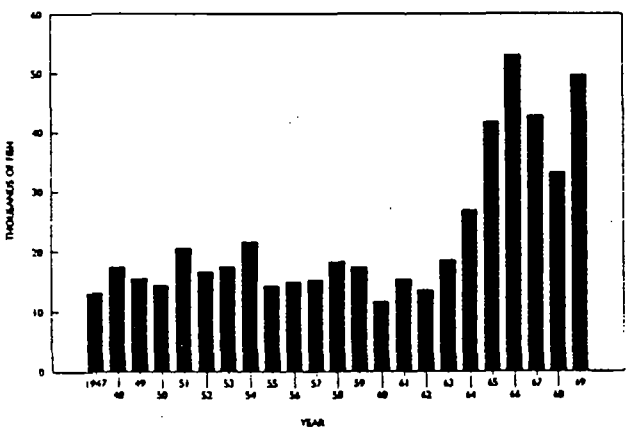
Although the commercial catch of California sheephead (*Semicossyphus pulcher*) dates back to the late 1800's, a renewed interest in this fishery has developed only recently. It is exploited today by sport divers, anglers, and a small but growing commercial industry.



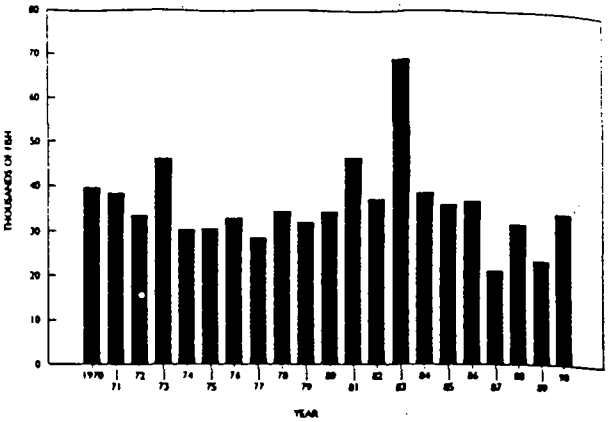
California commercial landings of sheephead, 1970-1991.

In the late 1800's, Chinese fishermen took large quantities of sheephead for drying and salting. However, except for brief periods, sheephead was not a targeted species until the 1980's. In the recently developed fishery, the fish are trapped and taken alive to supply Asian seafood restaurants. Because small fish, usually females, are easier to keep alive in small aquaria, prereproductive individuals are often taken.

The largest commercial catches of California sheephead were from 1927-1931, peaking in 1928 at more than 370,000 pounds. During and shortly after World War II (1943-1947) the sheephead catch increased from about 50,000 pounds to 267,000 pounds, probably because of their easy availability close to port. Since the 1940's, but prior to modern interest in



California commercial passenger-carrying fishing vessel landings of sheephead, 1947-1969.



California commercial passenger-carrying fishing vessel landings of sheephead, 1970-1990.

seafood, annual landings were usually around 10,000 pounds. The price during this period stayed under $0.10 per pound. During the 1980's, the price and catch increased, with catches rivaling those of the 1940's, and the price paid by restaurants for live fish reached as much as $9.00 per pound. The catch peaked in 1987 when the market price dropped to $0.27 per pound, but the live catch for 1988-1989, less than one seventh as large, had almost the same market value, the price having increased to $1.70 per pound.

The estimated recreational catch of sheephead between 1983 and 1986 averaged 312,400 pounds, with a maximum estimate of 448,800 pounds in 1986. Commercial passenger carrying vessel data from 1947-1990 indicate an average take of 29,200 fish per year, with a maximum of about 69,000 in 1983. Using an average weight of two pounds per fish (a low estimate), the sport catch, except in the above cited maximum periods, appears to be equivalent to or higher than the commercial catch. During the 1930's, sheephead were considered "junk fish" by most recreational anglers and were not kept because of their soft flesh. However the large size, fine flavor and use as a lobster substitute in salads and other recipes has more recently made them a preferred and even targeted species by anglers and sport divers.

California sheephead, *Semicossyphus pulcher*.

SMB-26912

Status of Biological Knowledge

The California sheephead ranges from Monterey Bay, California, south into the Gulf of California in depths to about 280 feet, but is not common north of Point Conception. It is a protogynous hermaphrodite, beginning its sexual life as a female with older, larger females developing into secondary males. Female sexual maturity may occur between three and six years and fishes may remain female for as long as fifteen. Timing of the transformation to males involves population sex ratio as well as size of available males and sometimes doesn't occur at all. Males have been aged at around 50 years. As growth rates are higher and mortality lower at the northern end of the range, the sexual transformation occurs later there and the males are larger. Batch spawning occurs between July and September, and estimates of yolky oocytes present in the ovary vary from 36,000 to 296,600 for fish from eight to 15 inches long. Larval drift averages about 37 days (range 34-52). The sheephead has a broad diet, with crabs, barnacles, mollusks, urchins, polychaetes and even bryozoa occasionally dominant. There appears to be no evidence of its preference for abalone and lobster as cited in earlier literature.

Status of Population

There has been no systematic analysis of the status of California sheephead. In studies at two localities, Palos Verdes Point and King Harbor breakwater, it was not abundant during the cooler water period of the early 1970's, but the population at both sites increased with the El Niño of 1977-1978. Since then, the population at King Harbor has gradually dwindled while the Palos Verdes population, coincident with the reestablishment of kelp beds there, peaked in 1981, and hasn't declined since. The sheephead population appears to be relatively stable, but the newly-developed fishery for prereproductives suggests that monitoring in the future would be desirable.

John Stephens
Occidental College

References

Cowan, R.J. 1985. Large scale patterns of recruitment by the labrid *Semicossyphus pulcher*, causes and implications. J. Mar. Res. 43(3)1985:719-742.

_____. 1990. Sex change and life history patterns of the labrid *Semicossyphus pulcher* across an environmental gradient. Copeia 1990(3):781-795.

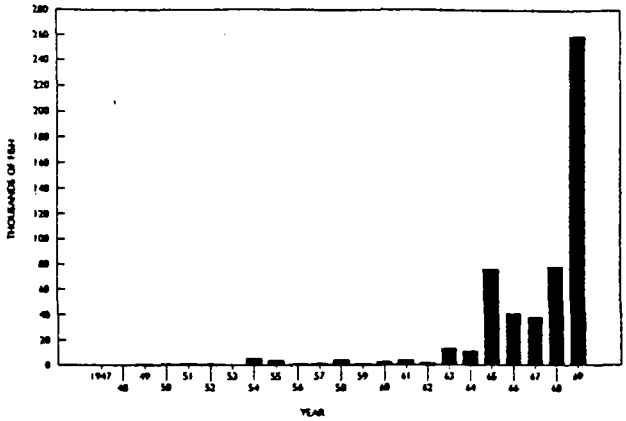
Victor, B.C. 1987. Growth, dispersal, and identification of planktonic labrid and pomocentrid reef fish larvae in the Eastern Pacific ocean. Mar. Biol. 95(1):145-152.

Warner, R.R. 1975. The reproductive biology of the proto-gynous hermaphrodite, *Pimelometopon pulchrum* (Pisces:Labridae) Fish. Bull. U.S. 73:262-283.

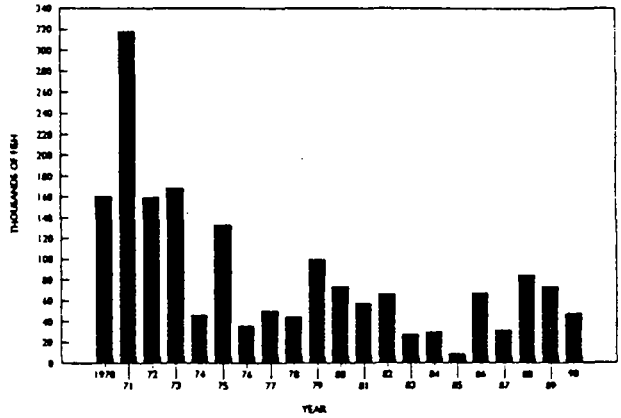
OPALEYE AND HALFMOON

History of the Fishery

Opaleye (*Girella nigricans*) and halfmoon (*Medialuna californiensis*) are members of the sea chub family (Kyphosidae). Neither species is part of a designated fishery but both appear regularly as incidental catch in commercial and recreational fisheries.



California commercial passenger-carrying fishing vessel landings of halfmoon, 1947-1969.



California commercial passenger-carrying fishing vessel landings of halfmoon, 1970-1990.

The commercial catch of opaleye and halfmoon generally has been small. During the 40 years that commercial catches of halfmoon have been recorded, the average catch has been 16,724 pounds, with a high of 50,007 in 1956. Recent recorded catches have been well below this mean. The mean catch of opaleye in 43 recorded years is 4,748 pounds, with a high of 23,688 pounds in 1973. Recent catches have been about average. Neither species was recorded in large numbers in the California Department of Fish and Game's gill and trammel net study, although the opaleye was at one time a bycatch of nearshore purse seiners. Recent party boat landings for opaleye are small (less than 600 fish per year) but halfmoon are taken in abundance, especially from island kelp beds. By contrast, both species were abundant in the pier and jetty survey of 1965-1966 and are likely an important element of that fishery today.

Status of Biological Knowledge

The sea chubs are important in southern California primarily because of their habit of herbivorous grazing. These are the

SMB-26913

only fishes that regularly harvest giant kelp and are effective in destroying isolated kelp plants, such as newly transplanted individuals.

Opaleye, *Girella nigricans*.

The opaleye reaches a maximum length of about 26 inches and weight of about 16 pounds, while the halfmoon reaches 19 inches and five pounds. Both species range from central California to Baja California. While the opaleye is more common than the halfmoon north of Point Conception, the halfmoon extends its range to the south into the Gulf of California. Opaleye are found to a depth of about 100 feet and halfmoon to about 130 feet.

Both opaleye and halfmoon browse on algae and take associated invertebrates. Larvae of both are pelagic and are followed by a pelagic juvenile schooling stage which appears in the nearshore environment. Larval distributions mirror those of the adults latitudinally, with the larvae primarily distributed in the surface neuston. CalCOFI data indicate that halfmoon larvae are occasionally taken well offshore, while most opaleye larvae are taken within 70 miles of the coast. Young opaleye leave this pelagic habitat and enter the intertidal zone when they are about one inch long. They are found in relatively high tidal pools preferring warm water (>75° F), and feed largely on invertebrates. As they grow to a length of three to six inches, the young leave the tide pools and eventually form small schools which feed in the kelp beds and on epiflora.

Young halfmoon stay in the shallow subtidal and kelp bed habitats, rarely entering the intertidal zone. Juvenile opaleye are known to clean parasites from other fish species on occasion.

Status of Population

The abundance of opaleye and halfmoon, and their status as incidental catch rather than as targeted species, make it unlikely that either the sport or commercial fisheries will have an effect on the population. Data gathered over the last 17 years indicate that, in the areas studied, both species are maintaining themselves adequately under the present fishing pressures and show regular recruitment.

John Stephens
Occidental College

References

Norris, K.S. 1963. The functions of temperature in the ecology of the percoid fish *Girella nigricans* (Ayres) Ecol. Monographs 33:23-62.

Orton, R.D., L.S. Wright, and H. Hess. 1987. Spot polymorphism in *Girella nigricans* (Perciformes: Kyphosidae)-geographic and inter-size class variation. Copeia(1)1987:198-203.

Stevens, E.G., W. Watson, and H.G.Moser. 1990. Development and distribution of larvae and pelagic juveniles of three kyphosid fishes (*Girella nigricans, Medialuna californiensis* and *Hermosilla azurae*) off California and Baja California. Fish. Bull. U.S. 87:745-768.

NEARSHORE FISHES: DISCUSSION

The nearshore fishes discussed in this section are an ecologically diverse group. Included are species that are typical of coastal reefs, nearshore and offshore sandy bottoms, and bays, as well as species which primarily inhabit the water column. Pacific barracuda, yellowtail and white seabass are migratory species from the south that are typical of the water column of the nearshore zone, although younger white seabass are found over sandy bottoms in shallow water. All three species migrate into southern California during the spring and summer months, before returning to the coast of Baja California for the winter.

In addition to white seabass, several other species of croakers are characteristic of sandy or muddy areas of the coast. These include the white croaker, which ranges from shore to deeper waters, the spotfin croaker and yellowfin croaker of shallow waters offshore of the surfzone, and the California corbina of the surfzone. All are most abundant in southern California, but white croaker is also abundant in central California. In addition, several species of surfperch, including the barred surfperch, calico surfperch, redtail surfperch, and walleye surfperch, commonly occur on sandy bottoms in or near the surfzone. Redtail and calico surfperches are most abundant in northern and central California, respectively, whereas barred and walleye surfperches are abundant in southern California. Barred sand bass are typical of deeper sandy areas of the nearshore coast and spotted sand bass are abundant in southern California bays.

Rocky reefs in southern California provide habitat for cabezon, giant sea bass, kelp bass, opaleye, halfmoon, California sheephead, rubberlip seaperch, and pile perch. Cabezon and pile perch are also found along reefs of central and northern California, where lingcod, kelp greenling, and striped seaperch are important members of the reef community. Most of these species feed on fish or invertebrates, but opaleye and halfmoon are primarily herbivorous.

These nearshore species are important in the recreational fisheries of California. Size and seasonal restrictions limit the recreational take of some species, and anglers are not allowed to keep giant sea bass caught off California.

Commercial utilization of nearshore species occurs primarily as a result of incidental catches in fisheries targeting other species. However, lingcod is important in trawl fisheries in central and northern California. The commercial catch of white

SMB-26914

seabass and giant sea bass is restricted, and commercial fishing for kelp bass, barred sand bass, spotted sand bass, California corbina, spotfin croaker, and yellowfin croaker is not allowed. White croaker fisheries are restricted in contaminated areas of southern California. The commercial fishery for white seabass and yellowtail may disappear when the nearshore gillnet fishery is stopped in 1994.

Although information is frequently limited, most species appear to have healthy populations that are able to withstand present fishing effort. Kelp bass and barred sand bass populations appear to have increased during the past decade, but giant sea bass, yellowtail, and white seabass populations have decreased. Giant sea bass populations are so depressed that fishing is severely restricted in the U.S. and may be similarly restricted in Mexican waters. Individual lingcod and yellowtail caught in recreational fisheries are smaller and younger, suggesting that present harvest levels are too high. Although populations of cabezon, spotted sand bass, spotfin croaker, yellowfin croaker, surfperches, and California sheephead are healthy at present, they may be affected by human activities in the nearshore zone. As human activities (including recreational fishing effort) increase along the California coast, it is expected that the number of species with healthy populations will decrease. Thus, it will be important to monitor the populations of nearshore fishes during the next decade.

M. James Allen
MBC Applied Environmental Sciences

SMB-26915

ABALONE

Remarkable progress has been made in recent years in the cultivation of abalone in California. The fledgling abalone aquaculture industry that began in the mid-1960's in central California had, by 1990, achieved a significant production level. But progress has not come easily.

Prospective abalone farmers are confronted with a number of regulatory constraints in the coastal zone. Suitable sites are relatively scarce and expensive, and the permitting process is lengthy, often exceeding a year, and can be expensive. Despite these obstacles, interest in cultivation of abalones remains high, prompted in part by a sharply declining commercial fishery, a continuing high market demand for abalone, and a good price to growers for the farmed product.

California's private sector principally grows three abalone species: the red (*Haliotis rufescens*), pink (*H. corrugata*), and green (*H. fulgens*). The latter two are warm water species and are grown at some of the southern California hatcheries. The red abalone is the mainstay of the industry and comprises more then 95 percent of total production. Aquaculturists grow out abalone either in land-based tanks or else an in-ocean barrel or cage culture system. With the latter (culture systems), the barrels and cages are either tethered from a dock or a floating raft or, in one instance, cages are positioned directly on the seabed. Abalone in the barrels and cages are harvested at about two- to three-inch shell lengths. Ocean ranching of abalone on state leased seabeds, exclusive of containment structures, has been tested, but has not yet proven feasible.

In 1991, there were 15 registered abalone aquaculturists in California. However, only three companies are at full production; another three companies are in a pilot-production phase and undergoing expansion, while the remaining nine companies are in various pilot or experimental phases.

In a typical hatchery operation, brood stock abalones are induced to spawn using hydrogen peroxide. The swimming larvae are reared for about one week, whereupon they are transferred to fiberglass nursery tanks, metamorphose and become benthonic, feeding on single-celled algae (chiefly diatoms). After five to six months, when the juvenile abalone are about 3/8-inch long, they are transferred to plastic mesh baskets. The abalones remain in these baskets for another three to four months, foraging on giant kelp. They are then transferred to concrete grow-out tanks and continue to be nurtured on giant kelp. Growing in these tanks for 20 months or longer, they attain three- to four-inch shell lengths and are then ready for harvest. Economics and market demand strongly influence harvest size. The export market prefers the four-inch live abalone. The two- to three-inch product is typically processed for the domestic market. The three-inch abalone yields a steak of about one ounce.

Statewide production of farmed abalone is somewhat difficult to estimate; based on information provided by the two largest growers, it was about 150,000 pounds in 1990 and is estimated at 175,000 pounds for 1991. The 1990 aquaculture harvest was almost 30 percent of commercial fishery landings.

Abalone nursery tanks at the Ab Lab, Port Hueneme.

Research

Although a considerable amount of research on abalone aquaculture has been done by the private sector, particularly from a technological standpoint, university and Department of Fish and Game scientists have made major contributions. The California Sea Grant program has supported abalone aquaculture research since 1971. Sea Grant-funded investigations have greatly increased our understanding of abalone developmental biology. Also, a spawning induction procedure and larval settlement inducer technique were developed by researchers funded through this program.

The Department began abalone culture investigations in 1971 at its Granite Canyon Laboratory near Monterey. Department biologists, working closely with industry, focused on the biotechnology of abalone cultivation. Noteworthy was the development of a through-flowing larval rearing system and the development of a flush-fill tank system that has been adopted by the industry. In 1978, the Department constructed a pilot-production abalone hatchery at Granite Canyon. The purpose was three-fold: 1) to train scientists and others in abalone cultivation procedures; 2) to grow seed abalone for a fishery restoration program; and 3) to disseminate information. In 1987, the Department began to phase out the abalone aquaculture program at Granite Canyon, and, by the end of 1990, the program was terminated.

Future Prospects

Coastal land sites suitable for abalone aquaculture are becoming limited and expensive to obtain and develop. The declining commercial fishery may make ocean ranching a more attractive option. Ocean ranching may yet prove feasible but

SMB-26916

will require considerable research. Also, given the expanding sea otter population in California, and the otter's known predacious habits on abalone, some type of exclusion containment structure would be required. Such structures may prove cost-prohibitive.

Harvesting red abalone at the Abalone Farm at Cayucos, near Morro Bay.

Abalone culturists depend upon giant kelp as the principal food for abalones. Giant kelp beds are extensive along the central and southern California coastal regions and offshore islands. The supply could be limiting, on a short-term basis, during an El Niño event. Some progress has been made on the development of artificial diets for abalone. Presently, some hatcheries employ an artificial diet for juvenile stages, but principally as a supplement to natural algal foods. Research is in progress on the development of an artificial abalone diet for later growth stages, in order to reduce the dependency on giant kelp. Abalone aquaculture will continue to expand in California, in spite of the various constraints, until, or unless, the commercial fishery recovers.

Earl E. Ebert
California Department of Fish and Game

References

Ebert, E.E. and J.L. Houk. 1984. Elements and innovations in the cultivation of red abalone *Haliotis rufescens*. Aquaculture 39:375-392.

Ebert, E.E. In press. Abalone aquaculture: A north American regional review. *In* Proceedings of the first international symposium on abalone biology, fisheries and culture. La Paz, B.C.S., Mexico, November 21-25, 1989.

Hahn, K.O. (editor). 1989. Handbook of culture of abalone and other marine gastropods. CRC Press, Inc., Boca Raton, FL.

Leighton, D.L. 1989. Abalone (genus *Haliotis*) mariculture on the North American Pacific coast. Fish. Bull., U.S. 87:689-702.

Morse, D.E., H. Duncan, N. Hooker, and A. Morse. 1977. Hydrogen peroxide induces spawning in molluscs, with activation of prostalandin endoperoxide synthetase. Science 196:298-300.

MUSSELS

Mussels of the genus *Mytilus* have fluctuated in importance in California as commercial and sport shellfish for food and bait since the early 1900's. Experiments in culturing wild seed stock and in developing hatchery and grow-out methods in the 1980's have increased the economic potential of mussels, particularly *Mytilus galloprovincialis* (the Mediterranean mussel), which occurs primarily in southern and central California. The Pacific Northwest mussel, *Mytilus trossulus*, and hybrids of *M. galloprovincialis* and *M. trossulus* have been found in central and northern California. In the past, these mussels were thought to be one species, *Mytilus edulis*, on the west coast, but recent studies have shown that California "bay" mussels are genetically distinct from *M. edulis* found on the east coast of the United States, Canada, and other parts of the world.

The sea mussel, *Mytilus californianus*, is of minor economic importance in California at present, though it is taken by sport harvesters and its landings are increasing as a food and bait shellfish. Wild harvested sea mussels are highly esteemed by gourmet chefs in Oregon and may have a future in California.

Between 1916 and 1927, over 470,000 pounds of mussels, ranging from 9,000 to 69,000 pounds per year, were landed in California. After 1927, most areas were closed to harvest by the California Department of Health Services due to a major outbreak that year of paralytic shellfish poisoning. Mussel landings declined to 1,610 pounds in 1928 and stayed depressed until 1972, when a record 111,000 pounds were landed, primarily for bait. Bait sales continued to be the most significant commercial activity for California mussels until improved methods of harvesting wild stocks were developed, new culture methods were adopted, and west coast markets began developing for this tasty shellfish in the early 1980's.

Divers harvesting mussels from overshore platforms for Ecomar.

Research on harvesting wild-set Mediterranean mussels from offshore oil-production platforms for food was initiated in the Santa Barbara Channel in 1979. Fouling organisms were routinely removed by divers from the submerged legs and

SMB-26917

support structures of the offshore platforms, at considerable expense to oil companies. An ecological consulting firm, hired to suggest ways to control the biofouling, found that various stages of the succession of organisms included settlement and growth of edible mussels, both *M. galloprovincialis* and *M. californianus*. Recognizing the potential for food production and increasing market demand for high quality shellfish, the owners of the firm contracted with various offshore oil companies to test the feasibility of harvesting and marketing the mussels.

Growing from the surface to 50 feet deep, Mediterranean mussels typically reach market size (2.5 to 6 inches) in nine months to two years on the offshore platforms. Using long handled scrapers and a venturi air-lift device, divers harvest clumps of mussels from the platform legs and lift them to the surface using large suction hoses. Mussel harvesting and marketing is generally a 10-month operation in the Santa Barbara Channel, with a two-month period of low production during the spring spawning season.

In 1985, approximately 104,000 pounds of mussels were harvested, primarily from offshore platforms, but by then a company in Tomales Bay also had begun to utilize European longline methods to grow a high quality mussel. Over the next seven years, three to five other Tomales Bay oyster growers diversified into mussel production. These growers utilized wild-caught and hatchery reared seed, with the latter being relied upon more, as natural recruitment often proved to be erratic and unreliable.

The total state mussel production tripled in 1986, reaching more than 334,000 pounds, with over 90% harvested from platforms in the Santa Barbara Channel and the remainder from Tomales Bay. Statewide production dropped slightly in 1987 to approximately 286,000 pounds and decreased further in 1988 to 151,000 pounds, due to major winter storms which dislodged market-ready mussels from platform structures. Production jumped to over 300,000 pounds in 1989, but dropped to 130,000 pounds in 1990 when a San Diego firm ceased production. The mussels harvested between 1986 and 1990 provided a return of $1.17 million to California growers. The price per pound has increased from $.80/pound in 1985 to $1.40/pound to wholesale distributors for large lots and $2.00/pound to restaurants in 1991.

California growers face stiff competition from mussels imported from Maine, Canada, New Zealand, and Washington state, due to the advent of low cost air transport of fresh shellfish and individual flash freezing methods. Competing on the world market is a challenge to California producers, because of massive production of mussels from China, Korea, New Zealand, Australia, and other Pacific Rim countries. Expansion of the industry is highly dependent on the maintenance of clean growing areas, a supportive regulatory environment, aggressive marketing, and a dependable source of seed.

Until 1986, all mussels grown commercially in California were set or collected as wild or natural seed. In 1985, a cooperative effort involving a northern California shellfish nurseryman, an Oregon hatchery operation, and a University of California researcher was initiated to produce the first commercial quantities of hatchery-reared mussel seed on the west coast. Approximately 20 shellfish growers in California, Oregon, and Washington participated in field grow-out trials using various mussel seed stocks and sizes. Growers utilized a variety of substrates and set the spat at different densities. A wide range of results, from zero survival to excellent survival and growth, were reported. The methods for growing out seed have evolved and matured in Tomales Bay, but have not, as yet, been proven on a commercial scale in south-central and southern California. Growers are optimistic, however, and experiments continue.

Currently, the five growers in Tomales Bay often purchase larger (0.5-1.0 inch) seed which can be grown to market size in six to nine months. Predation by scoter ducks continues to be a problem in Tomales Bay, as it has been in most other west coast mussel operations.

Status of Biological Knowledge

Genetic studies utilizing protein electrophoresis in the late 1980's showed that there were two distinct forms of *edulis*-like mussels on the west coast which are morphometrically similar. One of these forms is electrophoretically indistinguishable from *M. galloprovincialis*, the Mediterranean mussel, which is known to have recently colonized many disparate shores around the world. The other form is also distinct from the Atlantic *M. edulis* and was designated *M. trossulus*, the Pacific Northwest mussel. It was found to occur from Alaska to central California. The *galloprovincialis* and *trossulus* forms occur together and are reported to hybridize with one another. In southern California, only *M. galloprovincialis* has been documented, though more detailed studies are being conducted to further define the taxonomic status and geographic range of these mussels and other pan-Pacific mytilid species.

The hybridization and geographic range issues regarding *M. trossulus* in central and northern California confound the interpretation of earlier life history studies of mussels taxonomically classified as *M. edulis*, but, regardless of the taxonomic issue, all mussels share many common biological traits as they are all members of the bivalve class Pelecypoda (hatchet feet). Mussels have separate sexes, though some hermaphrodism occurs. There is evidence that changes in water temperatures, physical stimulation (such as disturbance by winter storms), variation in light levels, or phytoplankton blooms may contribute to spawning.

Spawning in *M. californianus* occurs throughout the year at a very low level, with peaks reported in July and December. The spawning and recruitment of *M. galloprovincialis* also occurs year round, although it is heaviest in February, March, and April and again in September and October in southern California. Mussels reaching 1.6 inches in length are found to have gonads in various stages of development and are able to spawn.

When spawning occurs in the natural environment, eggs and sperm are discharged through the excurrent chamber and fertilization takes place in the open ocean or estuary. Within 24 hours, the embryo develops into a free-swimming trochophore larvae which grows into a more advanced veliger stage within 24 hours. The development of the ciliated velum (approximately 48 hours after fertilization) gives the larvae more control in swimming and in gathering food. The veliger is also known

SMB-26918

as the "straight-hinge" stage, denoting the appearance of the first shell. In two to three weeks, veligers begin metamorphosis, a stage preceded by the development of an eyespot (a photosensitive organ) and a foot. This is the pediveliger stage, during which the veliger changes from a swimming larvae to a bottom dwelling juvenile mussel or spat (seed).

Newly settled mussels attach to substrates with proteinaceous threads (byssus or byssal threads) which are secreted by the postlarvae. Young mussels have the unique ability to detach their byssus, crawl to a different location, or drift away in a current to seek a more favorable substrate, and reattach. This trait is considered to be a significant problem for growers, as postlarvae have disappeared from various substrates soon after placement in open water.

Growth rates of both species of sea mussels in southern California have been reported to be at least 0.25 inch per month and as high as 0.5 inch per month in the Santa Barbara Channel. Growth rate was influenced primarily by the quantity and quality of food, rather than temperature, and mussels achieved a two-inch shell length in six to eight months.

Food consumed by mussels includes dinoflagellates, organic particles, small diatoms, zoospores, protozoans, unicellular algae, bacteria, and detritus. Phytoplankton is considered to be the main food item providing energy for rapid growth.

Competition for space is an important factor influencing growth and survival of mussels, both in wild and cultured populations. Mytilids of the same and different species compete for limited space in the rocky intertidal and subtidal growing areas. Cultured mussels on artificial substrates also can become overcrowded if seed stocking densities are too high. Crowding causes instability of mussel masses and, when coupled with high current speeds, turbulence, and drifting materials, losses frequently occur. Barnacles and sea anemones also compete for space with mussels.

Predators of California mussel species are abundant. They include two sea stars, five species of muricid gastropods, and three crabs. Scoter ducks, the black oyster catcher, and the sea otter are also important predators in coastal waters.

Status of Populations

The population size of wild mussels can vary extensively from season to season and year to year in relation to natural factors such as weather patterns, food availability, predation, tidal exposure, and competition for space. Pollution is a significant determinant in the health of mussel populations, especially to growers considering a new site for mussel culture. Clean growing waters are essential for health of mussels and for humans consuming them. Consequently, mussels are excellent bioindicators of water quality.

John B. Richards
University of California, Santa Barbara
Sea Grant Extension Program

George A. Trevelyan
Abalone Farms, Inc.

References

Koehn, R.K. 1991. The genetics and taxonomy of species in the genus *Mytilus*. Aquaculture 94: 125 - 145.

McDonald, J.H. and R.K. Koehn. 1988. The mussels *Mytilus galloprovincialis* and *M. trossulus* on the Pacific coast of North America. Mar. Biol. 79: 117-126.

Price, R.J. 1989. Paralytic shellfish poisoning and red tides. California Sea Grant Extension Program 89-1, University of California, Davis. 2 pp.

Shaw, W.N., T.J. Hassler, and D.P. Moran. 1988. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific southwest) - California sea mussel and bay mussel. U.S. Fish Wildl. Serv. Biol. Rep. 82 (11.84). U.S. Army Corps of Engineers, TR EL-82-4. 16 pp.

Trevelyan, G.A. 1991. Aquacultural ecology of hatchery-produced juvenile mussels, *Mytilus edulis L.* Ph.D. Dissertation, University of California, Davis.

OYSTERS

History of the Fishery

California's oyster fishery and oyster aquaculture industry have had a rich and colorful tradition. The fishery began in the 1850's, when Eastern immigrants with an appetite for oysters were attracted to California by the prospect of gold and new opportunities. Increases in population and market pressure for oysters had immediate impact on the state's shellfish resources. The only available oyster was the native oyster (*Ostrea lurida*), which was intensively fished, causing a rapid decline in the natural population. In response, native oysters were transported from Shoalwater Bay, Oregon (Willapa Bay) and later from other bays in the Pacific Northwest and Mexico, representing the initial attempts at oyster culture on the West Coast. Oysters were transplanted into San Francisco Bay, where they were maintained on oyster beds and then marketed throughout central California. The Shoalwater Bay trade of Olympic oysters dominated the California market from 1850 through 1869. Market demand for a larger, half-shell product stimulated experiments in transporting the Eastern oyster (*Crassostrea virginica*) from the Atlantic states to the West Coast. Several failed attempts were made to establish transport of the Eastern oyster to California by sailing ships. Successful transport of oysters was achieved only after the completion of the transcontinental railroad. Shipments of market-sized oysters were transported by rail in barrels of sawdust and ice and transplanted into San Francisco Bay. Cool summer water temperatures, however, prevented successful natural reproduction of the eastern oyster.

In 1875, transcontinental trade for Eastern oyster seed was established. Small, one- inch seed was transplanted for further growth in San Francisco Bay. The Shoalwater Bay trade for Olympic oysters was gradually terminated and, from 1872 until the early 1900's, California's San Francisco Bay Eastern oyster industry was the largest oyster industry on the West Coast. Maximum production was reached in 1899 with an estimated 2 5 million pounds of oyster meat produced.

SMB-26919

With California's population and industrial growth came a degradation of water quality in San Francisco Bay. By 1908, Eastern oyster production fell by 50 percent. By 1921, the quality of oyster meats produced declined to the extent that shipments of seed from the East Coast were terminated, and by 1939 the last of the San Francisco oysters were commercially harvested. Oysters were still transported and held in Tomales Bay until they could be marketed in San Francisco, but the industry based on the Eastern oyster did not recover. The industry and state began re-examining earlier experimental plantings with the Pacific oyster (*Crassostrea gigas*). In 1929, the California Department of Fish and Game (CDFG) and commercial entities made experimental plantings in Tomales Bay and Elkhorn Slough. In the 1930's, experimental plantings continued in a number of bays, including Drakes Estero, Bodega Lagoon, and Morro, Newport, and San Francisco Bays. Humboldt Bay was excluded from plantings, as the CDFG was trying to re-establish natural populations of native oysters. Several Pacific oyster plantings proved successful, demonstrating that imported Pacific oyster seed could be grown commercially in California. Shipments of seed from Japan were made through the 1930's, were suspended from 1940 through 1946, and increased significantly in 1947. The seed was inspected in Japan by CDFG personnel who were looking for organisms considered harmful if introduced into state waters. Boxes containing cultch with spat were shipped by boat, and the industry began its recovery on the West Coast. The CDFG lifted its restriction on Pacific oyster seed in Humboldt Bay in 1953, and in the next thirty years the California industry showed rapid growth. Production was centered in Humboldt Bay, Drakes Estero, Tomales Bay, Elkhorn Slough, and Morro Bay.

In the early 1980's, the oyster industry initiated other significant changes. These included the development of U.S.-based shellfish hatcheries and the ability to ship advanced oyster larvae for setting on cultch in heated tanks at remote growout locations. Currently, over 98 percent of the oysters grown in California are produced from hatcheries in Washington and Oregon and from several smaller specialty hatcheries located within the state. Oyster larvae shipped by millions are set on mother shell (cultch), or as cultchless seed where the larvae is set on a loose substrate such as sand or crushed shell. The latter, a California product, results in oysters grown as individuals instead of clusters attached to a mother shell. The hatchery systems also produce new species of Pacific oysters including the Miyagi and, to a lesser extent, the Kumamoto. Other minor species produced by hatcheries over the years include the European oyster (*Ostrea edulis)* and the Eastern oyster. The ability to ship oyster larvae long distance and set the spat at the growout areas has significantly reduced the cost of seed. Although the industry as a whole uses domestic seed, small shipments of Japanese seed are periodically imported to maintain these trade channels as insurance against problems in the domestic hatchery systems.

The production activity within the various bays has varied throughout the years, primarily based on water quality, site selection, and the financial viability of the oyster operations. Growing areas are leased from the state through the Fish & Game Commission, Harbor Districts, and Navigation Districts. Current production is primarily in Humboldt Bay, Drakes Estero, and Tomales Bay. The industry is testing the feasibility of offshore culture in the Santa Barbara Channel and culture in San Diego Bay. Tomales and Morro Bays have experienced reduced production in the past ten years; however, Tomales Bay is currently experiencing a resurgence of production by new growers using cultchless seed and targeting the half-shell markets. At present, about 90 percent of the state's oyster production is in Humboldt Bay and Drakes Estero. A variety of oyster culture methods are being used; each depends upon the physical characteristics of the production bay and the need to protect the younger oysters from predators such as bat rays, mud crabs, and drills (snails). Culture methods are influenced by factors such as substrate type, current velocity, tidal range, and phytoplankton productivity. California oysters are grown from spat to market size in 13 to 18 months, depending on the bay and the method of culture used.

Examining a container of cultchless oyster seed.

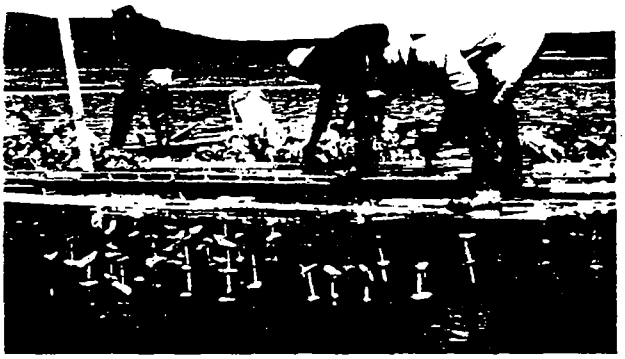
Disease has not been a major factor in the oyster industry since the 1960's, when major die-offs of Pacific oysters were attributed to an unidentified syndrome called "summer mortality." Some producers attribute recent avoidance to harvesting the oysters at a smaller, younger age. Pathologists have identified a "summer mortality syndrome" that can cause mortalities under certain conditions, but large mortalities have not been attributed to this disease, and the cause of the original disease has never been identified. West Coast producers have not experienced the cyclic, catastrophic haplosporidian diseases that have occurred with the Eastern oyster, even though extensive transplants of the oyster have been made. Culture of European oysters has declined in recent years because of the introduction of *Bonamia*, a disease organism that has caused significant mortalities among pre-market stocks. Many producers have switched to varieties of the Pacific oyster.

The primary culture technique used in Humboldt Bay is bottom culture. In bottom culture, cultch with attached spat are spread over selected areas in the bay, the oysters grown to a size

SMB-26920

of about four inches, and harvested by hydraulic dredge. Some off-bottom techniques are used, including bags of oysters supported by low racks and oyster bags attached to longlines.

Drakes Estero has one of the largest off-bottom, rack culture systems in the country. Off-bottom culture is used primarily to avoid predators, use more of the water column, and avoid siltation. The system of rack culture uses mother shells containing spat that are strung on lines. Each mother shell is separated by a tube spacer and the lines secured to hang over the rails of racks set in the bay. Another method, stake culture, consists of three mother shells separated by spacers and threaded on a solid stake that is driven into the substrate. This is used in selected shallow areas within the bay.



Hanging seed oysters from racks at Drake's Estero.

Tomales Bay growers use a variety of off-bottom techniques, including rack-and-bag, stake culture, and bag and longline. Rack-and-bag culture uses cultchless seed that is first grown in trays, then transferred to mesh bags that are positioned on low racks placed in the bay. Bag and longline culture use cultchless seed in mesh bags that are attached to an anchored line which suspends the bags in the water or secures the bags on a stable, hard bottom, intertidal area.

Production in Morro Bay has declined, but techniques have included bottom, rack-and-bag, and stake culture. Producers in the Santa Barbara Channel have used a system of longlines with attached bags of European oysters suspended from offshore rafts in the deep waters. San Diego Bay producers have used rack-and-bag culture for oysters, but are currently moving toward the culture of mussels.

Total annual oyster production for the state was about 1.5 million pounds of shucked meat in 1989 and is expected to increase. The product is marketed as shucked meat in gallons and 10-oz jars, and as shellstock for the half-shell and barbecue markets. The shucked product is marketed as small (200/gallon), medium (140/gallon), and large (100/gallon). Shellstock is marketed as small (2.5-3.5 inches), medium (3.5-4.5 inches), large (4.5+ inches), and clusters (attached, mixed). The demand for oyster products far exceeds the state's production level, and the majority of shellfish products consumed in the state are imported from the Pacific northwest and the Atlantic and Gulf states. The California product is considered prime, and the production areas are among the best in the country.

The California Department of Health Services has regulatory authority over product safety and conducts programs that determine growing area sanitation conditions. Two essential programs are the monitoring of the bays for indications of contamination by human sewage and for the occurrence of natural biotoxins such as paralytic shellfish poison produced by toxic phytoplankton. The programs provide a safe product for the consumer and an early warning system for people sport-harvesting shellfish in noncommercial areas. The water and meat quality monitoring programs also provide an assessment of the biological condition of the natural resource in the hope of preventing a repetition of events that led to the contamination of San Francisco Bay. The state looks on the oyster industry as a wise investment in the natural resource, a valuable renewable resource, and a guardian of water quality.

Status of Biological Knowledge

Oysters are bivalve mollusks that exhibit a variety of sizes, shapes, shell textures and colors, and vary in their mode of reproduction and sexual expression. These biological and physical features influence such aspects as where they grow and how they reproduce, which in turn influence commercial aspects such as culture practices and marketing strategy. Individual oysters conform to the shape of the substrate to which they are attached, and are therefore highly variable in shape. Shape is also influenced by other oysters or substrates pressing on their shells. Shell shape, texture, and color are all influenced by the oyster's genetics and physical environment such as salinity, attachment substrate, and food. They feed on phytoplankton and nutrient-bearing detritus by pumping water over their gills, which filter the food material and pass it into the oyster's mouth.

All oysters have typical molluscan trochophore larvae that develop into a veliger larval form capable of filtering food, swimming, and selecting a suitable substrate for attachment. The microscopic veliger settles, cements its left valve to the substrate, and undergoes metamorphosis into an oyster spat. For the rest of its life the attached spat will compete for space and nutrients and, if it survives, will grow into the adult form. The four oysters now found in California all belong to the same family. They represent two groups characterized by biological variations, including different modes of sexual expression, reproduction, and dispersal of young. The exact temperature at which the oysters will spawn and the rate of larval development and growth depend on a variety of factors, including the genetics of the species and variety and the latitude of the breeding population. Natural spawning is also influenced by lunar periodicity and tides.

The native and European oysters are rhythmical consecutive hermaphrodites; they can change sex either annually or within a closer interval. In their first year they are strongly protandric; the first expression of sex at maturity is male. They may become female in the same year or in the following year if the environmental conditions are good and food is plentiful. They are also larviparous (brooders); fertilization of eggs is

SMB-26921

internal and the larvae are held a period before release. Mature, egg-carrying females spawn at about 59-63° F. The eggs are released into the female's own mantle cavity and are fertilized as she takes in water containing the male's sperm. When the eggs hatch, the veliger larvae are held by the gill-blades and incubate for about 10 days before release. Once expelled, the advanced larvae swim freely and feed on phytoplankton for an additional period before settlement and metamorphosis (native, 14-18 days; European, 10-14 days).

The Pacific and Eastern oysters are alternative hermaphrodites; sex change occurs, but its timing is erratic. They have a tendency for protandry in their first year, but the tendency is not as strong as that of native and Eastern oysters. They are oviparous (broadcast spawners); the eggs are immediately released and fertilization takes place in the environment. Mature, egg-carrying females spawn at about 63-77° F, depending on the species, variety, and latitude. These oysters require higher water temperatures to establish a natural population than are consistently found in California. Since spawning and successful reproduction rarely take place in California, the oysters are spawned and reared in shellfish hatcheries at about 77° F. The eggs hatch into free-swimming trochophores, then veliger larvae; and within three to five days these settle, attach to a substrate, and metamorphose to the spat.

The native oyster is California's only indigenous oyster species, and occurs along the Pacific Coast from Sitka, Alaska to Cape San Lucas, Baja California. The largest concentrations occur in the Pacific Northwest along the coast of Washington's Puget Sound, and in Willapa Bay. Although still grown commercially in Washington in specially constructed beds, natural concentrations are not abundant enough to support commercial endeavors. In California, populations of the native oyster are still relatively low and it is a protected species. The adult is about two to three inches in length and more often irregular in shape. Shell textures vary from smooth to rough with concentric growth lines; and the exterior has purple-brown to brown axial bands. The two shell valves are symmetrical; their interior is colored as shades of olive-green or with a metallic sheen. The adult internal shell's muscle scar is usually centrally located and unpigmented.

The native oyster is found in many of the state's coastal inlets, especially mud flats and gravel bars located near the mouth of small rivers and streams. It cannot withstand high temperatures nor frost when exposed, and does not survive low salinity or turbid water conditions. In bays the natural beds are invariably located in the subtidal zone, where the oyster is better protected from both prolonged hot summer surface water temperatures and extreme cold winter water conditions. They are often found clinging to rocky outcroppings or other structures that offer protection from rays and other predatory fish.

Adult European oysters are about three to four inches in length, with a poorly developed beak that gives the valves an oval to round shape. The left or attachment valve is larger and deeper-cupped than the right valve, with 20 to 30 ribs and irregular, concentric lamellae. The upper, smaller valve is flat, with numerous concentric lamellae but no ribs. The hinge ligament consists of three parts: a middle flat part on the left valve and two projections on the right. The internal valves are white, and the muscle scar is eccentrically positioned and unpigmented.

Adult Eastern oysters may vary in length from two to six inches. The shells are asymmetrical, highly variable in texture and shape, and greatly influenced by environmental conditions. The external shell is usually a shade of gray, and the internal valves white with a variable-colored muscle scar, usually deep purple. The left valve is longer than the right, not deeply cupped, and the beak is usually elongated and strongly curved. The shell margins are usually straight or only slightly undulating, and the inner margins of the valves are smooth.

The adult Pacific oyster averages about four to six inches in length. The shell is coarse, with widely spaced concentric lamella and ridges. The shell is thinner than that of Eastern oysters, but more deeply cupped. The Kumamoto variety spawns in the fall in nature, grows slower than the Miyagi, is smaller, but is highly prized for its deeper cup. More recent work using genetic markers has suggested that the Kumomoto is a separate species from *C. gigas*. The Miyagi is the principal Pacific oyster variety grown on the West Coast. The Pacific oyster's shape may be highly variable and greatly influenced by environmental conditions. The upper, flat, right valve is smaller than the left, and the inner surface of the valves is white with a faint purple hue over the muscle scar.

Harvesting oysters from hanging culture racks at Drake's Estero.

Status of Populations

Native oysters can still be found in sporadic distribution among various bays, but in very low densities. There is periodic interest in attempts to revive the population at specific sites, at least in densities high enough to support limited sport harvest. It remains a noncommercial, protected species.

The commercial species will continue to be cultured in increasing numbers as long as the water quality of the bay systems is maintained and protected. The Pacific oyster continues to be the dominant species cultured, and producers will explore varieties and intra-specific variety crosses such as the Kumamoto X Miyagi. Because hatcheries can control reproduction, they are starting work to develop improved perfor-

SMB-26922

mance through genetics and production of triploid (3n-sterile) stocks of Pacific oysters that grow faster and do not undergo gonadal development.

Fred S. Conte
University of California

References

Barrett, E.M. 1963. The California Oyster Industry. Calif. Dept. Fish and Game Bull. No. 123, pp 103.

Bonnot, P. 1935. The California Oyster Industry. Calif. Dept. Fish and Game. 21(1):65-80.

Conte, F.S. and J.L. Dupuy. 1982. The California Oyster Industry. Proc. North American Oyster Workshop, World Mariculture Society, Special Publication No. 1. pp. 43-63.

ROCK SCALLOP

History of the Fishery

Purple-hinge rock scallops (*Crassadoma gigantea*) are very popular among sport divers and shore collectors in California, Mexico and the Pacific Northwest. The shellfish is prized for its flavorful, almost sweet meat (adductor muscle). No recent commercial harvest of rock scallops has been allowed in California. It was judged several decades ago by the California Department of Fish and Game that these mollusks were patchy in distribution and commercial exploitation would endanger their survival. Thus, rock scallops have remained in the domain of sportsmen. It is difficult to estimate total landings since many are taken incidentally. However, records of the Department of Fish and Game for the years 1978-1987 indicate an average of 928 were taken per year by divers from commercial passenger sport diving boats operating largely at the Channel Islands. The scallops are usually pried from their attachment surfaces with an abalone iron. The large adductor muscle is easily shucked from the opened shells and separated from mantle and viscera, and divers often eat the scallops fresh from the shell, either underwater or above! By almost all criteria, rock scallops ranked superior to other scallops in taste tests conducted by a professional taste panel engaged by investigators at San Diego State University.

Status of Biological Knowledge

The purple-hinge rock scallop is distinctive, having an irregular oval outline, a rugose (ridged) upper free shell (left valve) and a tentacle-bearing mantle, usually orange or gray. The interior aspect of the hinge line on both valves bears a zone of purple pigment. Adults typically are firmly attached to the substratum, in contrast to most other scallops that live free on or above the bottom. While passing a free-living juvenile life, attachment is achieved by temporary byssal threads. Permanent attachment occurs through deposition of shell material by the right valve in conformity to the microrelief of the substratum.

Throughout its range from Sitka, Alaska, to Magdalena Bay, Baja California, the rock scallop is generally found from the lower intertidal zone to depths as great as 100 feet. Offshore reefs are typically populated, but concrete pier pilings and jetty rock at entrances to bays in southern California have also become favored habitats. Commonly this shellfish measures five to six inches in shell diameter, but occasionally individuals exceeding eight inches are found.

Purple-hinge rock scallop, Crassadoma gigantea.

Sexes are separate, although cases of hermaphroditism have been reported. An increase in number of females relative to males among larger adults has suggested protandry (functioning early as males, but later becoming females). Other possible explanations for this finding include differential growth rates and/or survival. Southern California rock scallops exhibit a bimodal annual reproductive cycle, with spawning periods in late spring-early summer and again in mid-fall.

Rock scallops are filter feeders, deriving the bulk of their nutrition from phytoplankton and, to a lesser extent, detritus. Predation may limit numbers of rock scallops, chiefly due to losses of early free-living and newly cemented juveniles to sea stars and crabs. Adults enjoy a high degree of immunity to predation by virtue of their ability to close their sharp-margined valves quickly. However, sea otters may succeed in breaking the shells of adult rock scallops.

A study of the biology and aquaculture potential of the rock scallop undertaken at San Diego State University found that, under the most favorable conditions, growth rate of juveniles and young adults held in the sea in suspended culture exceeded two inches per year. It was found that the rock scallop could be reared from the microscopic egg to marketable size (four to five inches) in about two and a half years.

Rock scallops are intolerant of salinity reduction greater than 30 percent, and are not found in estuaries and bays where freshwater dilutes the saline water to levels below 25 ppt. In

SMB-26923

areas with well circulated oceanic water, adults are hardy and survival is high.

For many years, oyster farmers at Point Reyes have reared rock scallops in pens for sale at a local retail market. Juveniles set naturally among the oysters under cultivation in Drakes Estero are recovered and placed in submerged mesh cages for rearing to a size of about five inches (about two years). These scallops are sold for about $1 each. The adductor muscle in scallops of that size weighs about a tenth of a pound; scallop meats, therefore, were valued (1982) at $10 per pound.

Year-round spawning can be achieved in the hatchery. Larvae are reared through their planktonic stages (about five weeks) and fed unicellular algae until settlement and the onset of metamorphosis. Juvenile stages as small as 0.2 inch begin to cling to the substrate by byssal threads. These anchoring filaments may be detached by the young scallop, allowing swimming for brief periods and relocation if necessary. When the juvenile scallop reaches one-half to one inch (about six months), attachment becomes permanent through cementation. Plastic surfaces are provided for cementation in aquaculture.

Several aquaculture groups in California, Washington state, and British Columbia, are currently testing the concept of rock scallop spat collection as an alternative to production of young in the hatchery. The principal difficulties encountered so far are coincident collection of pink and spiny scallops in northern waters and kelp scallops in southern waters, making separations tedious. Typically, a single spat collection bag, approximately one cubic foot, immersed at a depth of 20 feet for two months, will yield between 500 and 1,000 juvenile scallops. About 25 percent of those would be rock scallops. Until commercial hatcheries are developed to produce substantial numbers of juvenile stock available to growers at a few cents each, the use of spat collectors seems a preferred practice.

Generally, rock scallops have not been subject to problems associated with pollutants. The adductor muscle, which is usually all that is consumed, is not a storage organ for metabolites or toxins. A single case of paralytic shellfish poisoning was reported in 1980 during a red tide off northern California. In this instance, which was fatal, a diver consumed viscera in addition to the adductor muscle from several scallops.

Status of Population

This shellfish is common on offshore reefs and other favored habitats, but in no case is it numerous. Heaviest take of rock scallops occurs at spots frequented by sport diving vessels. Larger adults are becoming rare in these locations and individuals as small as two inches are being taken in large numbers. The present bag limit is 10, but rock scallops may benefit from some size and seasonal limitations.

The rock scallop is a valuable marine resource to the sport diver, as well as a highly promising candidate for extensive cultivation in the sea by new methods of aquaculture.

David L. Leighton
Marine Bioculture

References

Leighton,D.L. 1991. Culture of *Hinnites* and related scallops on the Pacific American coast. *In*: Estuarine and Marine Bivalve Mollusk Culture. W. Menzel, Ed. CRC Press, Boca Raton, Florida.

Leighton, D.L. and C.F. Phleger. 1981. The Suitability of the Purple-hinge Rock Scallop for Marine Aquaculture. Univ. Calif. Sea Grant Program, Technical Series. San Diego State University, Center for Marine Studies, Contribution No. 50.

SALMON

History

Three types of operations are involved in salmon aquaculture: salmon ranching, land-based tank operations, and net-pen rearing. At salmon ranch hatcheries, adult fish are spawned, the eggs are hatched, and the young are reared in tanks to increase their size and to better their chance of survival in the wild. The salmon are then released and grow to market size while at liberty in the ocean. When they mature, the salmon return to the hatchery, where they are harvested. If at least three to five percent of the released salmon return to be harvested, the salmon ranch may be successful. It is not uncommon, however, for 98 to 99 percent of the salmon to be lost to natural and fishing mortality before they can return to the hatchery.

Land-based tank operations maintain all of the fish on the facility until harvest. Fish are kept in tanks made of concrete, fiberglass, or other materials. Round tanks are often 20 to 30 feet in diameter. Water is pumped through the tanks to maintain good water quality, and growth comes from manufactured feed provided by the aquaculturist.

In areas where net-pen rearing occurs, young fish are produced in hatcheries, then placed into pens and grown to market size. The pens are made from flexible netting material suspended from floats and can range in size from a few hundred square feet at the surface to many acres. The net-pens are usually placed in sheltered salt water areas where protection from ocean storms is provided, but where good water quality is maintained by natural currents.

Salmon are produced in California by both private and public hatcheries. While the history of private trout production in California dates back to the 1800's, private commercial production of salmon in California is just now developing. The first evidence of recent interest in commercial salmon production was the authorization by the California Legislature in 1968 for the first (and only) private salmon ranching operation. In 1979, the Legislature authorized the operation's move to its current site on Davenport Landing Creek in Santa Cruz County, where it remains an experimental pilot project. In California, land-based tank operations began in 1983 and have been the source of the State's private aquaculture production of salmon. Currently, salmon culture is not a major component of the State's private aquaculture sector, contributing less than five percent to the total value of the industry's production.

Public salmon hatchery operations play a key role in the management of California's natural resources. Hatcheries are

SMB-26924

built and operated to supplement natural salmon resources or to mitigate for the loss of natural production that occurs when water and power generation projects eliminate salmon spawning habitat. Thus, hatcheries help to provide for the multiple beneficial use of the State's water resources. Public hatcheries produce approximately 50 million fish each year and are critical to maintaining the State's sport and commercial salmon fisheries. Seventy percent of California's salmon harvest comes from south of Point Arena, where hatchery-produced fish generally make up over half of the catch.

Public hatchery production of salmon in California dates back to 1872 with the establishment of Baird Hatchery on the McCloud River in the upper Sacramento River drainage. Several other salmon hatcheries and egg taking stations also began operations in the late 1800's and early 1900's. Baird originally operated as an independent hatchery, then as an egg collecting station for salmon and trout reared at Mount Shasta Hatchery (then called Sisson Hatchery). After the construction of Shasta Dam, Mount Shasta Hatchery and the upper Sacramento spawning grounds were separated from the lower Sacramento River and the Pacific Ocean. Coleman National Fish Hatchery was built in 1942 to mitigate for those losses. It replaced many of the early hatcheries, including most of the salmon operations at Mount Shasta. Coleman is the only federally-operated fish hatchery in California.

Today there are seven California Department of Fish and Game-operated salmon mitigation hatcheries and two State-operated salmon restoration and enhancement hatcheries. All nine of these State-operated hatcheries have been built since 1955.

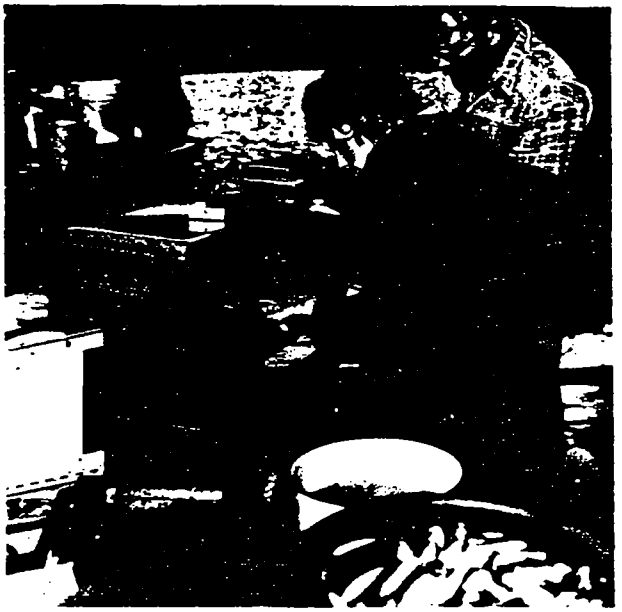
The mitigation hatcheries are located on central valley and north coast rivers downstream from dams constructed for water or power development. Iron Gate Hatchery is on the Klamath River below Copco Lake. Trinity Hatchery is on the Trinity River below Clair Engle Lake. Feather River Hatchery is located below Lake Oroville. Mokelumne River Fish Installation is located below Camanche Reservoir. Nimbus Hatchery is on the American River below Folsom Lake. Van Arsdale Fisheries Station is on the Eel River below Van Arsdale Reservoir. Warm Springs Hatchery is on a tributary to the Russian River below Lake Sonoma. Coleman National Fish Hatchery is on a tributary to the Sacramento River at Anderson, south of Redding.

The Department's two restoration and enhancement hatcheries are the Mad River Hatchery near Eureka and the Merced River Fish Installation below Lake McClure.

In addition, public or privately funded nonprofit salmon restoration and enhancement projects use a variety of habitat improvement, artificial spawning, and rearing techniques to improve runs of wild fish or to contribute additional fish to the fishery. Most are located on coastal streams in northern and central California. Saltwater pen-rearing operations are located at Tiburon, Port San Luis, and Ventura. In 1989-1990, a total of twenty-one projects planted an average of 54,000 fish per project.

Status

Currently, private aquaculture-produced salmon from California may come from either salmon ranching operations or from land-based tank rearing facilities. With the exception of the small sport-fishing salmon enhancement projects, there is no net-pen rearing of salmon in California. Commercial net-pen rearing is not prohibited; however, suitable sites have not been identified or developed which do not conflict with other established uses.



Volunteers tagging salmon for future evaluation of success of a non-profit salmon restoration project.

Every private aquaculture operation in California is required to register with the Department of Fish and Game. Before approving an application for registration, the Department must determine that each facility will not cause significant negative impacts on adjacent native fish and wildlife. Private salmon culture may be permitted throughout California, except that new commercial salmon farming is prohibited from the Smith River watershed.

Most commercially produced salmon have been from tank-rearing operations located in northern California, where the cold water suitable for salmon culture is more readily found. Fish are grown to market size in tanks using either fresh or salt water. Steelhead rainbow trout (*Oncorhynchus mykiss*) are produced from domestic brood stock maintained by California aquaculturists. However, coho salmon (*Oncorhynchus kisutch*) and Atlantic salmon (*Salmo salar*) eggs or fingerlings are imported from out of state to the California farms. The eggs are hatched and the juvenile fish are grown to market size.

Private salmon production in 1990 is estimated at around one million pounds. Most of this production entered the fresh fish market for human consumption. Some small quantities were used to stock reservoirs for recreational fishing. Total production for 1991 is expected to decrease from 1990 levels due to reduced production from the major tank-rearing operation.

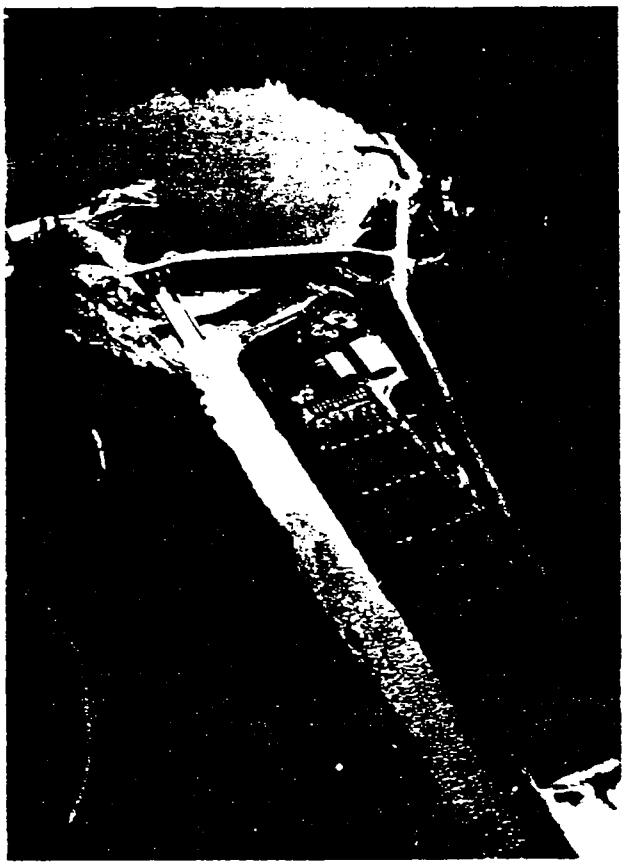
The lone California commercial salmon ranching project operates under a permit from the Fish and Game Commission, which reviews the permit annually. Commission authority to

SMB-26925

issue the salmon ranching permit is granted by the California Legislature. The Legislature reviews the authorization periodically and in 1990 extended authority to issue the permit to January 1, 1996. The project is authorized to ranch chinook salmon (*Oncorhynchus tshawytscha*), coho, and steelhead.

State and federal hatcheries produce chinook and coho salmon and steelhead using the same production techniques as other salmon ranching operations. Returning adults are artificially spawned and the offspring are reared to smolt or yearling size before they are released at the hatchery, or at other freshwater sites, to migrate to the ocean where they grow to adults. Chinook salmon return to be spawned, usually three or four years after release. Coho generally spend one year in freshwater and return from the ocean to be spawned as two- or three-year olds. Steelhead most often spend two seasons in fresh water and one or two seasons in the ocean.

Public hatchery production remains relatively constant; therefore, years of low natural production result in harvests with a larger proportion of hatchery fish. Depending upon the success of each year's natural production, Department of Fish and Game biologists estimate that hatchery-produced fish generally contribute from 30 to 50 percent of California's sport and commercial salmon harvests.



Trinity River Hatchery

Most of the public hatchery production of salmon in California is conducted to mitigate for the loss of habitat caused by construction of dams for water and power development. The concept of providing mitigation for losses to fish and wildlife caused by the building of a government project was originally established by the U.S. Congress when it enacted the Fish and Wildlife Coordination Act of 1934. The need to replace the natural fishery resources eliminated by these projects continues to have high priority with the people of California.

Bob Hulbrock
California Department of Fish and Game

References

California Advisory Committee on Salmon and Steelhead Trout. 1988. Restoring the balance: 1988 Annual Report. 84 p.

Leitritz, E. 1970. A history of California's fish hatcheries 1870-1960. Calif. Dept. Fish and Game, Fish Bull. 150. 86 p.

AQUACULTURE OF MARINE SPECIES: DISCUSSION

California's location, marine influences, and coastal topography that contribute so significantly to the rich Pacific assemblage of marine species have also supported substantial commercial and sports fisheries and a significant aquaculture industry. Although emphasis here is on aquaculture, the commercial and sports fisheries have had a strong relationship to aquaculture in the past and will be more strongly linked in the future. These relationships are recognized by state government and have resulted in legislative mandates assuring aquaculture's place in California's future.

A first link is aquaculture's relationship to commercial fisheries. Interest in aquaculture has increased over the past several decades as a result of public demand for aquatic products and the realization that our traditional natural fisheries are limited in their ability to meet this increased demand. Aquaculture now accounts for approximately 10 to 12 percent of fishery products consumed worldwide. Traditional marine fisheries, once considered unlimited, are now thought capable of producing a maximum sustained level of harvest at 100 to 120 million metric tons per year without harming the natural resource. This limit may be reached or exceeded for our traditional fisheries early in the next century. Options include increasing landings by use of nontraditional underutilized species and through the use of aquaculture, which is the controlled culture of aquatic organisms. Aquaculture is not being designed to replace the natural fishery, but to supplement the demand for fishery products as demand exceeds natural production.

A second link to aquaculture exists with both the commercial and sports fisheries, both of which have been major contributors to the state's economy. The link is aquaculture production of aquatic species that are released into the state's natural waters to mitigate the loss of wildstock through human activities, natural occurrences, or the effects of both. The State Resources Agency has a long history of public aquaculture for mitigation through its hatchery systems. More recently, the private sector has joined with agencies in cooperative programs

SMB-26926

operated under state control to produce aquatic species primarily for mitigation of sport fishing species.

California's 1,100 mile coast has a number of bays and inlets suitable for aquaculture, and most commercial operations from Crescent City to San Diego are located in these sheltered bays and inlets. Most of the coastline is dominated by rocky inshore areas with rough, steep cliffs, and recently facilities have been built that pump water over the cliffs to onshore tank culture operations. Strict coastal zone regulations also mandate compatibility with environmental and other local regulations.

Aquaculture in California is not new. In each instance it has matured from a fishery through developmental steps to controlled culture of the species. From its early application of culturing oysters in the 1860's and trout in the 1870's, the state's industry produces over 35 species. Ex-farm value is estimated to be in excess of 35 million dollars annually. The marine aquaculture industry has a good mix of commercially viable species and species under research and development that are expected to make the transition to economic viability in the future.

Marine aquaculture makes up almost one-half the total aquaculture industry, with the major food species produced being oysters, mussels, salmon, and abalone. Some marine and brackish water species, such as sturgeon and striped bass, are cultured at inland sites, thereby taking advantage of their anadromous nature and adaptability to fresh water. Other important aquacultural contributions to the state include non-profit salmon and steelhead production facilities operated by citizen organizations in cooperation with the resource agency to mitigate the natural fishery.

The future of California marine aquaculture is bright and essential, both for increased food production and to maintain the state's natural resources. If the quality of our coastal waters is maintained, the state's aquatic production of the species raised now will increase and become an even greater contributor to the state's economy. Research and development by industry and institutions will continue to add additional species to the list of those being cultured, both for food and in support of the natural resource where species are threatened or endangered. Aquaculture is a valuable inclusion within the coastal zone and can be compatible with the objectives of coastal zone management. A healthy environment and clean water are essential to aquatic production, and more often the monitoring programs mandated to assure seafood safety of aquaculture products are the sentinels that measure the quality of our coastal waters. California has a rich assemblage of marine species that contribute to our food base, to the economy of the state, and of equal importance contribute to our quality of life as a direct reflection of nature's gifts.

Fred S. Conte
University of California, Davis

SMB-26927

BOX CRAB

History of the Fishery

While they have rarely been marketed in California, box crabs (*Lopholithodes foraminatus*) have been used commercially in Oregon for several years. The meat, which is found mainly in the claws and legs, is tasty and has good texture, and the meat yield of about 25 percent of the total weight is high compared to that of the more familiar rock crabs. The shell takes on an appealing reddish tinge when cooked, but moderately sharp spines on the carapace and legs detract somewhat from the box crab's marketability. The shell is not as hard as that of rock crabs, however, so the meat is easier to extract.

Box crabs are a common bycatch in the groundfish fisheries of northern California. They are often entangled in gillnets that are used to catch rockfish in deep water, and are also captured, sometimes in large numbers, in trawl nets. Traps used to catch fish or Dungeness crab are also effective for catching box crabs, which are readily attracted to bait. Captured box crabs are usually discarded, or are eaten by fishermen, because of the lack of a market. No regulations apply to the commercial or sport take of box crabs.

An experimental trap fishery for box crab carried out in August and September, 1989, in southern California at the northern Channel Islands, produced only a few crabs. Most of the fishing was conducted in the shallow end of the box crab's range, which may partly account for the poor results. Observations made during that study suggest that long soak times are needed to catch box crab, which may not be as mobile as other crabs and lobsters. In fact it was suggested that trawling may be more efficient than trapping as a means of catching box crabs commercially. Box crabs do poorly in captivity in ambient surface sea water temperatures in southern California; so refrigerated systems are needed in order to keep them alive. On the other hand, they will remain alive out of water for at least two or three days if kept in temperatures under 45°.

The marketability of box crabs was discovered in Oregon in 1983, when El Niño conditions forced fishermen and dealers to look to substitute species for the many normal target species no longer available. Catches jumped from 16,000 pounds in 1983 to 272,000 pounds in 1984, then declined to 93,000 pounds in 1985. Much of the product was sold in the form of picked meat to buyers on the east coast, who needed substitutes for declining resources of "Jonah" crab. The crabs were caught mainly in Dungeness crab pots with entrances made a bit higher to accommodate the shape of box crabs.

Status of Biological Knowledge

When its legs and claws are folded under its body, the box crab resembles an oval rock or, arguably, a small box. Box crabs have a light brown carapace and are white below. The entire front margin of the carapace is armed with short, sharp spines. When the legs are folded inward, a round hole is formed at the angle of the middle joint between the claw and the first walking leg, from which the scientific name "*foraminatus*" was derived.

Box crab, *Lopholithodes foraminatus*.

In northern California, box crabs are abundant in depths of 300 to 800 feet. Further south, they are more common in somewhat greater depths of about 600 to 1,000 feet. The record depth of capture is 1,800 feet. Box crabs are found on sandy, muddy, and rocky bottom. They may possibly undergo migrations from deep to shallow waters and vice versa during certain seasons.

Little is known about the biology, behavior, or population parameters of this species. Egg-bearing females are common off southern California in February, and hatching probably occurs sometime in spring. Mature males weigh about 1.3 pounds, and the largest individuals are about 2.5 pounds and measure seven inches across the back. Females are smaller than males.

Like other crabs, box crabs probably feed mainly on invertebrates that occur in their habitat. The strong claws are used to grasp and tear their prey into manageable size. The major predator of box crabs is probably octopus. Other animals find it difficult to eat box crabs when they assume their defensive position, with all the appendages folded under the body.

Status of Population

Nothing is known about the abundance of box crabs. Occasional reports of catches of large numbers box crab by trawl fishermen in both northern and southern California suggest that the populations may be sizable. Near San Diego, researchers regularly caught box crabs in baited traps set in depths of 125-175 fathoms. We need to learn more about the life history as well as abundance of box crab in order to determine appropriate catch levels.

Susumu Kato
National Marine Fisheries Service

References

Schmitt, Waldo L. 1921. The Marine Decapod Crustacea of California. Univ. of Calif. Press, Berkeley, Calif. 470 p.

SMB-26928

KELLET'S WHELK

History of the Fishery

Relatively few Kellet's whelks (*Kelletia kelletii)* are taken commercially, and these are usually sold alive in southern California at local fish markets that specialize in live fishes. Consumers represent various ethnic groups used to eating similar kinds of shellfish, such as conch from the Caribbean, and other neptunid snails found in southeast Asia. The whelks are usually boiled whole, then the meat extracted and viscera removed. The shell can also be cracked and the meat removed before cooking. Live Kellet's whelks are presently sold by fishermen to wholesalers for 25 to 40 cents per pound. Some *Kelletia* meat is also imported from Mexico.

Presently, small commercial landings are made primarily by rock crab fishermen who catch Kellet's whelk incidentally in their traps. Lobster fishermen also catch and deliver whelk at times. Most of these catches are made near shore, from San Diego to Pt. Conception, and at the Channel Islands. Because landings of Kellet's whelk are recorded with other shellfish under the collective terms "sea snail," "miscellaneous mollusks," or "whelk" in catch statistics maintained by the Department of Fish and Game, the actual amount landed is unknown. However, except for some landings of "miscellaneous mollusks" with high unit value, landings under these categories recorded from San Diego to Santa Barbara can be safely assumed to be composed primarily of Kellet's whelk. From 1977 through 1989, the estimated catch in southern California ranged from 16,000 to 40,000 pounds, with an average of 28,000 pounds. No Kellet's whelk are caught commercially north of Point Conception.

No restrictions apply to fishing for whelk, but the high vulnerability of spawning aggregations may require seasonal protection of the species if the fishery should expand. Divers can easily harvest dense clusters of Kellet's whelk found in shallow water during the spring spawning season. The most productive fishing period using traps is from June through November, and the least productive is during the spawning season.

Kellet's whelk, *Kelletia kelletii.*

Status of Biological Knowledge

Among the largest gastropods found in southern California, Kellet's whelks are common there in shallow water. The ponderous shell is grayish white, often with a greenish tinge. They are common from central Baja California to Pt. Conception, and occur northward at least to Morro Bay. They are usually found in and adjacent to kelp beds and in nearshore areas with rocky bottom, in depths of six to 130 feet, and occasionally to 200 feet. They seem to prefer areas with boulders, ledges, and outcroppings rather than smooth rocky bottom, but can also be commonly found on sandy bottom adjacent to rocky areas.

The sexes are separate, and reproductively active pairs are frequently found during spring. Spawning usually starts around April at San Diego, where bottom temperatures at depths of 65-82 feet range from about 51° to 57° F. Females reach sexual maturity at a shell length of about 2.8 inches, while males mature when slightly smaller. Spawning is annual and each female deposits egg capsules for at least a month during the spawning season. Individuals have been observed laying 22 capsules in 24 hours and 85 capsules during four spawning episodes over a period of 30 days. Each capsule usually contains 400 to 1,000 eggs, but occasionally has over 2,000.

The egg capsules are attached in clusters to hard substrate, including dead shells, rocks, and shells of live whelks. Incubation time is around a month at 60° F. Little is known about the life history after the free swimming veliger larvae are hatched. One researcher estimated that adult whelks 2.5 to 3.0 inches long were about seven or eight years old. The maximum shell length is about six inches.

Kelletia is a carnivorous scavenger, feeding primarily on dead and dying animals found on the sea floor. Large numbers of the whelk are often found aggregated around carcasses of dead fish. Live animals eaten by *Kelletia* include barnacles, gastropods, pelecypods, polychaete worms, and ascidians. A long proboscis allows them to feed in crevices and narrow spaces where they are not able to enter.

Octopus and starfish are the major predators of large Kellet's whelk, while the young are eaten by these animals as well as various fishes.

Status of Population

Spawning aggregations of 15-20 whelks are common in some kelp beds, and as many as 200-300 whelks have been found within an area of 25 square yards, at a depth of 60 feet. During non-spawning seasons, densities of 28 to 60 whelks per 100 square yards were counted during underwater surveys of areas with good whelk habitat. Because annual catches have been low, populations of Kellet's whelk have probably not been adversely affected by fishing. Estimates of population size are not available for this species.

References

Reilly, Paul N. 1987. Population studies of rock crab, *Cancer antennarius*, yellow crab, *C. anthonyi*, and Kellet's whelk, *Kelletia kelletii*, in the vicinity of Little Cojo Bay, Santa Barbara County, California. Calif. Fish and Game 73(2) 88-98.

SMB-26929

Rosenthal, Richard J. 1970. Observations on the reproductive biology of the Kellet's whelk, *Kelletia kelletii*. The Veliger, 12(3):319-324.
Rosenthal, Richard J. 1971. Trophic interaction between the sea star *Pisaster giganteus* and the gastropod *Kelletia kelletii*. Fishery Bull. 69(3):669-679.

OCTOPUSES

History of the Fishery

Octopuses have been reported in California's commercial fishing records in every year since 1916 when the records were first collected. Between 1916 and 1990, landings ranged from a low of 1,160 pounds in 1960 to a high of 166,291 pounds in 1924. The average annual catch is about 45,000 pounds.

Very few published records exist regarding the nature of the fishery. Phillips gave a detailed description of the fishery in the Monterey Bay area in the period between 1920 and 1933. The "devilfish" pots in use then were cone-shaped wicker baskets with a funnel shaped mouth; the traps were four to five and a half feet high and about two to three feet in diameter at the wide end. They were constructed of rattan which was deemed better than wire because of its flexibility when in contact with rocks. The catches were made from rocky areas in 20 to 30 fathoms of water. Most of the catch was the giant octopus (*Octopus dofleini*) with an average weight of between 20 and 30 pounds.

From 1919 to 1944, almost the entire catch was landed at Monterey; then San Francisco became the leading port for a year, only to lose out to Eureka in 1946. San Francisco and Monterey then regained the lead, although landings at all ports were declining between 1950 and 1960. Landings rebounded strongly for about four years at San Francisco in the early 1960's. Catches then declined again, until only 1,804 pounds were landed statewide in 1971. Another striking up and down cycle took place between 1972 and 1984.

Since 1972, most of California's catch has come from the Eureka area and was incidental to trawl netting for rockfish and flatfish. Southern California annual landings since 1950 have been less than 10,000 pounds, with the bulk of that catch coming from the Santa Barbara area.

There is a slight declining seasonal trend in average monthly catch during the period 1947-1990, with the highest catch in January (average = 4,555 pounds) and the lowest in November (average = 2,205 pounds).

Early investigators commented that the commercial catch of octopuses is of little importance compared with most other California fisheries. This status continued between 1950 and 1970, with the average ex-vessel price at less than 10 cents per pound. Since then, however, there has been a steady trend of increasing ex-vessel value. Between 1970 and 1982, the average value increased from 10 to 55 cents per pound; over the next six years, the average price doubled.

A short-lived, high value, limited volume fishery for live octopus began in the Los Angeles area in 1983. In 1981 and 1982, the Los Angeles area value had been 75 and 93 cents per pound, respectively, while the statewide average was 50 and 55 cents. In 1983, the Los Angeles price climbed from $3.14 per pound to almost $13.00 (1987), before dipping slightly to $11.75 in 1988 and plunging to only 64 cents per pound in 1989. The ex-vessel value in the rest of the State remained under $1.00 per pound during this time.

There are no season or bag limits relating to the take of octopuses for commercial purposes.

Status of Biological Knowledge

The six species of octopuses commonly found in California's waters are all bottom dwellers as juveniles and adults. They are found from the intertidal zone to depths of about 500 fathoms and in many diverse habitats, including rocks, kelp holdfasts, and soft bottom substrates such as sand and mud. The giant octopus contributes most of the catch in northern California, while the California bigeye octopus (*O. californicus*) and the red octopus (*O. rubescens*) probably contribute most of the catch in Santa Barbara and to the south. Other species found in southern California are the California lilliput octopus (*O. micropyrsus*) and two nearly morphologically identical species, both called the California two-spot octopus (*O. bimaculatus* and *O. bimaculoides*). These latter two can be separated by differences in body size, color patterns, behavior, egg size, and kinds of parasites found in the kidneys.

The sexes are separate. During copulation, the male places packets of sperm (spermatophores) in the body cavity of the female by means of a modified arm (hectocotylus) with a suckerless, groove-shaped tip. The females lay eggs attached singly or in grape-like clusters to a hard substrate. The eggs range in number from a few hundred to the thousands. They are brooded for several weeks to several months by the females who usually do not feed while guarding the nest and often die when the eggs hatch. Young of some species hatch out with well-developed ink sacs and arms capable of feeding and crawling and take up benthic life, while young of other species enter a pelagic larval phase upon hatching.

Octopuses are voracious predators, feeding on a wide variety of invertebrates, principally crustaceans and other mollusks, and small fish. They use the suckers on their arms to catch and hold, the radula to rasp flesh, and the beak to bite. Octopuses often drill tiny holes in the shells of crabs, clams, and snails through which they inject a poison to paralyze and kill their prey. They in turn are fed on by marine birds, mammals, fishes, and man.

California octopuses are generally short lived, with a life span of from six to 18 months, although the giant octopus is thought to live to an age of three to five years. They range in weight from a few ounces to over 400 pounds and in size from two inches to about 30 feet in diameter (from arm tip to arm tip).

Status of Population

No surveys have been made to determine the abundance and distribution of California octopuses. At the present time it appears that the incidental fishery is far from utilizing the full potential of the resource. Recent catch levels of 10,000 to

SMB-26930

30,000 pounds per year are about 20 percent of the record catch, 165,000 pounds, taken in 1924.

John M. Duffy
California Department of Fish and Game

References

Cox, K.W. 1949. Octopus. Pages 170-172 *in* Bureau of Marine Fisheries. The commercial fish catch of California for the year 1947 with a historical review 1916-1947. Calif. Fish and Game, Fish Bull. 74.

Heath, H. 1917. Devilfish and squid. Calif. Fish and Game 3:103-108.

Hochberg, F.G., Jr. and W.G. Fields. 1980. Cephalopoda: The squids and octopuses. Pages 429-444 *in* R.H. Morris, D.P. Abbott, and E.C. Haderlie, Intertidal invertebrates of California. Stanford University Press. 690 p.

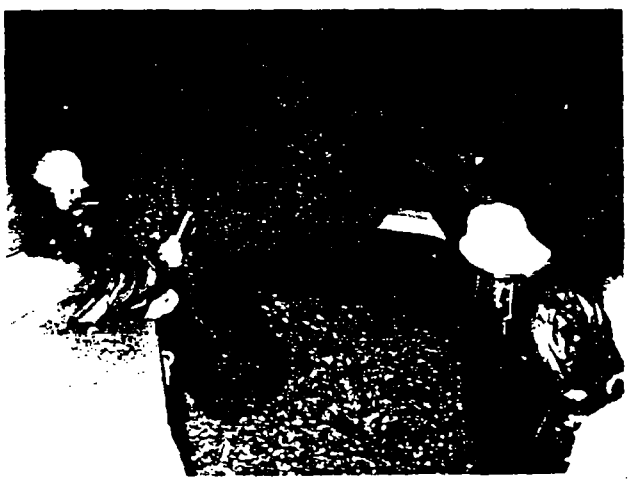
Lane, F.W. 1957. Kingdom of the octopus. Jarrolds. 287 p.

Phillips, J.B. 1933. Octopi of California. Calif. Fish and Game 20:20-29.

PELAGIC RED CRAB

History of the Fishery

Pelagic red crabs *(Pleuroncodes planipes)* constitute a large fishery resource when they periodically appear off the southern California coast. The bulk of the resource is centered off southern Baja California, but during warm water years many crabs are carried as far north as Monterey. Although this species is not now fished commercially, in the past it has been used in pet food and aquaculture feed, and other uses have been suggested. The flesh is edible (red crab is closely related to "langostino," which has been imported from Chile for many years), and the shell can be converted to "chitosan," a compound similar to cellulose with a number of practical applications. The carotenoid pigment in red crab can be used to enhance pigmentation in the flesh and skin of fishes, as well as feathers of birds such as captive flamingos. It also gives a desirable golden hue to the skin of chickens.



Midwater trawl catch of pelagic red crabs.

A small fishery for pelagic red crab was initiated in the early 1970's, with practically all of the catches being made off southern Baja California, Mexico. The fishery lasted until around 1977, when extended jurisdiction effectively closed all areas of dense concentration of red crabs to American fishermen. Throughout the fishery's existence, a single boat made all commercial landings of red crabs.

Although large numbers of red crabs are periodically seen off southern California, attempts to catch them in commercial quantities have proven difficult. Thus, the fishery was conducted in southern Baja California, particularly in and near Magdalena Bay. All the landings were made in San Pedro. Initially the crabs were used as an ingredient in canned cat food, but later they were minced and included in the formulation of a salmon feed known as "Oregon Moist Pellets," used extensively by salmon growers. The value of red crab lay in its high concentration of carotenoid pigments which, when ingested and assimilated by salmon, gave the fish flesh its characteristic color. Without the inclusion of carotenoid pigments in the diet, the flesh of cultured salmon is pale.

Both midwater and bottom trawls have been successfully used to catch pelagic red crab. A special problem occurs in unloading the catch from the trawl nets, because the crabs interlock with each other and splitting off manageable amounts in the cod end is difficult. On-board handling and storage are also difficult, because the crabs are light and bulky. Further, enzyme activity quickly causes spoilage. In order to store large quantities aboard a vessel, it was found that grinding and freezing the product in plastic bags was most practical.

Pelagic red crab, *Pleuroncodes planipes*.

Status of Biological Knowledge

The pelagic red crab is a striking red crustacean belonging to the family Galatheidae, which includes a number of lobster-like crabs. Adult red crabs attain body lengths of only about 2.5 inches, and 100 or more individuals are needed to make up a pound.

SMB-26931

Pelagic red crab is normally found off southern Baja California, Mexico, but in years when strong northward transport of water occurs along the west coast it can be found as far north as Monterey. They are found in surface layers, and on the bottom from shallow depths to around 150 fathoms. Although they have been found in temperatures of 48 to 82°, they seem to prefer water temperatures between 59 and 70° F.

Larval and young stages of red crab lead a planktonic life for about a year. In the second year, maturing crabs are about 0.6 inch in carapace length and spend some time on the bottom. By the end of the second year they are slightly larger than one inch long and become strictly benthic.

Red crabs become reproductively mature sometime in their second year. Each female may have two or three broods of eggs in one season, with up to 3,600 eggs in a brood. Eggs hatch about two weeks after they are carried externally. Spawning peaks in the winter, mainly off southern Baja California, but in warm water years spawning can occur as far north as southern California.

Planktonic red crabs feed on phyto- and zooplankton by filtration. Benthic stages probably feed primarily on detritus, but can also feed on dead animal matter and can even catch live copepods by using their chelipeds.

In nature, the red crab is an important food item for many fishes, birds and marine mammals, because of its great abundance and availability. Predators of red crab include most carnivorous fishes, especially tuna off southern Baja California, several species of birds, sea lions and some whales. Off southern California, they constitute an important food item for gulls and probably marine mammals as well, especially during El Niño years when other feed such as squid and anchovy are scarce.

Younger stages of pelagic red crab live up to their name, and are transported in all directions by currents from the primary spawning grounds off south-central Baja California. Windrows of these crabs are often seen stretching for miles on and near the surface. Mass strandings of pelagic red crabs occur regularly on beaches in Baja California and periodically happen as far north as Monterey.

Status of Population

Little information is available about the abundance of pelagic red crab. One survey by a Russian research vessel found around 300,000 tons of red crabs in an area of 77,000 square miles off Baja California. In another study, stomach contents of tunas caught in this area indicated that the fish ate around a pint of red crabs daily; so the total abundance must be considerable. Off California, however, large quantities occur only infrequently, when warm currents carry the crabs northward from the center of abundance off Baja California.

Susumu Kato
National Marine Fisheries Service

References

Boyd, C. M. 1962. The biology of a marine decapod crustacean, *Pleuroncodes planipes* Stimson 1860. Ph.D. Thesis, Univ. Calif., San Diego, 123 p.

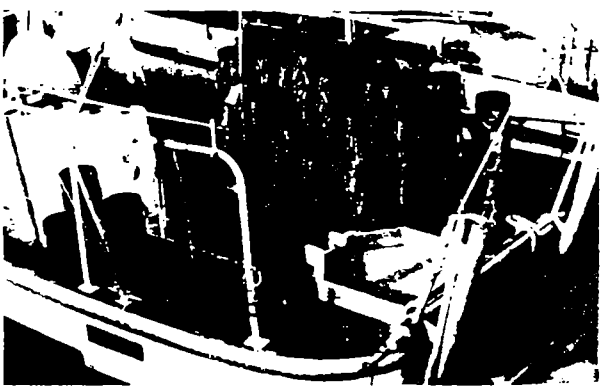
Kato, Susumu. 1974. Development of the pelagic red crab (Galatheidae, *Pleuroncodes planipes*) fishery in the Eastern Pacific Ocean. Mar. Fish. Rev. 36(10):1-9.

PACIFIC HAGFISH

History of the Fishery

Hagfish are primitive, eel-like vertebrates that are often called "slime eels" because of their ability to produce large amounts of mucus. Until the late 1980's, most fishermen in California thought of hagfish only as pests which would attack fish caught in gillnets, longlines and traps. This perception changed when buyers from the Republic of Korea (South Korea) came to California in search of hagfish. In Korea, hagfish are highly valued for their edible flesh and for their thin, durable skin, which is used to make "eelskin" leather.

A fishery for Pacific hagfish (*Eptatretus stoutii*) began in the San Francisco and Monterey areas in 1988. Eight boats participated in the fishery the first year, landing approximately 690,000 pounds of hagfish. The fishery grew rapidly, spreading north to Eureka and south to San Diego. The number of boats in the fishery increased to eighty in 1989, and landings increased to 2.6 million pounds. Landings rose again in 1990 to 4.9 million pounds with an ex-vessel value of over two million dollars. Fishing effort began to decline at the end of 1990 and the decline continued in 1991, due primarily to the decrease in the ex-vessel prices brought about by the availability of other sources of hagfish.



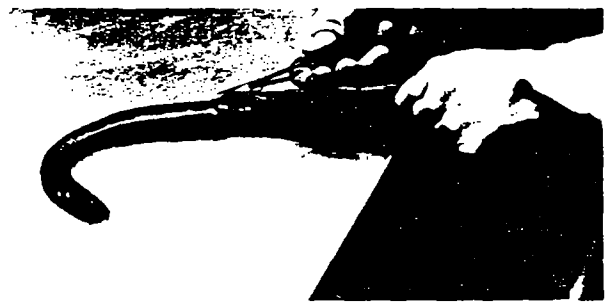
Hagfish traps onboard a Morro Bay fishing vessel.

Hagfish are caught with baited traps that are set on the ocean bottom. Several types of traps have been used in the fishery. The first type, imported from Korea, was a molded plastic tube perforated with small holes. It measured about five inches in diameter and two feet in length. One end of the Korean trap was closed, and the other had a removable one-way funnel. As the fishery developed, fishermen in California designed other traps. Some were made from four to six gallon plastic buckets, while others were made from 32 to 55 gallon plastic trash cans or pickle barrels. All the traps had small holes in their sidewalls and all had one-way funnel entrances. The lids or funnels of the traps were held in place by rubber bands tied to

SMB-26932

degradable cotton line, which served as a destruct device, required by law, to keep lost traps from continuing to catch and retain fish.

Most of the boats in the fishery were 30 to 50 feet in length and carried a crew of two to three people. They set 500 to 1,500 Korean traps, 200 to 500 bucket traps or 90 to 120 barrel traps at one time. The Korean and bucket traps were usually run on a single longline, while the barrel traps were run on three or four separate lines each with about 30 traps. Fishing occurred at depths ranging from 240 to 1,200 feet, with soak times from four to 24 hours.



Pacific hagfish, *Eptatretus stoutii*.

Status of Biological Knowledge

Pacific hagfish range from southeast Alaska to Baja California. They are bottom dwelling and occur at depths from 60 to 3,100 feet, but generally shallower than black hagfish (*E. deani*), whose range overlaps. Pacific hagfish inhabit a variety of substrates including mud, gravel and rock. However, they appear to prefer mud, in which they make burrows.

The smallest free-swimming Pacific hagfish on record is 2.36 inches long; the largest is 32.3 inches. Fish from 12 inches to 18 inches predominate in the commercial landings. Very little is known about the growth rate of Pacific hagfish, since they are difficult to age because they lack bones and other hard parts that bear annual marks. The few tagging experiments that have been conducted suggest a slow growth rate.

Hagfish have a single gonad that runs the length of the abdominal cavity. Sexual differentiation is a gradual and highly variable process; nevertheless, most differentiate into male or female before reaching nine inches in length. Until Pacific hagfish are about 7.8 inches in length, the anterior part of the gonad undergoes early stages of female differentiation. Females continue this development and most are mature by nine inches in length. In males, the ovarian structures in the anterior part of the gonad degenerate, and the posterior part of the gonad begins to differentiate into a testis; most males are mature by 11 inches.

Early researchers speculated that Pacific hagfish were hermaphrodites, but more recent studies have demonstrated that normally they are not. Rare cases of hermaphroditism as well as gonadal bisexuality do occur, however.

Fertilization is thought to be external. Females lay large yolky eggs which are covered by a horny shell. The oblong eggs range in length from 0.9 to 1.3 inches, and have tufts of filaments at each end which anchor the eggs to the bottom and to each other. Fecundity is low. Typically, 10 to 30 eggs mature during a reproductive cycle.

There is no apparent breeding season. The proportion of females with large (0.8 inch or longer) eggs is constant throughout the year. In addition, at anytime of the year, individual males contain testicular follicles in various stages of spermatogenesis. Pacific hagfish are thought to be repeat spawners because empty follicles, indicating recent ovulation, are often present in fish with developing eggs. The interval between successive spawnings is unknown.

Hagfish are scavengers of dead and injured animals, and may also be predators on benthic organisms. A study of Pacific hagfish in Monterey Bay showed that they eat a wide assortment of animals including cephalopods, polychaetes, shrimp, fish, and amphipods. They are notorious for devouring large prey from the inside out. Hagfish enter such prey through an orifice or by boring into the body cavity; then using their rasplike teeth they consume the flesh and viscera of the prey leaving behind a bag of skin and bones.

Aside from man, there are few known predators of Pacific hagfish. Hagfish eggs have been found in the guts of male Pacific hagfish and in sablefish. Adult black hagfish have been found in the guts of sablefish, and it is likely that sablefish also prey upon Pacific hagfish, since their distributions overlap.

Status of Population

As of 1991 there has been no study of the population of Pacific hagfish.

Constance J. Ryan
University of California
Sea Grant Extension Program

References

Gorbman, A. 1990. Sexual differentiation in the Hagfish *Eptatretus stouti*. Gen. Comp. Endocrin. 77:309-323.

Jensen, D. 1966. The hagfish. Sci. Amer. Feb.:82-90.

Worthington, J. 1905. Contributions to our knowledge of Myxinoids. Amer. Nat. 39:625-663.

SPOTTED RATFISH

History of the Fishery

The spotted ratfish or chimaera (*Hydrolagus colliei*) is presently not used commercially in California, and probably is eaten only rarely on the occasions when it is caught by recreational fishermen. However, fillets of chimaera have recently been imported into California, probably from Argentina and Chile, and have been sold in restaurants as well as fish markets. Chimaeras, called "ghostsharks" in New Zealand where the fillets are sometimes marketed as "pearl fillets," have been eaten there as well as in South Africa for many years. Chimaeras are also used as food in China, but no information is available on the amount consumed. The large liver also yields an all-purpose oil of good quality, which has been used as an

SMB-26933

external and internal medication as well as a lubricant. Spotted ratfish is commonly taken in trawl nets, and may represent a sizable underutilized resource in California. Total world landings are on the order of 3,000-4,000 tons annually, primarily in New Zealand, Chile, and Argentina.

Spotted ratfish are commonly found in the bycatch of bottom trawl nets. They are also caught by baited hooks that are fished near or on the bottom, and in bottom set gill nets.

Spotted ratfish or chimaera, *Hydrolagus colliei.*

Status of Biological Knowledge

The spotted ratfish is an extraordinary fish, with a silvery to bronze body dotted with numerous white spots, and a smooth, scaleless skin often having a metallic cast. Large green eyes are set in a head that resembles that of a rabbit. The strong dorsal spine contains a venom which, though not lethal, can cause severe pain. Chimaeras are similar to sharks in having a cartilaginous rather than bony skeleton.

Found from western Alaska to the tip of Baja California, and in the northern part of the Gulf of California, it is common in depths from 1,000 to 1,300 feet in spring. It is a bottom dweller, and occurs in shallow waters in the northern extremes of its range, but has been found as deep as 3,000 feet.

Studies which use marks on vertebrae and spines have not been successful in estimating the age of ratfish, nor have those which use eye lens weights and body length modes. Females apparently grow to a larger size than males. In one collection of 448 ratfish, no males were as long as 20.4 inches, while ten females were between 20.4 and 21 inches. The largest recorded length is 38 inches.

Some females are mature at a length of 18 inches, while all are mature by the time they are 20 inches long. Fertilization is internal. Males have two hooked clasping organs in front of the pelvic fins and, like male sharks, are equipped with a pair of claspers which are used to transfer sperm capsules into females.

The female lays leathery egg cases which are five to six inches long and are wide at one end and narrowly tapered at the other, which sticks into the mud bottom. Egg-laying usually occurs in spring and summer, but some females and most males are reproductively active throughout the year. Egg capsules are probably laid in pairs, and it is possible that fertilization of a second pair of eggs may follow soon after the first pair is released, and that those are released soon thereafter.

The teeth of ratfish are arranged in three pairs of large flat plates, two pairs in the upper jaw and one pair in the lower. Feeding habits reflect an opportunistic nature, and the diet includes clams, snails, shrimps, nudibranchs, annelid and polychaete worms, coelenterates, amphipods, small fishes, and heart urchins. Many large fishes such as lingcod, rockfish, and halibut, as well as several species of sharks and marine mammals, probably eat ratfish.

Spotted ratfish in the Gulf of California apparently migrate seasonally, but this may be due to special hydrographic conditions within the Gulf and may not be indicative of distribution patterns elsewhere.

Status of Population

Nothing is known about the size of the population of spotted ratfish. The species has never been purposely sought in California, but is caught regularly by fishermen targeting other species. Spotted ratfish are common in relatively shallow smooth bottom grounds where trawlers work, and are also found in rocky areas. Since they are not gregarious, it is rare to catch them in large numbers. Fecundity is low and, like sharks, chimaeras are probably more susceptible to overfishing than are bony fishes, which produce a large number of offspring.

Susumu Kato
National Marine Fisheries Service

References

Eschmeyer, William N., Earl S. Herald, and Howard Hammann. 1983. A field guide to Pacific Coast fishes of North America. Peterson Field Guide Series, Houghton Mifflin Co., Boston. 336 p.

Johnson, Allyn G. and Howard F. Horton. 1972. Length-weight relationships, food habits, parasites, and sex and age determination of the ratfish, *Hydrolagus colliei* (Lay and Bennett). Fish. Bull. 70(2):421-429.

Mathews, C. P. 1975. Note on the ecology of the ratfish *Hydrolagus collei* (sic), in the Gulf of California. Calif. Fish and Game 61(1):47-53.

PACIFIC GRENADIER

History of the Fishery

Pacific grenadier (*Coryphaenoides acrolepis*) has scarcely been utilized in California, but its catch and consumption is growing. Annual landings of this species have increased in the 1980's to an average of 128,000 pounds from around 85,000 pounds in the 1970's. The catch for 1989 amounted to a record 263,000 pounds. There is no directed fishery for grenadiers. Rather, they constitute a significant part of the by-catch in the deep-water bottom trawl fishery for Dover sole, thornyhead, and sablefish. Pacific grenadier are found off the entire California coast, but most landings have been made at Eureka. Some Pacific grenadier have also been caught and sold at Monterey, primarily by sablefish trap fishermen, but also by deep-water trawlers.

The Pacific grenadier has several attributes that make it a desirable market fish. The color of the meat is light, and the flavor mild. Moreover, its low oil content, around 0.5 percent, contributes to a long shelf life, as rancidity is not a problem. Because grenadiers are among the most abundant species on the

SMB-26934

deep continental slope, they constitute an important latent resource that may be utilized fully one day.

Presently, most catches of Pacific grenadier are made with trawl gear, but hook and line is also effective. In fishing trials, vertical longlines caught fish on about 50 percent of baited hooks in areas where the fish were abundant. A hook and line fishery would be quite selective for grenadiers, except in shallower depths of their range, where sablefish are also abundant.

Pacific grenadier are included with a group of miscellaneous species that bring just $0.14 per pound to trawl fishermen. Reasons for the low price include a low fillet yield, small average size, and an unfamiliarity among the industry and public with the good attributes of the flesh. The annual ex-vessel value was around $25,000 in 1988 and 1989. All the fish were filleted by processors and sold to markets in northern California and Oregon.

Pacific grenadier, *Coryphaenoides acrolepis*.

Status of Biological Knowledge

Pacific grenadier are distributed along the coast of North America from northern Baja California to Alaska, across the Bering Sea to the Okhotsk Sea and the coast of northern Japan. They are inhabitants of continental slope waters from about 1,000 to 10,000 feet, although occasionally are taken much deeper. Off California and Oregon, they are most commonly captured at depths of 2,000 to 6,500 feet and are among the most abundant fishes at these depths.

Pacific grenadier are among the larger of the 300 plus members of the family Macrouridae, attaining lengths of 38 inches and 8.8 pounds. Most, however, are less than 31 inches in length, with females attaining slightly larger sizes than males.

Spawning appears to take place mostly from late winter through early summer off southern California, although spent females are found throughout the year. In more northern areas, ripe females are found earlier, beginning in September and October. Fecundity is relatively high, with estimates given in the literature of 22,000 to 118,000 eggs in females from Oregon, to as much as 150,000 from a 4.4-pound female off California. Size at maturity is around 26 inches in females and about 20 inches in males. Calculations of age using otoliths suggest that these sizes are reached in 10 or more years. Larvae and juveniles are rare, and eggs are not known from the plankton. The youngest larvae are found in the upper 660 feet, whereas older larvae and juveniles occur deeper. Spawning depth is unknown. One hypothesis would have the fish spawn in the upper water layers and descend to the bottom as juveniles of about three inches. Alternatively, the fish may spawn at lower levels and the eggs float toward the surface, where they hatch and the fish descend as juveniles.

Pacific grenadiers feed primarily on pelagic cephalopods, crustaceans, and fish, although young individuals probably feed mostly on bottom-dwelling invertebrates. These food items, and the occasional capture of adults well off bottom, suggest that Pacific grenadiers sometime rove up into the water column to feed. It has been suggested that the larger species of squid found in the stomachs of grenadiers were eaten after they had died and settled on the ocean floor. That grenadiers are good scavengers is suggested by their ready attraction to baited traps and hooks set on the bottom.

Status of Population

The status of the population is unknown. Although the species is broadly distributed in California and the North Pacific, only a small segment of the population is currently being fished.

Tomio Iwamoto
California Academy of Sciences

References

Iwamoto, T., and D. L. Stein. A systematic review of the rattail fishes (Macrouridae: Gadiformes) from Oregon and adjacent waters. Occas. Pap. Calif. Acad. Sci. (111): 1-79.

Matsui, T., S. Kato, and S. E. Smith. 1990. Biology and potential use of Pacific grenadier, *Coryphaenoides acrolepis*, off California. Mar. Fish. Rev. 52(3):1-17.

Stein, D.L., and W.G. Pearcy. 1981. Aspects of reproduction, early life history, and biology of macrourid fishes off Oregon, U.S.A. Deep-Sea Research 29 (11A):1313-1329

PACIFIC SAURY

History of the Fishery

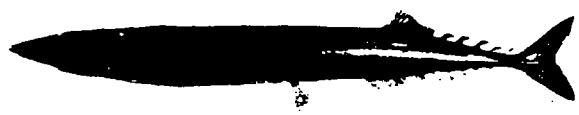
In California, interest in fishing Pacific saury (*Cololabis saira*) was initiated in the 1950's, when the decline in abundance of Pacific sardine caused fishermen and processors to look for substitute species which could be used to make fish meal. Sporadic landings of saury were made in San Pedro, where the fish were reduced into oil and meal. In the late 1960's and early 1970's, Japan, the Soviet Union, and the U.S. became interested in harvesting saury off the U.S. west coast because western Pacific stocks had fallen to all-time low levels.

Fishing trials by U.S. researchers and fishermen were conducted north of Monterey, where larger saury were more common. Most of these trials, which involved the use of purse seines and a Japanese fishing method using light attraction together with a type of blanket net (called *bo-uke ami*), were largely unsuccessful. Japanese saury fishing vessels which fished off the west coast around the same time were a little more successful. From 1969 through 1972 they caught 507, 3,600, 1,430, and 77 tons. Japanese vessels were larger than those of the U.S., and used attracting lamps with 50 kilowatts of power. Catches per unit of effort were not considered high enough for economical fishing, however. Rough seas off the Oregon and

SMB-26935

Washington coasts, and scarcity of dense concentrations of large saury, were blamed for the low catch rate. The fish averaged just eight to nine inches in length and had a low oil content.

After western Pacific stocks rebounded in the mid-1970's, efforts to harvest saury here were discontinued. Because of its large biomass and good eating qualities, the saury resource will likely be utilized some day off California and elsewhere in the eastern Pacific. However, economics of fishing, handling, and processing, coupled with the present lack of a domestic market make fishery development doubtful in the near term. Export as a food product is also unlikely, because of the large catches in the western Pacific and because the Japanese prefer their own fish, which appear to have a higher fat content. Externally attached copepods also detract from the appearance of eastern Pacific saury.



Pacific saury, *Cololabis saira*.

Status of Biological Knowledge

Pacific saury are slender, silvery fish common throughout the entire temperate north Pacific Ocean. They grow to about 12-13 inches "knob length," the distance from the tip of the lower jaw to the muscular knob at the base of the tail fin (approximately 94% total length). The flesh of saury is firm and rather oily. The fish is widely used in Japan, where it is sold in fresh, frozen, dried, and canned form. The meat yield is around 60 percent, and the oil content varies from three to 10 percent. In addition to its use as food and fish meal, saury is a preferred baitfish in the longline fishery for tuna.

Pacific saury are found in a broad band across the Pacific Ocean, from around 20-25° north latitude to the Gulf of Alaska. Within this broad area, three groups of saury are distinguishable: one in the eastern Pacific, the second in the central Pacific and the major group in the western Pacific. Off the U.S. west coast, saury occur from near shore to perhaps 300 miles offshore, but are most common from 40-100 miles off the coast.

Young fish appear to remain in California waters, while older fish migrate to the north, probably to the southern Gulf of Alaska, when coastal waters warm up in summer. As the water cools in fall and winter, saury again move south to preferred temperatures off California. One study found mean lengths of 7.9, 9.3, and 10.9 inches for saury from California, Oregon, and Washington. No fish greater than 12 inches were found off California and, conversely, all fish caught off Washington were larger than seven inches. Optimum temperature range for saury off California is 57-63° F.

During the day saury are usually found in depths of 100-230 feet, where they feed, but have been found as deep as 750 feet. At night, they usually swim near the surface and are attracted to light. Large numbers often accumulate under the lights of stationary or slow-moving vessels. Fish over 11 inches show poor attraction to light, however, especially during spawning periods. In California, fishing for adult saury is apt to be most successful in the fall, north of San Francisco, and from 40-120 miles offshore.

Growth rate and longevity of Pacific saury have been subjects of controversy for many years. Interpretations of growth marks on scales and otoliths, as well as results derived from analyses of sizes of fish caught by commercial fisheries, have produced conflicting hypotheses. Various earlier workers in Japan and the Soviet Union felt that western Pacific saury had a life span of three to six years, and that saury were capable of spawning at age two. Females were thought to spawn three times a year, releasing 500 to 2,000 eggs, or perhaps as many as 5,000 eggs depending on their size, during each spawning episode, in a season of around seven months starting in late August. Later Japanese studies indicated that two major groups existed, one spawning in spring and the other in autumn, and that the probable life span was two or two and a half years. More recent studies involving daily growth rings on saury otoliths suggest that most saury in the western Pacific live for only a year, while some may reach two years of age. Fish around 11.4 inches, which are commonly caught in the Japanese commercial fishery, are thought to be nearly a year old. Fish over 12.6 inches, relatively scarce in the catch, may be 1.5 to two years old. Examination of otoliths of larval and early juvenile saury grown from eggs in tanks showed that the growth rings were indeed laid down daily, at least for the first month.

Daily growth rings found on the otoliths of eastern Pacific saury suggest that the growth rate is considerably lower than that of fish from the western Pacific. By the end of the first year, eastern Pacific saury are thought to grow to nine inches, while western Pacific fish attain 12 inches. Some researchers think, however, that eastern Pacific saury reach a length of only 6.5 inches at the end of the first year, and are about 10.6 inches at the end of the fourth year. The largest fish are about 13.4 inches and 6.5 ounces. Fish of this size are rare, and only a few are thought to survive beyond age five. Sexual maturity occurs during the second year, when the fish are around 7.9 inches. Fecundity was estimated at 1,600 eggs for a female of 10 inches, for each of three spawning episodes in a season. Spring- and autumn-born groups were also identified in the eastern Pacific, with the former predominating in fish sampled from California to Washington. Studies on genetics of the two spawning groups revealed no differences.

Spawning occurs primarily in spring off California, and in August, October, and winter off Washington. In California, the highest number of eggs was found in the plankton from Morro Bay to San Diego, mostly from April through June. Although saury spawn at all hours, peak number of eggs are found around midnight, early morning, and mid-afternoon. Eggs normally attach to each other and to floating objects by means of filamentous threads. The larvae hatch out in 10 days at 68° F, and 17 days at 58° F, and are usually found just under the water surface. Juveniles can be found down to depths of 80 feet. Prevailing currents in southern California disperse some larvae to the west as well as northward, but most remain near the spawning grounds.

Pacific saury feed on small zooplankton, particularly copepods, euphausiids, crab megalops, and other small crustaceans.

SMB-26936

Yellowtail, bluefin and albacore tuna, and striped marlin are major predators of saury, as are fur seals, sei whales, some birds and squid.

Status of Population

Although there is some disagreement among researchers, it is generally thought that the eastern and western stocks do not mix, while the central stock mixes with the western and perhaps also to a lesser degree with the eastern Pacific stock. Genetic studies of western saury stocks indicate that they are comprised of perhaps four subpopulations, but exchanges of genes often occur among the groups.

The western and central stocks appear to be indistinguishable genetically; so mixing may be considerable. The eastern Pacific stock may provide recruits to the central area also. Rather large differences in growth rate and longevity suggest that eastern and western Pacific stocks, however, are isolated.

Recent estimates of population size of eastern Pacific stocks of saury are unavailable. In the past, surveys by research vessels showed that the number of eggs and larvae, and by extension the spawning populations, of saury off Mexico and California fluctuated considerably through the years. The estimated quantity of adult saury in the area between central Baja California and San Francisco ranged from 97,000 to 294,000 tons per year, averaging 200,000 tons, between 1950 and 1966. The size of the total population in the northeastern Pacific is probably on the order of 450,000 tons. An annual limit of around 33,000 tons of adult saury, half of the estimated maximum sustainable yield, has been suggested for the entire west coast stocks, including Canada.

Susumu Kato
National Marine Fisheries Service

References

Hughes, Steven E. 1974. Stock composition, growth, mortality, and availability of Pacific saury, *Cololabis saira*, of the northeastern Pacific Ocean. Fishery Bulletin 72(1):121-131.

Odate, Shigeru. 1977. On the distribution of Pacific saury in the north Pacific Ocean. Research Institute of North Pacific Fisheries, Special Volume, pp. 353-381. (In Japanese). Translated by Language Service Branch, International Analysis & Services Division, National Marine Fisheries Service, Washington, D.C.

Sunada, John S. 1974. Age and growth of the Pacific saury, *Cololabis saira*. Calif. Fish and Game 60(2):64-73.

Watanabe, Yoshiro, John L. Butler, and Tsukasa Mori. 1988. Growth of Pacific saury, *Cololabis saira*, in the northeastern and northwestern Pacific Ocean. Fishery Bulletin 86(3):489-498.

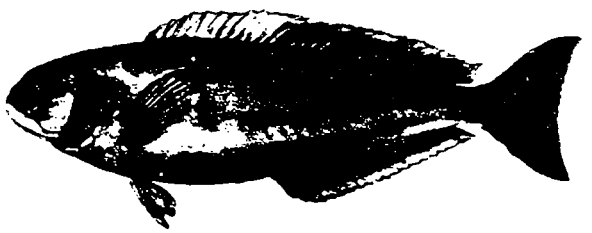
OCEAN WHITEFISH

History of the Fishery

Ocean whitefish (*Caulolatilus princeps*), is a popular sport fish in southern California, is also a commercial species, but landings in recent years have been rather low. The greatest landings of whitefish were made in 1926, when 368,000 pounds were recorded in southern California. Some of these fish may have been caught off Baja California. Landings since then have declined, but the value of ocean whitefish catch almost tripled from 1978 to 1989.

Annual catches made from commercial passenger fishing vessels ranged from 22,000 to 84,000 fish from 1977 through 1989. Most of these fish were caught near the Channel Islands and at offshore banks, particularly Cortez and Tanner Banks near San Clemente Island. They are caught exclusively with baited hooks, and no special fishing regulations pertain to their catch. The vicinity of the Coronados Islands off Mexico is a favorite whitefish fishing area for sport fishermen.

It is a food fish favored by sportsmen, and the small amount of ocean whitefish that is landed commercially is sold in fresh fish markets. It makes excellent sashimi, being comparable in flavor and texture to any of the most esteemed white-fleshed fish used for this purpose. In Japan, species of tilefish similar to ocean whitefish command premium prices in the fresh fish market. In fact, several years ago, two longline fishing vessels were sent from Japan to fish for ocean whitefish at offshore banks near southern Baja California. Unfortunately, here in California ocean whitefish has acquired a mixed reputation because a few bitter-tasting individuals turn up every now and then. The cause of the bitter flesh is unknown, but these fish are evidently restricted to shallow waters, especially near kelp beds. Smaller individuals make excellent aquarium pets, as they are hardy, handsome, active, and alert when placed in tanks.



Ocean whitefish, *Caulolatilus princeps*.

Status of Biological Knowledge

Ocean whitefish are attractive fish with robust, elongate bodies. They are white below and light brown on the back, with fins marked with blue and yellow streaks and yellow margins.

The range of ocean whitefish is from Vancouver, British Columbia to Peru or possibly to Antofagasta, Chile, and the vicinity of the Galapagos Islands. In California, it is common south of Pt. Conception and rare to the north. Its depth range is 30-450 feet, and its principal habitats appear to be near offshore islands and over shallow banks, at depths of 50-150 feet.

The southern California population of ocean whitefish is derived from central and southern Baja California. No information is available on the timing or the size at which most of these fish migrate northward. It is also not known if the fish move south again to spawn, or if any spawning occurs off California.

Fish close to spawning have been found in Baja California from October through April. Most larvae occur within 100

SMB-26937

miles of the central Baja California coast. These larvae are found throughout the year, but their numbers peak in summer. Pelagic juvenile stages barely one-half inch long have been found far offshore from Baja California. Juveniles move inshore by the time the fish reach 2.5 inches or so. At an age of six years whitefish are 20-21 inches long and weigh three to four pounds, while at age 13, which is about their life span, they average around 25 inches and 7.5 pounds. Ocean whitefish may grow to a maximum of 40 inches and 12 pounds.

Ocean whitefish have a relatively small mouth, and accordingly they feed upon small animals, including shrimps, crabs, pelagic red crab, octopi, squid, and various fishes, especially anchovy and lanternfish. They are usually encountered over rocky grounds, and anglers find that they usually take baited hooks before the lures reach bottom.

Young ocean whitefish are eaten by a number of fishes, including albacore tuna. Older stages are prey for giant sea bass, sharks, and no doubt other large fishes. Otoliths (earbones) of whitefish found in middens at San Clemente Island attest that this fish was an important food fish for Native Americans.

Status of Population

Because the center of distribution of ocean whitefish is far to the south off central Baja California, the numbers of ocean whitefish near southern California have never been very high. The decrease in commercial landings after the mid-1940's may not reflect reduction in availability or abundance of ocean whitefish, but rather a disinterest by the market. No information is available on the size of the populations, either in southern California or in Mexico.

Susumu Kato
National Marine Fisheries Service

References

Fitch, John E. and Robert J. Lavenberg. 1971. Marine Food and Game Fishes of California. California Natural History Guides, No. 28. Univ. Calif. Press, Berkeley, Calif. 179 p.

Moser, H. Geoffrey, Barbara Sumida, David A. Ambrose, Elaine Sandknop, and Elizabeth G. Stevens. 1986. Development and distribution of larvae and pelagic juveniles of ocean whitefish, *Caulolatilus princeps*, in the CalCOFI survey region. CalCOFI Rept., Vol. XXVII:162-169.

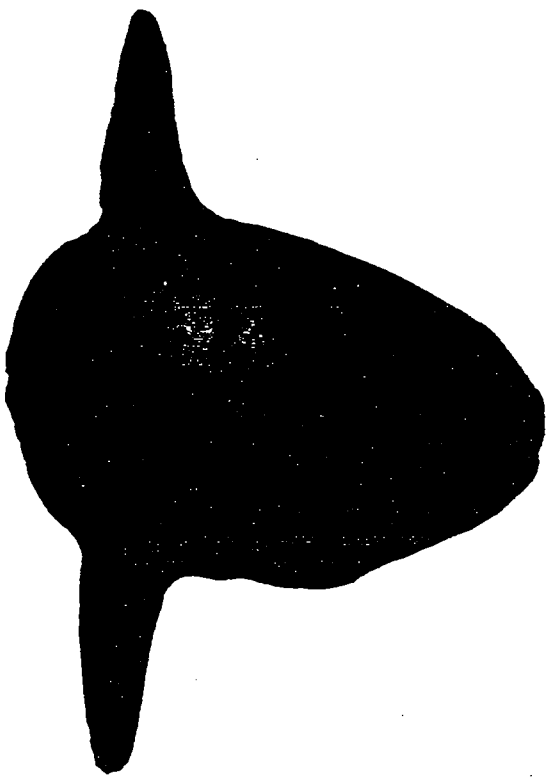
OCEAN SUNFISH

History of the Fishery

The ocean sunfish (*Mola mola*) is presently not sought by most commercial or sport fishermen here. However, a few fishermen who have learned from Mediterranean or Asian counterparts about its excellent eating quality consider it a delicacy. In Japan the liver is also used as a condiment for sunfish meat sashimi, and in Taiwan the intestine is the most expensive part of the fish.

Ocean sunfish is not sold here, but wholesale prices in Japan for the meat and liver are well over $5.00 per pound, and in Taiwan the intestines bring over $11.00 per pound. The flesh of ocean sunfish has at times been reported to be toxic, but a thorough review and investigation of such reports disclose no authenticated case of poisoning from eating it. On the contrary, it is considered delectable by those that eat it. Since the flesh is somewhat watery, it is better to parboil the meat to remove some moisture. The meat then becomes firm, and the texture similar to that of shellfish. The flesh is sometimes infested with long string-like parasites, but these can be easily removed and, in any case, are not harmful when ingested. Another negative attribute is the low yield of meat found in sunfish. Because the skin and cartilaginous skeleton are so heavy, only about 20 percent of the weight of the fish is edible flesh.

Only a few ocean sunfish are brought in by fishermen for food, and very little reaches the fish market. The fish are often caught in drift gillnets which target swordfish and sharks. At times as many as 200 sunfish are caught in a mile-long net, but nearly all the fish are released alive by the fishermen. Some sunfish are also caught incidentally in roundhaul nets together with mackerel, anchovy, or sardine. Most incidental catches of ocean sunfish are made in southern California, but at times drift gillnetters also catch substantial numbers between San Francisco and Pt. Conception. Roundhaul net catches are also made primarily in southern California, but the small wetfish fleet in Monterey also captures some sunfish. A few sunfish are also caught on hook and line, as well as with harpoons. No fishing restrictions apply to ocean sunfish.



Ocean sunfish, *Mola mola*.

SMB-26938

Status of Biological Knowledge

The ocean sunfish is a peculiar looking fish, with a truncated body and no tail. Its silvery body is oval and compressed, with tall slender fins sticking out near the posterior end. Its skin is leathery, and underlined with a thick layer of heavy cartilage. Ocean sunfish are found in most temperate and warm seas of the world. Most sightings of this fish in California are from south of Point Conception during winter and spring, and from there to San Francisco in summer and early fall. Ocean sunfish are usually observed swimming casually on the surface, with their long dorsal fin sticking high up in the air, but they are also sometimes seen lying on their side at the surface. Sunfish no doubt also occur in midwater, wherever food organisms are abundant.

Little is known about the natural history of ocean sunfish. Most sunfish caught in driftnets in southern California are under two feet long and less than 20 pounds, but larger individuals to 100 pounds or more are not uncommon. The largest individuals reported in the literature were estimated to have been over 10 feet long and nearly as wide between the tips of dorsal and anal fins, and weighing perhaps as much as 3,000 pounds.

Spawning grounds have been found in the northwestern Pacific Ocean, at around 30° N latitude and 130° E longitude. One large female of about 4.5 feet was estimated to have had 300 million eggs, although not all of those would be laid at one time. A few planktonic post-larvae of sunfish have been found on the high seas, but fertilized eggs or early larval stages are absent from plankton collections. The shape of young larvae is similar to that of other fishes, but the sunfish larva soon loses its tail and acquires a number of long spike-like projections all over the body.

The ocean sunfish has a small mouth and its teeth are fused into a sharp-edged plate in both the upper and lower jaw. It usually eats small crustaceans, fish, mollusks, jellyfish and other soft-bodied forms that are found near the ocean surface. Larger fish have also been found in their stomachs at times. The long intestine of ocean sunfish is reminiscent of algae eaters, and indeed seaweed has also been found in their stomachs. Sharks and sea lions are the major predators of ocean sunfish.

Occasionally they are seen on the surface hovering patiently while seabirds peck on their tough hides, apparently picking off external parasites. They also have been observed by divers being "cleaned" of these parasites by small fishes which do this service for many species of fish. Ocean sunfish have frequently been seen leaping high in the air, though it's hard to imagine how they can find enough momentum without the aid of a tail fin. Mass mortalities of small ocean sunfish have occurred from August through October in Monterey Bay, where dozens of the silvery fish have been found dead on the shallow bay floor or floating on the surface. No explanations have been offered for such mass deaths.

Status of Population

Nothing is known about the population size or structure of ocean sunfish. Since they occur throughout most temperate and warm seas, it is possible that all ocean sunfish are part of a single population, at least in the Pacific Ocean. In California, those that are caught are usually returned to the ocean alive by gillnetters and, since there is no directed fishery for them, abundance of ocean sunfish here is probably rather uniform from year to year. The effect of mass mortalities is unknown, but they no doubt cause lowered population levels in localized areas.

Susumu Kato
National Marine Fisheries Service

References

Fitch, John E. and Robert J. Lavenberg. 1971. Marine food and game fishes of California. Univ. of California Press, Berkeley. 179 p.

Fraser-Brunner, A. 1951. The ocean sunfishes (Family Molidae). Bull. British Mus. (Nat. Hist.), Zool., 1(6):89-121.

SMB-26939

History of the Fisheries

Marine recreational fishing is an important social, cultural, and economic influence in California. The National Marine Fisheries Service's Marine Recreational Fishery Statistics Survey (MRFSS) data for California indicate that some two million people made over seven million trips and caught nearly 32 million salt water fish in 1989. Anglers' expenditures in 1989 were estimated to be $260 million in northern California and $536 million in southern California, for a total value of $796 million. About two thirds of the marine recreational fishing activity is in southern California, from San Luis Obispo County to the Mexican border. California marine recreational fishing is broad based and involves numerous species (*eg.* billfish, salmon, striped bass, tuna, bottomfish, and shellfish), as well as various forms (*eg.* pier/jetty, beach/bank, commercial passenger fishing vessel (CPFV), and private boats).

Fishing for sharks, such as this leopard shark, has grown in popularity in recent years.

An angler enjoying a peaceful morning of fishing off the rocks.

A natural geographical separation exists between California's marine recreational fisheries in northern California and in southern California. The region off Point Conception is an oceanic transition zone between the north and south. North of Point Conception the water is cold and sea conditions are often severe. To the south, waters are usually warmer, and sea conditions more moderate. The species composition of the two regions is also different. Sport fishes that are common in northern California are rockfish, lingcod, surfperch, smelt, salmon, striped bass, shark, and sturgeon. Those which characterize southern California include rockfish, Pacific mackerel, kelp/sand bass, California barracuda, Pacific bonito, California sheephead, white seabass, California halibut, yellowtail, and striped marlin. In warm periods yellowfin and bigeye tuna, dolphin (fish), jumbo squid, and other species common in Mexican waters find their way into southern California.

Marine recreational fishing is a year-round activity involving many gear types, and ranges from single to multi-species fisheries. The most prevalent gear type in the fishery is the rod and reel, which may be used with artificial lures, live bait, or dead bait. Hoop nets, spears, shovels, hands, and various other implements are also used. Hoop netters generally target crabs, lobsters, or shrimp. Spear fishers, primarily skin and SCUBA divers, target a wide variety of finfish (invertebrates are also targeted by divers but without the aid of spears). Shore pickers usually target invertebrates, most commonly working at low tides when searching beneath rocks or digging in the sand is most productive. Shore pickers also target finfish, particularly the California grunion (southern California) and surf smelt (northern California).

Analyzing the condition of marine recreational fishing in California is a complex matter affected by numerous variables (*e.g.* species abundance, fishing pressure, regulations, oceanic and weather conditions, and the type of equipment used). Oceanic and weather conditions can affect species' health and composition as well as accessibility. The condition of targeted fish stocks affects fishing pressure and catch trends. Fishing methods and gear may influence catch and catch-per-unit-of-effort. Regulations related to size limitations, area or seasonal closures, bag limits, and species closures also have pronounced effects on catch statistics but are not easy to interpret when reviewing only the numerical data. It is also necessary to distinguish between catch and landings, terms that are often used interchangeably. Catch refers to the number of fish brought to the boat and landings to the number of fish kept. Differences between catch and landings result primarily from catch-and-release fishing and adherence to minimum size limitations. In 1989, forty-eight percent of all fish caught were released alive. Forty-two percent of the fish released in southern California were in the mackerel group (low value to many fishermen) or the kelp/sand bass group (all have minimum size limits). Fish having size limits are typically released in large numbers. In 1989, for example, 93 percent of all California halibut and 87 percent of all California barracuda were released.

Fishing participation varies annually, but since 1980 has usually been about two million people. In 1989, 2.2 million

SMB-26940

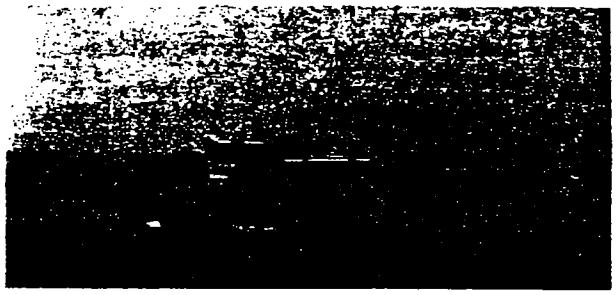
marine recreational anglers made about seven million fishing trips, a decline of 26 and 34 percent, respectively, for northern and southern California when compared to 1980. During approximately the same period (1980-1990) there has been a 29 percent decrease in the sale of annual resident fishing licenses. Reasons given by survey respondents for the decrease included loss of interest, lack of time, no available fishing partner, and concern about pollution. A fourfold increase in State fishing license fees between 1979 and 1990 (to $20.50 per year) may also be a factor in the reduced sales, although, a study conducted for the California Department of Fish and Game did not find such a correlation. The recent decline in California recreational fishing is even more dramatic than the above trends indicate if the 25 percent increase in California's population between 1979 and 1989 is considered.

Thousands of anglers utilize fishing piers daily, especially in southern California.

In 1979, the MRFSS was started by the National Marine Fisheries Service in cooperation with the California Department of Fish and Game and the Pacific States Marine Fisheries Commission. Through 1989, no consistent trend in total catch was apparent. Between 1980 and 1989, catch averaged 40 million fish per year (plus or minus seven million fish), except for the peak catch of 72.2 million fish in 1980. Sport caught salmon (not included in the above data) do not have a significant effect on the total catch numbers, as they averaged only 115,000 fish per year during the same time period. Nevertheless, the salmon fishery is important economically in central and northern California.

Between 1980 and 1985, fishing from private boats was the dominant fishing method (35 percent), fishing from manmade structures was next (25 percent), while CPFV's and beach/bank were each about 20 percent. Recently, there has been an increase in the CPFV mode to about 30 percent, while the beach/bank and manmade structure modes have declined.

Trends in marine recreational fishing prior to 1980 are reflected in CPFV landings data. CPFV landings increased gradually from two million fish in 1947 to nearly six million fish in 1969. This trend was generally accompanied by an increase in fishing effort, better equipment, and larger and newer vessels. Since 1969, there have been only five years when CPFV landings exceeded the 1969 peak.



Commercial passenger-carrying fishing vessel (CPFV) trolling for salmon near the Farallon Islands.

Data on the total number of anglers using CPFV's have been available since 1960. These data show that there was a steady increase from about 600,000 anglers in 1960 to 873,000 in 1970. Generally, participation has remained above 700,000 since then, with the exception of a dip in 1986 to 660,000. Although angler participation on California CPFV's has gradually increased since 1985, the increase has not been great enough to prevent some vessels from going out of business. Starting in 1947, the number of CPFV's rose steadily from 343 to a peak in 1954 of 612. A decline in the number of vessels ensued, reaching a low of 287 in 1985. Since then, there has been a modest increase to 309 in 1990. The recent decline in the viability of the CPFV industry is related to a number of factors, such as reduced fish availability, high operating costs, competition with other recreational activities, and a sluggish economy.

The late 1960's, early 1970's and early 1980's yielded the best CPFV landings. However about 50,000 more anglers landed the same number of fish in 1988 as were landed in 1963. Conversely, it took about 70,000 more anglers in 1967 to equal the 1988 landings. The lack of consistent trends in catch-per-unit-of-effort for CPFV's may be misleading in that less desirable species and/or smaller size fish seem to be more common in recent landings. (See CPFV statistics for 1947-1990 in appendix).

The upturn in CPFV landings since 1986 can be attributed largely to steady increases in the landings of the kelp/sand bass complex and rockfishes. Rockfishes have been the most abundant component of annual CPFV landings in recent years, peaking in 1967 at about four million fish. Rockfish landings were about three million fish per year through 1982, dropped to about 2.3 million fish in 1983, and have been below that level ever since (through 1990). The kelp/sand bass complex generally comprised the second most abundant category during this time period, except between 1977 and 1985, when the Pacific mackerel moved to second place. The high CPFV Pacific mackerel landings between 1977 and 1985 were coincident with a warming trend between 1975 and 1985 that included two El Niño events (1976-1977 and 1982-1983). Recently kelp/sand bass CPFV landings have averaged about 700,000 fish per year, with a peak of 1.3 million in 1968.

The MRFSS and the California Department of Fish and Game CPFV landing data for the coincident period of record (1980-1989) tend to agree on the most abundant species taken in California. Actual ranking of different species varies annually but is relatively similar. For example, rockfish, kelp/sand

SMB-26941

bass, and Pacific mackerel, respectively, usually ranked as the top three species landed; the order, however, was not always the same in both surveys.

The harvest of invertebrates is an important element of a number of marine recreational fishing activities. Abalone and lobster are the most important species for marine recreational divers. Shore picking targets a wide variety of invertebrate species, such as moon snails, mussels, and various clams. Abalones, pismo clams, and rock crabs are the most important species for shore pickers. A recently completed southern California sport fish economic survey showed that in an eight-month period (March-October 1989) some 380,000 shellfishing trips were made, 46 percent for abalone, 30 percent for lobster, and 24 percent for clams. Catch and effort data for the sport shellfish fishery are sparse, although there are indications that both are declining. Abalone catch and catch-per-unit-of-effort are clearly on the decline, a situation that can be attributed to a combination of factors, including increased sport and commercial fishing pressure, expanding sea otter populations, pollution, and poaching.

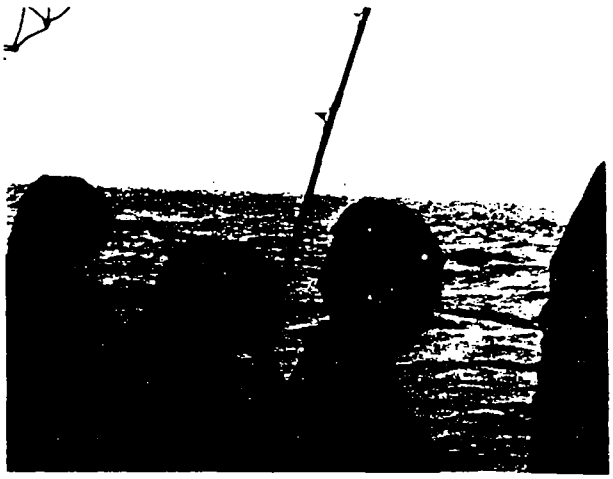
California marine recreational fishing is not confined to California waters. Annually, between 1985 and 1990, approximately 127,000 trips were made to Mexico, most of them originating in San Diego. Recreational fishing trips to Mexico can be generally separated into long-range, multi-day trips and short-range trips of one day or less. Target species for the long-range fishery are yellowtail, dolphin (fish) and tunas. Short-range trips concentrate on rockfish, kelp bass and barracuda. Since 1980, catches of tuna (albacore, bluefin, skipjack, yellowfin) were the most abundant in five of the years and rockfishes in four. Annual landings have averaged 271,000 fish, with a peak of 404,000 and a low of 183,000 between 1980 and 1990.

Marine Recreational Fisheries Issues

Among the concerns reported by anglers are the impact of marine mammals on fisheries resources, habitat deterioration, and overfishing. Some sport fishing groups are becoming active in fisheries management issues from both a political and scientific perspective.

California sea lions and harbor seal populations have generally been increasing since the passage of the Marine Mammal Protection Act of 1972. Since their diet consists of fish, they compete with many favored sport species for food. In some cases they also compete directly with fishermen. At the mouth of the Russian River a sizeable harbor seal population feeds on steelhead. The expanding range and population of sea otters is increasing the competition for shellfish such as the abalone, pismo clam, and lobster. Whether the competition is for prey species or species targeted by the fisheries, the impact of increasing marine mammal populations is felt by sport fishermen.

Habitat deterioration is a direct threat to the health of many fisheries resources. Water management in California has not placed a high priority on maintaining fish habitat compared to other uses. About 85 percent of the State's water use is for agriculture, often at the expense of fish. Water diversions deprive estuarine zones of essential nutrients and freshwater inflow, confuse and delay migrating fish, and kill fish in pumping plants. The last six years of drought has exacerbated water problems in California, but that is not the primary cause of the deterioration of fish habitat. The water problems of the State will probably continue as long as agricultural water costs are subsidized. Largely as a result of past water management practices, the Sacramento River winter run chinook salmon has been designated as threatened (August 1989) and the striped bass, delta smelt and other populations have declined significantly. Most salmon and steelhead runs face similar problems in California. Indeed, the runs have all but disappeared from the San Joaquin River system.



Recreational fishing is often a family activity.

Groundwater removal and irrigation return flows present additional threats. Lowering of the water table, a consequence of groundwater removal, causes streams to dry up or run intermittently. Irrigation return flows are polluted with fertilizers, pesticides, and herbicides, and are warm and turbid, all of which can be lethal or chronically debilitating to fish. Industrial effluents cause similar results.

Wetland destruction also has taken a significant toll. Since the late 1800's, about 90 percent of California's coastal wetlands have been eliminated. Wetlands are an essential element in the production of many kinds of nutrients, and their elimination has had a permanent adverse impact on fisheries resources at every trophic level.

Arguments persist over the allocation of fish stocks between commercial and sport fishers. High seas drift gillnet fisheries (beyond 200 miles from shore) have been implicated as a factor in reduced salmon and albacore catches. A perceived concern (not substantiated by data) that coastal gillnetting is having a significant effect on the sport catch (especially rockfish and California halibut) was an issue in the 1991 referendum by California voters that will eliminate the use of gill-nets in State waters by January 1, 1994. Concern for seabird and marine mammal kills was also an important factor in the passage of the referendum.

Species presently closed to marine sport fishing in California are the garibaldi, giant (black) sea bass (sport limit was one fish until 1982), broomtail grouper, and Gulf grouper. The

SMB-26942

closure for these fish is due largely to their vulnerability to spear fishing; additionally, the groupers comprise small populations extending into southern California from Mexico.

Green sturgeon, eulachon, delta smelt, longfin smelt and various runs of chinook and coho salmon are being reviewed for nomination to threatened or endangered status. Although rockfishes continue to be a key component of the sport catch, they have potential to be overfished as they are a slow-growing long-lived fish (some may live 50 to 70 years). Sharks are another long lived group of fishes that have recently become popular among sport fishermen. Recent research indicates that at least some rockfish and shark stocks are being overfished and that additional management requirements may be needed.

Many private and public projects are conducted to enhance marine recreational fishing in California. Since 1958, the California Department of Fish and Game has built 32 artificial reefs, which attract aggregations of sport fishes and prey species and contribute to production of fisheries resources. Additionally, a number of hatchery projects have been undertaken, mostly by private organizations, to raise fish for ocean release. Most notable are several salmon rearing projects, a California halibut, and a white seabass rearing project. Hatchery programs account for about half of the State salmon production. The State of California has also conducted a number of experimental projects to reestablish abalone stocks in depleted areas; however, survival has generally been low. A common concern for many of these projects is a need for better evaluation of the success, effectiveness, and benefits they are designed to provide.

Marine refuges, reserves, and sanctuaries are also being used to provide a safe haven for various kinds of marine life. Such areas can provide a source of seed stock to areas outside of the haven. Havens have been established by various government agencies for many purposes, and include small estuaries, short stretches of shoreline, subtidal areas and expansive areas of ocean. Each has its own set of regulations, and may be managed to protect a single species, selected groups of marine life, all marine life, or to protect a habitat. California has 53 marine havens; only a few, however, are managed to prohibit the take of all marine life. The 1991 gillnet referendum included a provision for adding four new marine refuges in California by January 1, 1994.

Presently, with the exception of a few species, the marine recreational fisheries in California are in reasonably good shape. However, the cumulative effect of various environmental problems coincident with overfishing of some species, may lead to declines in more of the resources if effective management policies are not implemented.

Martin F. Golden
National Marine Fisheries Service

References

Dewees, C.M., E.M. Strange, and G. Guagnano. 1990. Competing for the recreational dollar: an analysis of the California commercial passenger-carrying fishing vessel industry. Mar. Fish. Rev. 52 (1):1-6.

Helvey, M., S.J. Crooke, and P.A. Milone. 1987. Marine recreational fishing and associated state-federal research in California, Hawaii, and the Pacific Island Territories. Mar. Fish. Rev. 49 (2):8-14.

Smith, S.E. 1979. Changes in saltwater angling methods and gear in California. Mar. Fish. Rev. Vol. 41(9): 32-44.

Squire, J.L., Jr. and S.E. Smith. 1977. Anglers' guide to the United States Pacific Coast marine fish, fishing grounds & facilities. U.S. Dept. Commerce, NOAA, NMFS. Seattle, WA 139 pp.

Thompson, C.J. and S.J. Crooke. 1991. Results of the southern California sportfish economic survey. U.S. Dept. Commerce, NOAA, NMFS, NOAA Technical Memorandum No. NOAA-TM-NMFS-SWFS-164. La Jolla, CA. 181 pp.

SMB-26943

PINNIPEDS

History

There are six pinniped species inhabiting the California coast and offshore islands: the California sea lion (*Zalophus californianus*), Steller (or northern) sea lion (*Eumetopias jubatus*), Pacific harbor seal (*Phoca vitulina*), northern elephant seal (*Mirounga angustirostris*), northern fur seal (*Callorhinus ursinus*) and Guadalupe fur seal (*Arctocephalus townsendi*). The ribbon seal (*Phoca fasciata*) and the hooded seal (*Cystophora cristata*) have been reported in California waters, but these were extremely rare events and they are not considered normal California visitors.

The California sea lion and Pacific harbor seal are probably the best known and most often seen pinnipeds in California waters. Californians and visitors from around the world enjoy watching the playful behavior of these animals cavorting in the water near shore or hauled out to rest on buoys, rocks and other solid objects. They also enjoy seeing them in public display aquaria or as performers in animal shows at zoos and parks. Pinnipeds are amusing and intelligent entertainers, but there is another aspect of the pinniped story which is related to their diet of fish and their expanding populations.

In recent years, California sea lions have gained notoriety by taking over portions of marinas in Monterey and San Francisco Bays and by eating endangered or threatened salmon and steelhead moving upstream to spawn. Marina operators and boat owners consider them a major nuisance, but revenue brought by tourists eager to see them has quieted many of their complaints. Some who fish commercially or for sport believe that pinnipeds compete for fish or are costly pests consuming tons of valuable fish, destroying valuable fishing gear and interfering with fishing operations. They complain that any sea lion is attracted to fishing operations and that the mere presence of a sea lion scares fish away from the fishing area. Research biologists speculate that most of those problems are caused by a relatively few "rogue" pinnipeds. Those rogues have learned that a fish caught in a net or hooked on a line is an easier meal than a free-swimming fish. A major concern is that this behavior will spread as the pinniped populations grow.

Faced with decreasing catches, increasing marine mammal populations and increasing fishery interactions, some sport and commercial fishers contend that sea lion populations have reached the point where nuisance animals should be exterminated. On the other hand, environmental groups and marine mammal aficionados support these animals and feel their populations should be allowed to increase unimpeded by human interests or needs.

Food habit studies conclude that pinnipeds consume a variety of prey species, depending on availability, and that, contrary to claims made by many fishers, the normal pinniped diet does not usually include fish which are considered valuable for sport or sale. Their main diet consists of fish such as anchovies, mackerel, herring, hake, rockfish, salmon, and cephalopods such as squid and octopus. An example of their opportunistic feeding behavior was seen during the 1982-1983 El Niño event. Pelagic red crabs, usually not found in large numbers off California, were very abundant at that time, and were found to be a major diet component for sea lions until ocean conditions returned to normal.

In the 1860's and 1870's, many pinnipeds were killed for their oil or body parts and many females (cows) were captured for displays or animal acts. Pinnipeds were hunted commercially until 1938, when California law gave them complete protection from hunting. Nevertheless, sport and commercial fishers were free to kill sea lions and harbor seals that were destroying gear or otherwise interfering with fishing operations. In 1972, the Marine Mammal Protection Act was passed prohibiting the take (pursuit, harassment, capture, or kill) of marine mammals except under special permitted conditions. Such conditions include research, public display, certain fishery interactions, or entanglement in fishing gear.

To determine the extent of the intentional and accidental kills in various fisheries, observers were placed aboard fishing vessels. Their observations, along with calculations of fishing effort, were used to estimate total numbers of marine mammals killed during fishing operations. In California waters, it was estimated that 2,000 to 4,000 California sea lions, fewer than 100 elephant seals and between 800 and 2,000 harbor seals were killed annually during the 1980-1990 period.

Research has been conducted on methods of reducing the impacts that pinnipeds have on certain fisheries. Taste aversion substances and acoustic harassment devices have been tested but have met with only moderate success. In most cases, the animals appear to acclimate to the deterrents, and sometimes have used the purported scare devices as "dinner bells" signifying active fishing boats and an easy food source.

Status of Biological Knowledge

California sea lion, *Zalophus californianus*.

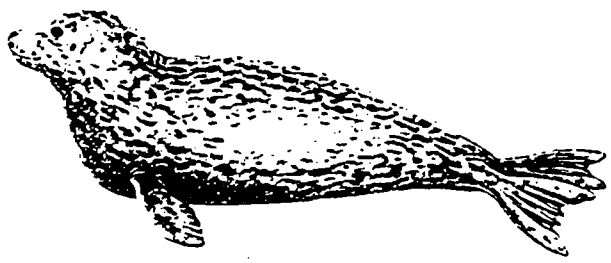
California sea lion. The California sea lion ranges from British Columbia south to Tres Marias Islands off Mexico.

SMB-26944

Breeding grounds are mainly on offshore islands from the Channel Islands south into Mexico. Breeding takes place in June and early July within a few days after the females give birth. The pups are weaned at six months to a year or more. Males and females reach sexual maturity between four and five years of age. Males weigh between 500 and 1,000 pounds and reach seven to eight feet in length. Females weigh between 200 and 600 pounds and reach six feet. Adult males have a pronounced sagittal crest (a ridge on top of the skull extending from the forehead to the rear of the skull), a characteristic distinguishing this species from the Steller sea lion. Food of the California sea lion consists largely of squid, octopus, and a variety of fishes (anchovies, mackerel, herring, rockfish, hake, and salmon).

Steller sea lion, *Eumetopias jubatus*.

Steller sea lion. The Steller sea lion's distribution partially overlaps that of the California sea lion. It ranges from the Bering Strait off Alaska to southern California. Breeding grounds extend from the Pribilof Islands to the Channel Islands; however, only a small percentage breeds south of Año Nuevo Island. The largest breeding colonies in California are at Año Nuevo and the Farallon Islands. Breeding is in late June, after which the animals migrate northward. This species is a tawny or yellowish-brown color in contrast to the darker reddish color of the California sea lion. Males are 1,500 to 2,200 pounds and reach a length of 13 feet. Females can weigh a little over 600 pounds and reach a length of nine feet. Food of the Steller sea lion consists primarily of squid and fish. Because of recent declines in the population, Stellar sea lions have been designated as threatened under the Endangered Species Act.



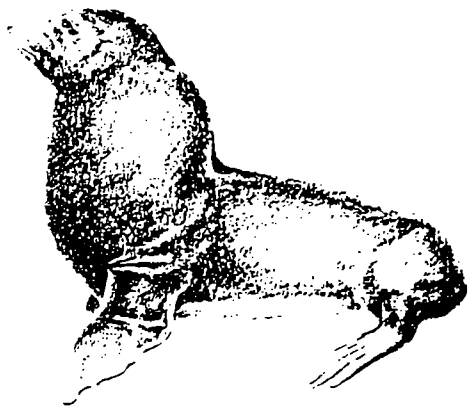
Pacific harbor seal, *Phoca vitulina*.

Pacific harbor seal. The Pacific harbor seal ranges along the northwest coast of America from the Gulf of Alaska to Cedros Island off Baja California. For management purposes, the U.S. harbor seal population has been divided into three stocks as follows: 1) Washington inner coastal waters, 2) Washington and Oregon outer coastal, and 3) California. In California, harbor seals are abundant along the entire coast. Adult male Pacific harbor seals reach a length of six feet and weight of up to 240 pounds, while females reach 5.5 feet and 275 pounds (when pregnant). The coloration patterns of adults vary from black with white spots to white with black spots. Breeding season varies with latitude, starting in April to May on the Channel Islands of southern California and continuing later up the coast. Age at sexual maturity is three to four years for females and five years for males. Newborn pups are approximately 32 inches in length and weigh about 22 pounds. They are weaned at five to six weeks at an average weight of 50 pounds. Adult females ovulate and mate at the end of weaning, with a two-month delayed implantation of the developing embryo. Their diet consists of fish such as flounders, herring, tomcod, hake, and lampreys, and cephalopods such as squid and octopus.

Northern fur seal, *Callorhinus ursinus*.

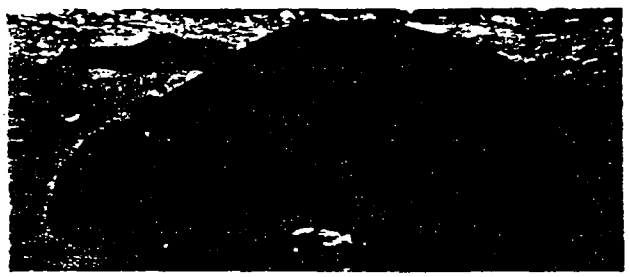
Northern fur seal. The northern fur seal is one of the best-known seals in the world because of its valuable fur, for which it was hunted to near extinction. Historical populations centered on the Pribilof Islands, Alaska, are estimated at two million animals, but in 1911, when international treaties were established to protect and manage this species, there were fewer than 125,000 animals. San Miguel Island, off Santa Barbara, California, hosts a small breeding colony and is the southernmost extent of its range. The peak breeding and pupping period is in July. After breeding, the males migrate out to sea where they spend as many as 10 months. The pups are weaned at four months of age and are left to travel in the northward migrations on their own. Fur seals are distinguished from sea lions by their pelage, composed of a very dense undercoat and a thinner, coarser layer of guard hairs, and by their relatively long flippers. The northern fur seal is closely related to the Guadalupe fur seal and is distinguished from its close relative by its very short muzzle. Males reach a length of eight feet and weigh up to 700 pounds. Females are only four to five feet in length and weigh about 130 pounds. Sexual maturity is attained between three and seven years of age, with longevity reported to be up to 26 years.

SMB-26945



Guadalupe fur seal, *Arctocephalus townsendi*.

Guadalupe fur seal. The Guadalupe fur seal was presumned extinct until 1926, when a group of 60 animals was discovered on Guadalupe Island, Mexico. The population is recovering slowly from near extinction brought about by sealers in the last century. This is a rare pinniped in California waters, seen only occasionally at islands in the Southern California Bight. They breed only on Guadalupe Island and the total population is estimated to be less than 2,500 animals. They are identified by a "collie-like," long pointed muzzle. Males reach up to six feet in length; females are slightly smaller.



Northern elephant seal, *Mirounga angustirostris*.

Northern elephant seal. The comeback of the northern elephant seal, the largest of all the seals, is one of the great success stories for an animal threatened with extinction. Male elephant seals reach a length of 15 to 16 feet and weight of about 4,000 to 5,000 pounds. Females reach a length of 11 feet and weigh about 1,700 pounds. The male develops a bulbous enlargement of the snout from which, along with its size, it gets its common name. Breeding colonies exist on San Miguel Island, Santa Barbara Island, San Nicolas Island, Año Nuevo Island, Southeast Farallon Island, and Point Reyes Peninsula. They have also begun hauling out at several other mainland sites where historically they did not haul out. The breeding season is from December through March. Harems consist of one male and eight to 40 females. The gestation period is about 11.5 months. Pups are weaned by four weeks but remain on the rookery another eight to 10 weeks, sleeping during the day and gradually starting to enter the water at night. Departure from the rookery occurs at an age of approximately three months. Females begin breeding as young as two years of age. Males reach sexual maturity at five years; but older, larger males prevent young and socially immature males from mating until they are at least eight or nine years old. Males and females both live about 14 years.

Elephant seals do most of their feeding at night and probably in deep water as evidenced by the fact that they have been caught in nets at 2,000-foot depths. Time-depth recorder experiments show that elephant seals can dive to 5,200 feet, and stay beneath the surface for up to an hour. Stomach content analyses indicate that they feed on small sharks, rays, ratfish, rockfish, and squid.

Status of Populations

The Marine Mammal Protection Act recognizes marine mammals as components of the marine ecosystem and requires maintenance of stocks above levels at which they would lose their function in the ecosystem. In practice, marine mammal management is directed toward maintaining the optimum sustainable population size (OSP) for each species within its geographical range. To be optimal, the population size should be between the rate at which maximum growth occurs and the carrying capacity of the environment. A variety of procedures are used to asses population status.

California sea lion. California sea lions breeding on U.S. rookeries are assumed to comprise a single stock. Their status was last assessed in 1986. At that time, there were approximately 17,800 pups counted on U.S. rookeries, representing 21,000 births. That number of births would represent a total U.S. population (stock) size of about 87,000 animals. More recent unpublished data suggest that the population had grown to about 120,000 animals by 1991. The growth rate was assumed to be equal to that observed before the 1983 El Niño event, at which time the California sea lion population in the Southern California Bight was near the lower end of the OSP range.

Steller sea lion. Population estimates for northern sea lions are based on counts of animals hauled-out during the breeding season. A decline of this species is occurring throughout its range, including the Gulf of Alaska and Aleutian Islands, which support 75 percent of the world's population. The current west coast population of northern sea lions is around 68,000 animals, which is less than half of the population level during 1956-1960. The dramatic decline in numbers of Steller sea lion throughout most of its range has prompted its listing as threatened under the Endangered Species Act and depleted under the Marine Mammal Protection Act.

Pacific harbor seal. From aerial census data, the harbor seal population along the California coast appears to be increasing, and concurrently, the number of occupied sites has increased. In 1991, the mainland count was 18,346 seals, and the count for the eight Channel Islands was 4,743 seals, for a minimum population estimate of 23,089 seals in the California stock. This is a minimum population estimate because a substantial fraction of the population is not hauled out during the census.

The 1986 assessment did not confirm that the stock was large enough to fall within the range of OSP, but the counts since 1982 indicate that the rate of growth may be slowing. However,

SMB-26946

the occurrence of the 1983-1984 El Niño and the possibility of increased incidental fishing mortality might have affected the population dynamics of this stock. It is likely that the survival and reproduction of harbor seals were altered during the El Niño period and that some of those effects persisted for several years. Additionally, fishing effort in the gill net fishery increased substantially during the 1970-1990 period and the resultant kill of harbor seals undoubtedly altered the population structure. Fishing effort in the gill net fishery is currently declining and should become less of a mortality factor for harbor seals.

Northern fur seal. In 1983, the estimated abundance was about 1.2 million. No significant changes have been documented since that time, although recent counts of Aleutian Island animals decreased. The adult count at San Miguel Island, the only place in California where the northern fur seal breeds, was around 4,000, which was a very small percentage of the worldwide population in 1984. Fur seals are occasionally taken incidentally in the high-seas gillnet fisheries for salmon and squid. They also entangle in discarded fishing debris and die. Although entanglement mortality is not known, there is evidence that it may be contributing to declining trends in the Pribilof Island population. That population has been designated as depleted under the Endangered Species Act and the Marine Mammal Protection Act. Further research on population assessment and trend analysis for the California Channel Island population is needed to determine its size and growth rates.

Guadalupe fur seal. The historical distribution and abundance of the Guadalupe fur seal are unknown because commercial sealers and other observers failed to distinguish between it and the northern fur seal in their records. This species, once thought to be extinct, has an estimated population of about 1,500 to 2,000 animals, with an annual pup production of approximately 200 pups. Although the primary breeding colony is on Guadalupe Island, recent sightings of adult and juvenile seals on some of the Channel Islands suggest that recolonization of that area may occur in the future. The Guadalupe fur seal is listed as threatened under the Endangered Species Act and depleted under the Marine Mammal Protection Act. These listings are based on the concept that the population could become endangered within the foreseeable future, even though it currently does not appear to be in danger of extinction. The population is being closely monitored.

Northern elephant seal. The exploitation and subsequent recovery of the northern elephant seal population is a remarkable story. Biologists estimate that only 100 to 500 animals were left on Guadalupe Island before protective legislation was passed. They claim that the entire current population may have originated from this small group of animals. Based on pup counts, the current U.S. population has grown to an estimated 80,000 animals, ranging from Alaska to Baja California. The apparent growth rate since 1980 has been about 8.75 percent annually. Annual surveys indicate that this species has reoccupied most or all of its historical rookeries and hauling grounds. Using data through 1986, the population appears to be within the OSP. Presumably, the increased size of the population may lead to increased interactions with fisheries and other human activities.

Doyle Hanan
California Department of Fish and Game

Joyce Sisson
National Marine Fisheries Service

References

Antonelis, G.A., S. Leatherwood, and D. K. Odell. 1981. Population growth and censuses of the northern elephant seal, *Mirounga angustirostris*, on the California channel islands, 1958-1978. Fish. Bull., U.S. 79:562-567.

Boveng, P. 1988. Status of the northern elephant seal population on the U.S. west coast. NOAA/NMFS SWFC Admin. Rep. LJ-88-05. 35 p.

Boveng, P. 1988. Status of the Pacific harbor seal population on the U.S. west coast. NOAA/NMFS SWFC Admin. Rep. LJ-88-06. 43 p.

Boveng, P. 1988. Status of the California sea lion population on the U.S. west coast. NOAA/NMFS SWFC Admin. Rep. LJ-88-07. 26 p.

Hanan, D.A., L.M. Jones, and M.J. Beeson. 1992. Harbor seal, *Phoca vitulina richardsi*, census in California, May-June 1991. NOAA/NMFS SWFC Admin. Rpt. LJ-92-03. 68 p.

Hanan, D.A. and S.L. Diamond. 1989. Estimates of sea lion, harbor seal, and harbor porpoise mortalities in California set net fisheries for the 1986-87 fishing year. Final Rpt. Cooperative agreement No. NA-86-ABH-00018. Submitted NOAA/NMFS SWR, January 1989. 10 p.

Lowry, M.S., C.W. Oliver, C. Macky, and J.B. Wexler. 1990. Food habits of California sea lions *Zalophus californianus* at San Clemente Island, California, 1981-86. Fish. Bull., U. S. 88:509-521.

Miller, D., M. Herder, and J. Scholl. 1983. California marine mammal-fishery interaction study, 1979-1981. NOAA/NMFS SWFC Admin. Rep. LJ-83-13C. 233 p.

WHALES, DOLPHINS, AND PORPOISES

History

Marine mammals played an important role in shaping the early history of California. By the late eighteenth century, English whaleships had voyaged to the waters of California in search of sperm whales. Portuguese immigrants from the Azores and Cape Verde followed in the 1840's, manning and operating the first shore-based whaling industry. Shore whaling was distinct from nineteenth century Yankee pelagic whaling, because whales were pursued from a vessel launched from a nearby coastline. Deploying row boats from shore and using harpoons, whalers typically pursued, captured, and towed whales back to the whaling stations. At shore-based whaling stations, workers extracted oil from the whale's blubber. The lure of gold and quick prosperity brought numerous crewmen from New England's whaling industry in the late 1840's and early 1850's. After the gold rush abated, many returned to their previous occupations on whaling ships. The early shore-based

SMB-26947

whaling industry in California primarily caught gray and humpback whales, because shore whalers were limited to within 10 miles of the coastline. However, whalers occasionally took the right, blue, and fin whales, more highly prized due to the greater oil content of their blubber. Until 1901, at least 15 stations operated at various locations between Crescent City and San Diego.

After more than 40 years of whaling along the California coast, whale populations and the demand for expensive whale oil declined, and subsequently the whaling industry became less profitable in the late 1800's. Nevertheless, modern whaling vessels caught a small number of gray whales and many humpback whales in California waters after the turn of the century. Powered by engines, modern whaling vessels hunted whales more efficiently through the use of explosives, mounted cannons, and grenades. Whalers would deliver carcasses to floating processing plants where the oil was extracted. Modern catcher boats originating from shore stations also periodically took whales during this period. The last remaining whaling station in the United States, near Richmond, California, closed in 1971.

In 1931, 50 nations, including the United States, agreed upon the International Convention for the Regulation of Whaling. This agreement was the first international effort to control the decimation of the world's whale populations. The primary protection measures included full protection for right whales and, for all other species, a ban on the killing of calves, suckling whales, immature whales, and females with calves. The agreement was ineffective, however, because the major whaling nations did not join. Several international agreements followed which attempted to improve upon this initial document. In 1946, the International Whaling Commission (IWC) was established, both to ensure the development of the whaling industry and to conserve the world's whale stocks for the interests of future generations. For many years, the IWC concentrated its efforts on maximizing the level of removal of whales rather than on whale conservation. However, in recent years, the IWC has moved noticeably towards whale conservation.

In 1972, the United States Congress enacted the Marine Mammal Protection Act (MMPA), which established a complex and comprehensive federal policy of marine mammal management. The MMPA made it unlawful to take (defined as kill, capture, pursue, or harass) marine mammals in the waters of the United States and it also prohibited U. S. citizens from taking marine mammals on the high seas. Under limited circumstances, exceptions may be authorized for the taking of some marine mammals, provided that the level of removal will not cause the population to decline below sustainable levels. For instance, marine mammals may be removed for public display and scientific research, or incidental to activities such as shipping and commercial fishing.

Current Utilization

Since the enactment of the MMPA in 1972, the focus of concern has shifted to the incidental capture of marine mammals during commercial fishing operations. Due to the rapid expansion of several of California's coastal fisheries, there has been an increase in the incidental capture of marine mammals in recent years. Nonetheless, in California, the level of take of cetaceans is lower than it is for other marine mammals (*i.e.*, pinnipeds). The National Marine Fisheries Service (NMFS) is currently developing a management regime to govern the incidental taking of marine mammals in commercial fishing operations. Moreover, the California Department of Fish and Game (CDFG) has developed regulations to help minimize the incidental take of marine mammals in the coastal gillnet fishery.

Due to the recovery of the gray whale population and accessibility of migrating gray whales along the California coastline, a large and diverse whalewatching industry has developed. Since the 1970's, commercial whalewatching has become an important recreational, educational, and economic activity. The 1983-1984 whalewatching season alone generated an estimated total gross income of $2.6 million. This estimate did not include regional economic benefits from the sale of meals, fuel, lodging, whale paraphernalia and other whale-related activities. In 1985, the commercial whalewatching industry in California was the largest in the United States, with 74 boats in operation.

The rapid growth of commercial whalewatching, and increased interest by private boaters in observing and approaching whales in the wild, have been accompanied by concerns that these activities could cause adverse biological impacts to whales. In California, NMFS adopted whalewatching guidelines that established minimum approach distances (100 yards) for vessels and aircraft, as well as additional operational guidelines for vessels. Nevertheless, each year there are numerous reports of harassment of whales by commercial whalewatching vessels and private boaters. NMFS is currently developing regulations that will provide mechanisms to enforce minimum approach distances.

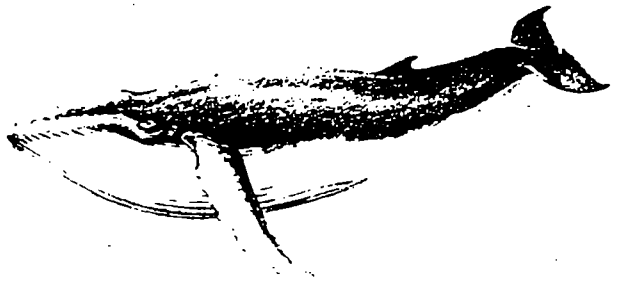
Partly as a result of the protection and management achieved from regulatory measures, and partly because of increased public awareness and appreciation of marine mammals, some populations have rebounded since the years of commercial exploitation. Marine mammals that inhabit the coastal waters of California now represent resources that enhance both the wealth and recreational benefits of the State. For many people, a commercial whalewatching cruise is their first contact with the marine environment. Thus, the value of observing marine mammals in the wild not only increases public awareness of these animals, but also contributes to increased public appreciation of the diversity and abundance of other living marine resources.

The waters of California provide essential habitat to a large variety and abundance of whales, dolphins, porpoises, and other marine mammals. These animals play an important role in maintaining the balance of marine ecosystems. Consequently, protecting California's marine mammals is an integral part of the conservation of all living marine resources in California.

Status of Biological Knowledge and Populations

Humpback whale. Humpback whales (*Megaptera novaeangliae*) are distinguished by their exceptionally long, almost entirely white flippers and robust body that may reach a

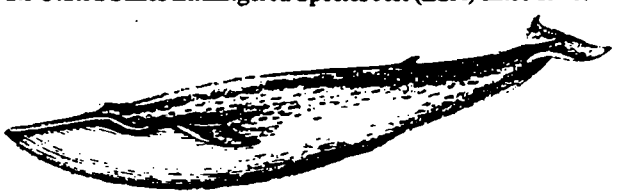
SMB-26948



Humpback whale, *Megaptera novaeangliae.*

length of over 50 feet. There appear to be two distinct populations of humpback whales in the North Pacific. The Alaska feeding population migrates to its breeding grounds in Hawaii and offshore islands in Mexico. The California, Oregon, and Washington feeding population migrates to coastal Mexico and Central America to breed. During their seasonal migrations, humpback whales may frequently be seen along the California coast from April through November. Some individuals appear to remain in California year-round. In the Gulf of the Farallons, humpbacks may be observed feeding during August and September. Off southern California, humpbacks often migrate along submarine ridges (*e.g.*, Santa Rosa-Cortez Ridge) and occasionally enter the coastal waters of the San Pedro and Santa Barbara Channels. They obtain their food by straining krill (small shrimplike crustaceans) and schools of small fish with their baleen. Humpback whales are well known for their complex songs, thought to be used in courtship or male competition. The songs on their breeding grounds can last up to several hours.

Near the turn of the century, an estimated 15,000 humpback whales inhabited the North Pacific Ocean. Commercial whaling reduced this population to dangerously low levels, and in 1966 the IWC established a moratorium on harvesting them. Despite this protection, the population has recovered only to a size of 1,200 to 2,100 individuals. The California feeding population is thought to consist of at least 400 animals. The humpback whale has been listed as an endangered species under the United States Endangered Species Act (ESA) since 1970.



Blue whale, *Balaenoptera musculus.*

Blue whale. Blue whales (*Balaenoptera musculus*) are the largest animals in the world, sometimes attaining a size of over 90 feet. An individual blue whale may consume up to eight tons of krill in a single day. The majority of the eastern North Pacific population spends the summer on feeding grounds between central California, the Gulf of Alaska and the Aleutian Islands. Like all baleen whales, the blue whale seasonally migrates to lower latitudes in the winter to calve and breed. Migratory routes generally follow the continental shelf and slope, but blue whales are occasionally found in deep oceanic zones and shallow inshore areas. Blue whales are usually seen off the California coast traveling alone or in pairs, from June to January, although they have been observed in every month of the year. They frequently may be seen feeding in the Farallon Islands between July and October and occasionally are sighted in Monterey Bay and over deep coastal submarine canyons off central and southern California. Historically, the North Pacific population may have been comprised of over 5,000 individuals before its severe depletion by modern whaling operations. An estimated 1,000 to 1,500 blue whales currently inhabit the North Pacific Ocean. The California feeding population is estimated to be comprised of at least 400 whales. The blue whale has been listed as an endangered species under the ESA since 1970.

Fin whale, *Balaenoptera physalus.*

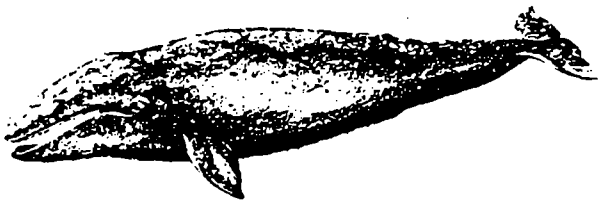
Fin whale. The fin whale (*Balaenoptera physalus*) is a common, large cetacean occurring off the California coast. Fin whales can reach a size of up to 87 feet and may be distinguished by the white coloration of their lower right lip and V-shaped head. They are distributed throughout the world's oceans, but little is known of their seasonal movements in the North Pacific. The North Pacific population reportedly winters between central California southward to 20° N latitude and summers from Baja California to the Chukchi Sea. Fin whales have been observed in every month of the year in California. The North Pacific population is estimated to consist of nearly 15,000 animals. This species uses its baleen to filter krill, capelin, sand lance, squid, herring, and lantern fish from the water. They have been listed as an endangered species under the ESA since 1970.

Minke whale, *Balaenoptera acutorostrata.*

Minke whale. Minke whales (*Balaenoptera acutorostrata*) inhabit both the high seas and nearshore waters where they are known to enter bays, inlets, and estuaries. This species is the smallest of the baleen whales in California waters, attaining a size of up to 32 feet, and is distinguished by a transverse white band on its flippers and its relatively tall and falcate (hooked) dorsal fin. In the summer months, minke

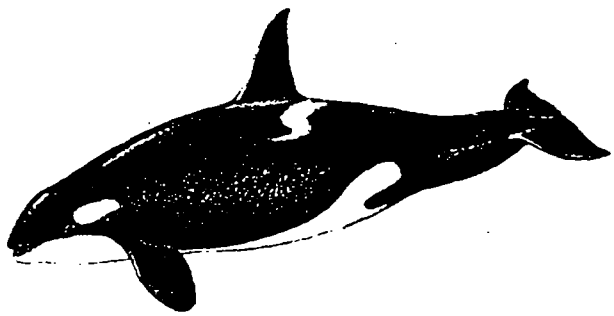
SMB-26949

whales feed on krill, copepods, sand lance, and herring in the Bering Sea and Arctic Ocean. During the winter months, they migrate south along the North America coastline to Mexico. There are some year-round residents off California. Population estimates are not available for minke whales, although they may number over 10,000 in the North Pacific Ocean. Minke whales are occasionally seen from whalewatching and sport fishing vessels in California.



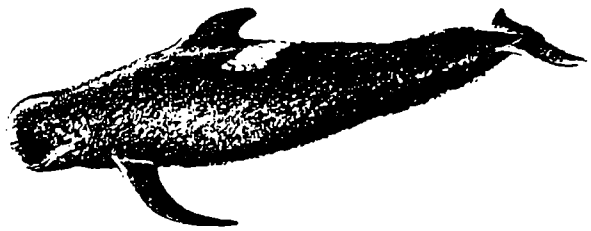
Gray whale, *Eschrichtius robustus*.

Gray whale. Gray whales (*Eschrichtius robustus*) are distinguished by their mottled gray body, narrow head and absence of a dorsal fin. They can reach a length of over 45 feet. The gray whale undergoes one of the longest migrations in the animal kingdom. Perhaps the best known of the great whales off California, the eastern North Pacific gray whale migrates from its feeding grounds in the Bering Sea and Arctic Ocean to its calving and breeding areas in the subtropical lagoons along the west coast of Baja California. This population generally migrates along the coastline, often within a few miles of shore. The gray whale migration can be observed from several locations in California such as Point Loma, Point Vincente, Point Sur, and Point Reyes. They begin to enter California waters in late November and December on their southward migration. In mid-February, gray whales begin their return migration north, passing through southern California waters until late May or early June. Some immature whales reportedly remain in kelp beds to feed over the winter months off California. The northbound cow/calf migration usually occurs during April and May. Gray whales use their baleen to sift out crustaceans, mollusks and other invertebrates which they suck up from bottom sediments. The most recent population estimate is approximately 21,000 animals. Although still listed as endangered under the ESA, the number of gray whales appears to be approaching a level that existed prior to exploitation by whalers.



Killer whale, *Orcinus orca*.

Killer whale. Killer whales (*Orcinus orca*), actually largest of the dolphins, are year-round residents in California. They have been seen entering kelp beds, bays, or inlets, but are more common offshore. The killer whale is widely known due to its popularity in oceanaria. It is easily distinguished by its striking black and white color pattern and erect dorsal fin, which can be up to six feet tall in adult males. This species may reach a size of nearly 30 feet. Killer whales are top predators in the ocean, using their sharp conical teeth for grasping and tearing prey. They have been observed attacking the largest animal on Earth, the blue whale. Killer whales were so named for their habit of attacking seals and whales; however, fish are the most important component of their diet. Small groups of related individuals (pods) often hunt in a coordinated and cooperative manner. Killer whales have strong social bonds, remaining in pods of five to 30 individuals for decades. There are no estimates of population abundance for killer whales in California.

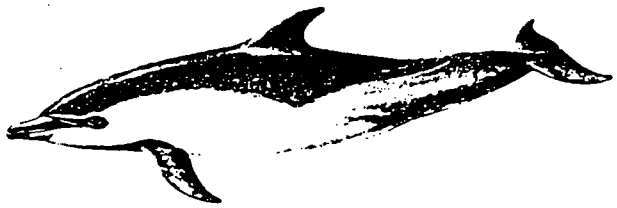


Short-finned pilot whale, *Globicephala macrorhynchus*.

Short-finned pilot whale. The short-finned pilot whale (*Globicephala macrorhynchus*) can reach a size in excess of 17 feet, and is distinguished by its bulbous forehead and broad based slightly falcate dorsal fin. In California, these whales are commonly found south of Point Conception, but there have been sightings as far north as San Francisco Bay. Following movements of local squid populations, short-finned pilot whales may move seasonally nearshore in the winter and offshore during other times of the year. Before the El Niño event in 1982 and 1983, the number of short-finned pilots whales was near 2,000 during peak periods off southern California. However their numbers declined during the El Niño, presumably due to emigration, and the population has not returned to its previous level. One hypothesis for the population's failure to rebound is that it was competitively excluded by the Risso's dolphin population in California. No one is certain where the remainder of the population has gone. Currently, the population size is unknown, but there appears to be no more than a few hundred individuals present in the nearshore waters of California. This species was the first "whale" displayed in captivity and is still used widely in oceanaria.

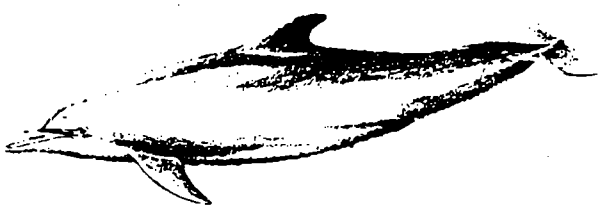
Common dolphin. The common dolphin (*Delphinus delphis*) is the most abundant cetacean in California. Common dolphins can reach nearly eight feet in length and can be distinguished by the unique hourglass coloration on their sides which appears as a V-shaped black or dark gray saddle when they are observed at sea. Among the most gregarious of cetaceans, common dolphins often form groups of over 100 animals, sometimes numbering in the thousands. Population

SMB-26950



Common dolphin, *Delphinus delphis*.

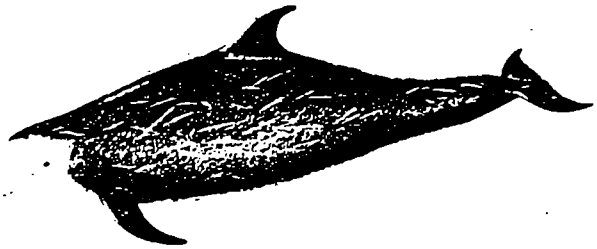
surveys conducted over a decade ago estimated that over 57,000 common dolphins inhabited the waters off southern California between summer and autumn, diminishing to around 15,000 individuals between winter and spring. Common dolphins frequently engage in bow-riding and aerial acrobatics. Two types of common dolphins have been identified in California. One form, "Baja neritic," has a relatively longer beak and occurs from offshore southern California waters south to Islas Tres Marias and throughout the coast in the Gulf of California. The other form, "northern," has a relatively shorter beak and is more common offshore from Isla Cedros north.



Bottlenose dolphin, *Tursiops truncatus*.

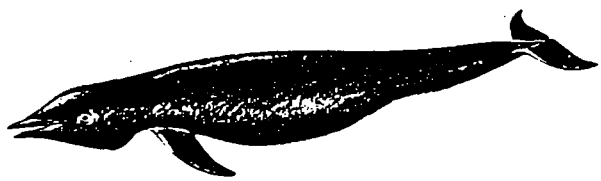
Bottlenose dolphin. Bottlenose dolphins (*Tursiops truncatus*) are readily recognizable by the public due to their antics on television, their performances in oceanaria, and because the coastal form is occasionally seen surfing in the waves along populated southern California beaches. This species may reach a size of over 12 feet and is distinguished by its gray coloration, lightly colored belly, and moderately tall and falcate dorsal fin. South of Point Conception, bottlenose dolphins are common, whereas few animals are encountered further north. In California, both a coastal and offshore form are found. The coastal form inhabits shallow water just beyond the surfzone, and is known to frequent bays and estuaries from Santa Monica south. Groups of 10 to 25 animals may travel together and make regular migrations along this area of the coastline. There are reportedly seasonal north-south shifts in their distribution, but the extent to which this occurs is uncertain. It is estimated that the coastal form is comprised of approximately 240 animals. No population estimate is available for the offshore form, although it has been characterized as abundant in the southern California area. This species often rides the bow wave of vessels, and swims in the wake of large whales.

Risso's dolphin. Risso's dolphins (*Grampus griseus*) are known to reach a size of over 13 feet, usually have extensive scarring over their white to light-gray colored body, and lack a beak. The last surveys, conducted in the early 1980's, indicated that from 15,000 to 30,000 Risso's dolphins resided off California at the time. Since El Niño (1982-1983), their numbers are



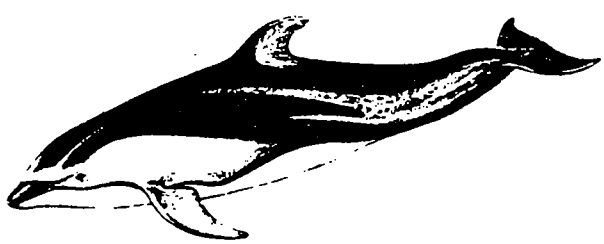
Risso's dolphin, *Grampus griseus*.

believed to have increased. Risso's dolphins normally appear in pods of 25 to 50 individuals and do not usually bow ride but will perform some acrobatics such as spy-hopping and breaching. They are distributed widely, frequently being found in deep water areas with warm temperate to tropical water conditions. Risso's dolphins are occasionally observed in central and northern California waters.



Northern right-whale dolphin, *Lissodelphis borealis*.

Northern right-whale dolphin. Northern right-whale dolphins (*Lissodelphis borealis*) have no dorsal fin and have a very slim and graceful black body that may attain a length of ten feet. They appear to prefer offshore, cold temperate waters and only occur inshore over deep submarine canyons. The northern right-whale dolphin is commonly found in the waters off central and northern California, although they also appear in winter and spring off southern California. There appears to be some seasonal north-south shift in their distribution as a result of water temperature changes and prey availability. Population surveys in the early 1980's estimated that over 80,000 northern right-whale dolphins may have been present in California at the time. This gregarious species sometimes occurs in large herds of up to several thousand and is noted for its fleetness. Northern right-whale dolphins rarely approach vessels.

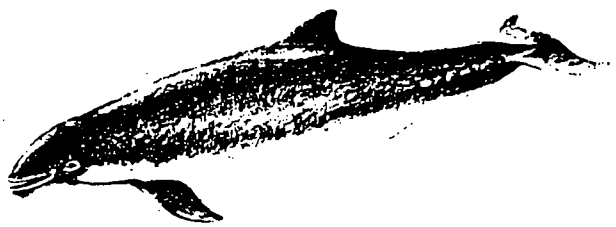


Pacific white-sided dolphin, *Lagenorhynchus obliquidens*.

Pacific white-sided dolphin. The Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) has a short, thick beak,

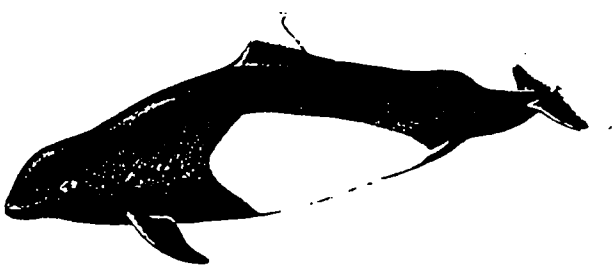
SMB-26951

a falcate dorsal fin and may reach a size of at least seven feet. The species is thought to be the second most abundant dolphin off southern California, and the most common off northern California. The Pacific white-sided dolphin is seen year-round, frequenting the continental shelf and slope waters, sometimes appearing in Monterey Bay. They may occur in herds of over a few thousand individuals but groups of several hundred are more common. In the early 1980's, seasonal abundance of Pacific white-sided dolphins in California, north of Point Conception was estimated to fluctuate from 26,000 animals in the summer to 86,000 animals in the autumn. This species is known for its acrobatic behavior and bow riding abilities. Pacific white-sided dolphins are occasionally displayed in oceanaria.



Harbor porpoise, *Phocoena phocoena*.

Harbor porpoise. The harbor porpoise (*Phocoena phocoena*) is the smallest cetacean found in California waters, rarely reaching a length of over six feet. It may be distinguished by its lack of a beak and its triangular dorsal fin. Harbor porpoises frequent the cooler waters of central and northern California, seldom straying south of Point Conception. Locally abundant concentrations exist between Cape Mendocino and Point Reyes and in Monterey Bay. They are not known to migrate extensively, but may move between inshore and offshore areas. The harbor porpoise occurs primarily in relatively shallow nearshore water and, thus, is vulnerable to human activities such as the coastal gillnet fishery in California. In response to the general increase in gillnetting, CDFG has implemented several management mechanisms to reduce the incidental take of harbor porpoises. This species never approaches vessels or bow rides. The harbor porpoise population off California may consist of over 11,000 individuals.



Dall's porpoise, *Phocoenoides dalli*.

Dall's porpoise. The Dall's porpoise (*Phocoenoides dalli*) has a stocky body, and the striking white pattern on its belly, flank, and tips of dorsal fin and tail, contrasts with its generally black body. This species may attain a size of over seven feet. The Dall's porpoise inhabits the cooler waters of the continental shelf in central and northern California, and also frequents a variety of other areas including nearshore deep-water canyons and the open sea. The Dall's porpoise can be found off northern California in autumn and winter, however individuals can also be found in southern California at this time. There appear to be nearshore-offshore shifts in their distribution whereby they remain inshore in autumn and move northward and offshore in the late spring. Dall's porpoises travel in small groups of 10 to 20 individuals and are known to bow ride. A population survey in the early 1980's estimated that approximately 461,000 individuals inhabit the eastern North Pacific. The size of the Dall's porpoise population off California is unknown.

Irma Lagomarsino
National Marine Fisheries Service

References

Dohl, T. P., K. S. Norris, R. C. Guess, J. D. Bryant, and M. W. Honig. 1980. Cetacea of the Southern California Bight, *In*: Marine Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978. Vol. 3 - Investigator's Reports, Part II. NTIS PB81-248-71. 414 pp.

Dohl, T. P., R. C. Guess, M. L. Dunman, and R. C. Helm. 1983. Cetaceans of Central and Northern California, 1980-1983: Status, Abundance, and Distribution, Unpublished Report. MMS Contract #14-12-0001-29090. OCS Study MMS 84-0045. Pacific OCS Region MMS, Los Angeles, California. 284 pp.

Haley, D. 1978. Marine Mammals of Eastern North Pacific and Arctic Waters. Pacific Search Press. 254 pp.

Jones, M. L., S. L. Swartz, and S. Leatherwood. 1984. The Gray Whale, Eschrichtius robustus. Academic Press, Inc., Orlando. 600 pp.

Leatherwood, S., and R. R. Reeves. 1983. The Sierra Club Handbook of Whales and Dolphins. Sierra Club Books, San Francisco. 303 pp.

Leatherwood, S., B. S. Stewart, and P. A. Folkens. 1987. Cetaceans of the Channel Islands National Marine Sanctuary. National Marine Fisheries Service, National Oceanic Atmospheric Administration. 66 pp.

Orr, R.T. and R.C. Helm. 1990. Marine Mammals of California. New and revised Edition. Calif. Natural History Guides:29. U.C. Press, Berkeley. 93 p.

Tilt, W. C. 1985. Whalewatching in California: An industry profile. Yale School of Forestry and Environmental Studies, New Haven, CT. 17 pp.

SEA OTTER

History

Sea otters (*Enhydra lutris*) once ranged from extreme northern Japan through the Kuril Islands, southern Sakhalin Island, southern Kamchatka Peninsula, Commander Islands, Alcutian Islands, southern Alaska, British Columbia, Washington, Oregon and California, extending south to about the midpoint of the Pacific coast of Baja California, Mexico. Prior to 1741, human contact with sea otters was limited to native

SMB-26952

cultures through much of the range and to Spanish colonists in California and Mexico.

Commercial utilization of sea otters followed the Bering Expedition of 1741 to the mainland of southern Alaska and the Aleutian and Commander islands. Reports of vast numbers of sea otters stimulated the fur trade and contributed to the eventual settlement and economic development of the west coast of North America by nonnative people. Russian fur traders developed facilities at several locations on the North American coast, most notably at Kodiak Island and Sitka. The southernmost outpost, at Fort Ross, California, was established in 1812. Russian hunters worked at least as far south as the islands off Santa Barbara, but the Russian presence in California was contested by Spanish colonists. Spanish trade in sea otter pelts began in 1786 and was the most important industry in coastal California for several decades.

The early Russian otter traders utilized enslaved Aleut natives as hunters. The Aleuts worked from native canoes, hunting with spears and clubs. Later, American and European hunters entered the trade using firearms as primary tools of capture. By the 1840's, the sea otter population in California was greatly reduced in numbers as a result of overexploitation.

Sea otters were approaching extinction at the beginning of the twentieth century. Thirteen remnant populations, totaling perhaps 1,000 to 2,000 individuals, survived in the North Pacific in 1911. Sea otters were widely regarded as extinct in California by 1900, but scientists and game wardens were aware of a surviving group near Point Sur in Monterey County as early as 1914. Rough population estimates in the early 1900's ranged from less than 50 to about 100 sea otters in California. Other remnant populations were known to exist in 1911 in Mexico, Canada, Alaska and Russia. The remnant populations in Mexico and Canada were thought to be extinct by 1920.

Sea otter, *Enhydra lutris*.

The International Fur Seal Treaty was signed in 1911 by Canada (for Great Britain), Japan, Russia and the United States. The Treaty recognized the serious overexploitation of northern fur seals and sea otters and provided full protection for both species. State law has prohibited take or possession of sea otters or their pelts in California since 1913. With the termination of the trade in sea otter pelts, the California sea otter population began to grow in numbers and range. State Highway 1 was opened between Monterey and San Simeon in 1937, traversing a coastal segment previously not accessible by automobile. Highway access led to the much publicized "rediscovery" of California sea otters by the general public at Bixby Creek in 1938. The sea otter population numbered roughly 300 individuals at that time. The state of California provided additional protection for sea otters by creating the Sea Otter Game Refuge, extending along 100 miles of coastline from the Carmel River, near Monterey, to Santa Rosa Creek, near Cambria.

Passage of the federal Marine Mammal Protection Act of 1972 provided new authority for protection of sea otters in all U.S. waters. The Act transferred management responsibility for California sea otters from the state to the federal government.

Between the 1930's and the late 1970's, the California sea otter population grew at an average annual rate of about five percent, extending its range to more than 200 miles of coastline from Santa Cruz to Pismo Beach. In the early 1980's, a reduced rate of population growth was recognized, and some argued that the population was declining in numbers. Studies by federal and state agencies determined that the nearshore set-net fishery for halibut was causing significant mortality of sea otters as a result of incidental entanglement and drowning. Estimates of annual mortality in nets ranged as high as 80-100 animals, a rate sufficient to account for the diminished rate of population growth. Legislation by the state imposed restrictions on set-net activity, greatly reducing incidental take of sea otters in nets. By the middle 1980's, it was apparent that population growth had returned to levels previously observed.

Status of Biological Knowledge

The subspecific status of various populations of the sea otter has been in dispute for many years. The most recent studies, based on skull morphology, identified the California population as a separate subspecies. Definition of the subspecies of sea otters likely will remain controversial.

Sea otters in California occur predominantly along rocky shores supporting forests of the large kelps. Along the mainland coast the kelps typically form extensive surface canopies in waters less than 80 feet in depth where the substratum is rock. Sea otters commonly form groups, known as rafts, in kelp canopies, especially when at rest. Rafts typically contain up to 10 individuals, but under certain circumstances may include more than 100 otters. Most sea otters remain within one mile of shore, but in some situations, such as in Monterey Bay, otters are regularly seen foraging and resting three miles or more offshore. Juvenile males tend to range farther offshore than other age/sex categories. Sea otters also are able to successfully utilize habitats with soft substrates. In California, records from the fur trade suggest that sea otters once were abundant in the soft-bottom habitats of San Francisco Bay.

Adult male sea otters in California typically weigh 60 to 75 pounds, reaching a length of four to 4.5 feet. Adult females typically reach a weight of 40 to 55 pounds and a length of four feet. The largest sea otter recorded in California was a male weighing 92 pounds.

Sea otter pelage includes outer guard hairs and dense, fine underfur. Density of sea otter fur is higher than that of any other

SMB-26953

mammal. Sea otter pelage provides the primary thermoregulatory barrier between the animal and the chilling effects of sea water. Most other marine mammals rely on subcutaneous fat rather than pelage for thermal protection. The effectiveness of the pelage as a thermal barrier depends on frequent grooming and consequent cleanliness. Soiling of the fur largely eliminates the insulative qualities, resulting in rapid heat loss. Food consumption rates equivalent to 25 percent or more of individual body mass must be consumed daily to maintain the high metabolic rate typical of sea otters.

Male sea otters reach sexual maturity at five to six years of age. In California, adult males establish and defend territories in areas of high female density, seasonally in some areas and year-round in others. Younger males typically are excluded from breeding areas by territorial males. Female sea otters become reproductively mature at three to five years of age. Mature females typically come into estrus within a few days to a few weeks after weaning of pups. Gestation is four to six months and involves delayed implantation. After implantation, development to birth normally requires about four months. Virtually all births are single. Twinning has been observed, but females apparently are unable to care successfully for more than one pup at a time. Care of dependent pups is entirely maternal. Period of pup dependency averages six months in California, with a range of 4.5 to 9.5 months. Studies suggest that preweaning mortality rate for firstborn pups may exceed 50 percent. Survival of dependent pups improves with the experience of the mother. Most adult females produce one pup per year. In cases of premature death of dependent pups, females may come back into estrus and be reimpregnated within a few weeks after loss of the pup. In California, rates of pup birth apparently peak in late winter, with a secondary peak in late summer or early fall. Pupping may be nonseasonal in certain California locations.

Sea otters typically weigh four to five pounds at birth, and 20 to 30 pounds at weaning. In most sea otter populations, maximum longevity probably is in the range of 11 to 15 years. Captive animals are known to have lived as long as 20 years.

Known predators of sea otters include sharks, eagles, coyotes and bears. Attack by white sharks probably occurs at a low rate throughout the California range. Predation generally is regarded as less important than food limitation in controlling the size of sea otter populations.

Patterns of activity vary widely among sea otter populations and among individuals within sea otter populations. In California, most otters forage during morning hours, rest from late morning through mid-afternoon and resume foraging in late afternoon. Sometimes a third period of foraging occurs at night, between about 11:00 p.m. and 2:00 a.m. Juvenile females typically spend more time foraging than other categories, often feeding during hours when other otters are at rest.

In California, home ranges of adult males during the principal breeding season (summer and fall) have a mean coastline length of about 0.5 mile and an area of about 100 acres. During winter the range approximately doubles for those individuals that remain in breeding territories. Long-distance movements among high-use areas range from 35 to 60 miles and often are seasonal. Males may remain within a high-use area for months at a time, but travel between such areas rarely requires more than a few days. Females follow the same general pattern as males, but high-use areas are typically 1.5 to two times larger for females than for males. Females also travel long distances in short periods, but such travel is much less frequent for females than for males. Substantial short-term movement of females among high-use areas often occurs in association with pupping. Juvenile males tend to utilize larger areas and travel greater distances than other age/sex categories. Various studies have shown that sea otters are capable of homing from distances as great as 300 miles.

Sea otters generally feed on large-bodied, bottom-dwelling invertebrates obtained during dives. They are able to dive to at least 320 feet, but most foraging dives in California are in waters less than 80 feet deep. Dive duration may be as long as four minutes, but more typically is 50 to 80 seconds. Individual otters typically feed on a relatively few species of prey. At the population level, however, sea otters are dietary generalists. More than 160 species have been reported as sea otter prey. Composition of sea otter diet relates to patterns of population growth. In California, diet is predominantly sea urchins, abalones, large crabs and large clams when otters have recently reoccupied a foraging area. As the period of occupation increases, preferred prey decline in availability and the diet diversifies. In cases of occupation by sea otters for more than a few years, the most common prey in California are crabs and small snails. Other frequent prey include octopus, mussels and clams. Sea otters are well known for their abilities in using stones as tools while foraging. Stones may be used as hammers to dislodge prey from the substrate during dives and may be used as anvils for breaking shells of prey during surface intervals. Fish are common prey for sea otters at certain locations in Alaska and Russia. Consumption of fish by sea otters is rare in California.

Sea otters have important effects on the character of nearshore biological communities. In a number of circumstances it has been reported that otters substantially reduce prey abundance and individual size. The best-known cases involve species such as abalones and sea urchins that are sought in commercial or recreational fisheries. Such interactions have provided grist for intensive political discord for many years regarding approaches to management of sea otter populations. Such conflicts first arose in regard to the central California abalone fishery in the 1960's. More recent conflicts involve sea urchins, Dungeness crabs and several species of clams. Human over-harvesting of shellfish populations sometimes contributes to management difficulties and political controversies associated with conflicts of sea otters and shellfisheries.

The control of herbivorous invertebrates by sea otters allows secondary development of dense algal populations, including kelps, that may substantially alter the structure and dynamics of nearshore ecosystems. Proliferation of algae as a consequence of growing sea otter populations has been reported at a number of locations throughout the range of the species.

The 1989 *Exxon Valdez* disaster in Prince William Sound demonstrated the potential vulnerability of sea otter populations to catastrophic oil spills. About 1,000 sea otter carcasses

SMB-26954

were recovered after the spill. Most apparently had died as a result of contact with oil. Total mortality of sea otters remains unknown. Over 350 oiled sea otters were captured alive after the spill, but survival was less than 50 percent despite intensive efforts to treat and rehabilitate oiled animals. Oiled sea otters died primarily from toxic effects of oil ingested during futile grooming efforts, from hypothermia resulting from matted pelage, and from stress.

Status of the Population

The sea otter population in California currently ranges along 225 miles of coastline from Año Nuevo Island, north of Santa Cruz, to approximately the Santa Maria River, south of Pismo Beach. Determination of trends in the number of sea otters has been complicated by the variety of survey techniques used, differing in accuracy and precision. In 1982, a standard survey method was adopted for assessments of the California population. The most recent count in California, in the spring of 1992, located 1,810 adults and 291 dependent pups. The California population continues to grow at a rate of about five to seven percent per year.

Table 1. Results of spring surveys, California sea otter population, 1983-1992.

Survey	Independent animals	Pups	Total
1983	1156	121	1277
1984	1180	123	1303
1985	1119	242	1361
1986	1358	228	1586
1987	1435	226	1661
1988	1504	221	1725
1989	1571	285	1856
1990	1466	214	1680
1991	1700	241	1941
1992	1810	291	2101

In 1977, the California sea otter was listed as threatened under the federal Endangered Species Act of 1973, requiring development of a Recovery Plan for sea otters in California. A primary element of the Plan, issued in 1982, was establishment of a new colony of sea otters by translocation within California. The colony was to be well separated from the existing mainland range, thereby reducing the possibility that a single large oil spill or similar disaster could contaminate all sea otters in California.

Between 1987 and 1990, 139 sea otters were translocated from their mainland range to San Nicolas Island, off southern California. The most recent survey at the island, in July 1992, found 10 adult sea otters and four dependent pups. The status and future of the sea otter colony at San Nicolas Island remain uncertain.

The Recovery Plan for sea otters in California is currently (summer 1992) in revision. The primary goal of the new Plan, like the old, will be attainment of a sea otter population with sufficient numbers and range to eliminate the possibility of disasters such as the *Exxon Valdez* exposing all California sea otters to contamination and possible injury or death.

Glenn R. VanBlaricom
U.S. Fish and Wildlife Service

Robert A. Hardy
California Department of Fish and Game

References

Estes, J. A. and G. R. VanBlaricom. 1985. Sea otters and shellfisheries. Pages 187-235 *in* R. Beverton, J. Beddington, and D. Lavigne (eds). Conflicts between marine mammals and fisheries. Allen and Unwin, London, England.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific ocean. North American Fauna 68. 352 p.

Ogden, A. 1941. The California sea otter trade, 1784-1848. University of California Press, Berkeley. 251 p.

Riedman, M. 1990. Sea otters. Monterey Bay Aquarium, Monterey. 80 p.

Riedman, M. L. and J. A. Estes. 1990. The sea otter (*Enhydra lutris*): Behavior, ecology, and natural history. U.S. Fish and Wildl. Serv. Biol. Rep. 90(14). 126 p.

Wild, P. W. and J. A. Ames. 1974. A report on the sea otter, *Enhydra lutris* L., in California. Calif. Dept. Fish and Game, Mar. Resour. Tech. Rep. 20. 93 p.

MARINE MAMMALS: DISCUSSION

Most of the marine mammals known from California waters have been reviewed in this section, including California populations of whales, dolphins, porpoises, seals, sea lions, and sea otters. The previous articles have indicated that marine mammals are an important part of the living marine resources of California. From their initial historic value as a harvestable resource for world trade as seal and sea otter furs, through the commercial whaling era, to their primary present-day value as tourist attractions, marine mammals have continually ranked among the most economically valuable of all marine resources in California. The variety and abundance of marine mammals also play an important role in the balance of marine ecosystems.

Some marine mammal populations that occur in California are still in a recovery phase after severe reduction from commercial harvest during the nineteenth and early twentieth centuries. Recovery of populations ranges from slight in some, such as the humpback whale, to others, such as the northern elephant seal, that may be nearing the carrying capacity of their habitat.

Populations of other marine mammals, because they have increased so dramatically, have been affected more recently by interactions with increased commercial fishing activity. Mortality in the central California set net fishery during the early 1980's was significant for sea otters and probably for harbor porpoises. Restrictions on set net activity greatly reduced inci-

SMB-26955

dental take of both species, as well as harbor seals, California sea lions, and northern elephant seals.

Authority to manage marine mammal populations rests with the National Marine Fisheries Service and Fish and Wildlife Service. Currently, the take of marine mammals incidental to commercial fisheries is authorized under a five-year exemption, enacted in 1988, from the moratorium on taking marine mammals. The purpose of the exemption is to enable commercial fisheries to continue to operate while information essential for long-term management of marine mammal-fishery interactions is being developed.

The 1988 amendments to the Marine Mammal Protection Act directed the Secretary of Commerce, after consultation with the Marine Mammal Commission, regional fishery management councils, and other interested agencies and organizations, to provide to Congress a suggested regime to govern incidental taking after October 1, 1993.

Marine mammal management in California's future will need to provide for larger populations of marine mammals than are now present. Some populations, such as northern elephant seals, already occupy rookeries in areas that were probably not available to them historically because of access to predators such as wolves and grizzly bears. The current push toward complete protection for all marine mammal populations will result in continued growth for some of them and will require innovative techniques to reduce the likelihood of serious interactions as human use of marine resources also increases.

Robert A. Hardy
California Department of Fish and Game

SMB-26956

MARINE BIRD RESOURCES

Seabirds are a diverse assortment of bird species that inhabit salt or brackish water environments for at least a part of their annual cycle. This discussion is limited to the pelagic species of birds that breed on offshore islands and make their living by utilizing the food web in the upper layers of the ocean in contrast to the waterfowl (ducks, geese, grebes, loons, wading birds, and shorebirds) that live mostly in the coastal marsh areas or nest in arctic tundra or inland lakes and marshes. Seabirds can be further divided into resident (breeding) and non-resident (not breeding) species. Birds in these ecological categories are very different in how they affect or are affected by the natural environment and human-related events along our coast.

Table 1. Seabirds which breed off the California coast, their distributional status relative to areas north and south of California, the approximate sizes of their breeding populations in the 1980's and their status in the 1990's (X indicates presence, 0 indicates absence).

Common Name (Scientific Name)	Distribution in: Alaska	California[1]	Baja Cfa	Estimated CA Breeding Pop. in the 1980's[2]	CA Status in the 1990's
Forked-tailed storm-petrel (*Oceanodroma furcata*)	X	X	0	300	Unknown
Leach's storm-petrel (*Oceanodroma leucorhoa*)	X	X	X	18,300	Declining
Ashy storm-petrel (*Oceanodroma homochroa*)	0	X	0	5,200	Unknown
Black storm-petrel (*Oceanodroma melania*)	0	X	0	150	Unknown
Brown pelican (*Pelecannus occidentalis*)	0	X	X	2,700	Increasing
Double-crested cormorant (*Phalacrocorax auritus*)	X	X	X	1,900	Stable/Increasing
Brandt's cormorant (*Phalacrocorax penicillatus*)	0	X	X	64,200	Stable/Increasing
Pelagic cormorant (*Phalacrocorax pelagicus*)	X	X	0	15,900	Stable/Increasing
Western gull (*Larus occidentalis*)	0	X	0	51,000	Increasing
Common murre (*Uria aalge*)	X	X	0	363,200	Declining
Pigeon guillemot (*Cepphus columba*)	X	X	0	14,700	Stable
Marbled murrelet (*Brachyramphus marmoratus*)	X	X	0	2,000	Declining
Xantus' murrelet (*Synthliboramphus hypoliucus*)	0	X	X	3,600	Stable/Declining
Cassin's auklet (*Ptychoramphus aleuticus*)	X	X	X	131,200	Unknown
Rhinoceros auklet (*Cerorhinca monocerata*)	X	X	0	400	Increasing
Tufted puffin (*Fratercula cirrhata*)	X	X	0	250	Stable
Number species in common		10	-	7	
Total breeding species	28 (30)	16 (23)	14 (22)		

[1]Some species in Alaska or Baja California are not listed because they do not occur off California. The number of breeding species in California can be increased by adding up to five terns (*Sterna sp.*), the black skimmer (*Rynchops niger*), and the California gull (*Larus californicus*); numbers in parentheses indicate additions of this type for each area.

[2] The extimated Alaskan breeding seabird total population is about 40,200,000 compared to about 700,000 for California. These numbers represent approximate mean levels throughout the 1980's, and recent updates will be published in 1993. Ten to forty percent should be added to include non-breeders and immatures, a proportion which varies from year to year and species to species. In California four species (common murre, Brandt's cormorant, Cassin's auklet, and western gull) comprise almost 90 percent of the total number of breeders.

SMB-26957

There are 23 species of seabirds that breed along the coast of California. Point Conception is generally considered a major area of transition between characteristically northern seabirds (such as those found in the Gulf of Alaska and Washington) and subtropical seabirds (such as those found in the Gulf of California). North of Point Conception, marine waters are dominated by the California Current System in which cold, nutrient-rich water is upwelled along the coast. South of Point Conception, upwelling mainly occurs only far offshore, and warmer, clearer, nutrient-poor waters extend up from the Subtropics. Ecologically, this makes California's marine birds among the most interesting and taxonomically diverse in the northern hemisphere.

California's breeding seabirds are about evenly divided between southern and northern species. The northern seabird species have a greater biomass, however. One of the reasons for this is that northern waters are generally more productive and, therefore, support greater seabird populations. In California, many of our breeding seabirds, such as common murres, Brandt's cormorants, and Cassin's auklets (all primarily northern species) are concentrated at the Farallon Islands (off San Francisco) and Castle Rock National Wildlife Refuges (near Crescent City). The Farallons are the most important single seabird breeding site in California, and large seabird populations there are associated with abundant availability of suitable and protected nesting habitat, coupled with strong and productive upwelling systems that provide large prey resources in the same area.

A brood of three California brown pelicans on Anacapa Island off southern California. Improvement in reproductive success is linked to a decline in DDE residues in the offshore environment.

Another major California breeding area south of Point Conception in the Southern California Bight is the Channel Islands. These islands harbor important nesting colonies for some seabirds of northern affinity (such as Cassin's auklets) but also the state's entire nesting population of brown pelicans (presently a recovering endangered species) and the rare Xantus' murrelet. Both species have southern breeding distributions and also nest off Baja California; but the brown pelican is of tropical affinity (origin), whereas the Xantus' murrelet is of subarctic affinity. One of the most unique and interesting breeding seabirds off central and northern California is the marbled murrelet, a small seabird that nests inland in coastal, old-growth coniferous forests, often over a hundred feet high in the tree tops. Unfortunately, this little bird is becoming endangered because of the loss of its nesting habitat due to logging, and because of mortality caused by oil spills and gill-net fishing.

Usually, between the end of summer after the Upwelling Period and before the end of the year, the California Current System experiences an immigration, emigration, and reshuffling of seabirds from the north, south, and within California. The abundance and diversity of seabirds increases immensely at this time. One of the most abundant seabird species in the world, the sooty shearwater, comes through California waters by the millions, mostly from New Zealand. Another exciting sighting involves one of several species of albatrosses which seem to be showing up off California in increasing numbers. Similarly, southern seabirds, such as boobies, red-billed tropicbirds, and magnificent frigatebirds, can provide the highlight of any boat trip. From the Mexican Sea of Cortez around July, come several species of storm-petrels, Heermann's gulls, elegant terns, and many more brown pelicans than nest in California. From the north, especially into the winter, we witness the arrival of northern seabirds like the northern fulmar, tufted and horned puffins and other alcids, the black-legged kittiwake, the brant (one of the few species of wild geese that migrates along the coast to wintering areas in Mexico), and many others. Such diversity and abundance adds to the overall richness and value of California's total marine resources.

Table 2. Scientific names of birds mentioned in text but not included in Table 1.

Albatross	*Diomedia sp.*
Boobies	*Sula sp.*
Black-legged kittiwake	*Rissa tridactyla*
Brant	*Branta bernicla*
California least tern	*Sterna antillarum*
Elegant tern	*Thalasseus elegans*
Heermann's gull	*Larus heermanni*
Horned puffin	*Fratercula corniculata*
Magnificent frigatebird	*Fregata magnificens*
Northern fulmar	*Fulmarus glacialis*
Red-billed tropicbirds	*Phaethon aethereus*
Sooty shearwater	*Puffinus griseus*

History and Utilization

Marine birds or seabirds are the most conspicuous and familiar elements of marine communities, and are a source of pleasure and enjoyment for people at sea or along the coast. They are unique and important biotic elements of marine ecosystems and are good indicators of the general health of coastal offshore environments. Yet, people working or recreating at sea often know little about them. And, although often omitted from marine resource reference works such as this, seabirds require management and protection, just as do other elements of marine ecosystems.

Seabirds are prominent elements in the biodiversity of marine ecosystems. They perform what ecologist Paul Ehrlich calls "ecological services," such as nutrient cycling and scavenging of biological waste materials and debris from waters and

SMB-26958

beaches. They often guide fishermen to fish. They are fun to watch, and consequently, contribute to local economies by attracting tourists. Healthy seabird populations give us the justified feeling that all is well at sea, and a "missing," sick, or oiled bird tells us that it might not be.

Like most marine wildlife, marine birds have historically suffered severe and relentless exploitations by man. In California, this was especially true at the Farallon Islands during and after the gold rush in the late-1800's, where common murres were heavily exploited for their eggs. There was no regulation of take, and the murre populations incurred severe declines, so that only a few thousand individuals were left by the late-1920's. The Farallon murre population did not recover for several decades and even now is far below numbers of the 1800's. Exploitation of seabirds or seabird products is neither a local or recent phenomenon. Recall the ancient, managed harvest of guano by the Incas of Peru, or the harvest of guano for manufacturing gunpowder by the imperialistic navies of Europe in the 16th-18th centuries. Empires were won or lost over control of the seabird islands! Early sailors and explorers often utilized seabirds or their eggs, driving some species to the point of extinction. In general, however, there has been little success worldwide in utilizing seabirds for sustainable food or other product sources. The few exceptions include guano harvests in Peru, harvest of eider down from seaducks in Iceland, "muttonbird" harvests (shearwaters) for oil in New Zealand, and the harvest of seabird guano from man-made islands off South Africa. There is no successful, sustainable harvest of seabirds or seabird products in California or the West Coast. Since the early days of exploitation, management has usually involved putting the nesting islands into a protection system. This is the case for most islands off California.

After World War II, California's abundant seabird populations began to suffer from new problems. For example, birds and marine mammals experienced population depletions as a result of offshore chemical pollutant discharges from industries in Southern California. In a different kind of example, bird populations in central and southern California declined from excessive sardine fishing. Many species of seabirds feed almost exclusively on surface-feeding fishes which are also sought in commercial fisheries. The depletion of sardines off Monterey is thought to have had deleterious effects on some species of seabirds. It is not well known, however, how long it takes to bring about a population decline of seabirds and how effectively various kinds of marine birds can switch to other prey. Since the 1950's, large oil spills and chronic waste oil discharges have become increasingly frequent, and large numbers of seabirds have been killed. Although acute oiling of seabirds (oil spills and the associated publicity they get) receives more attention, it might be that chronic oiling of the offshore environment causes the greatest damage to seabirds and other marine wildlife. Rehabilitation of oiled birds and mammals has not been very successful. Most birds die before rehabilitation can be attempted and many birds that receive care die anyway. Prevention of oil spills and chronic oiling is still the best solution.

Since seabirds are visibly affected when people misuse marine resources, the well-being of our seabird populations helps tell us about the health of our oceans. Potential effects on seabirds are often examined to help evaluate the overall projected effects on the marine environment of future development activities. Such activities include increased levels of offshore oil extraction and transport; mining of other ocean resources; development of alternate forms of energy; use of new fishing techniques; fish farming and fish ranching at sea; and new marine product development and exploitation. Increasing levels of marine debris, including fishing gear and seemingly edible items made of plastic and other materials present other hazards. Additionally, "eco-tourism," a rapidly growing industry, can lead to unregulated intrusion onto nesting islands that are important to seabird populations. There is already a history of disappearance of seabird colonies on islands visited too frequently by unsupervised tourists. Global warming, if it occurs, may have detrimental effects on seabirds.

Recognition of the importance of seabirds as indicators and of the effects that human activities can have on them has led to a surge of activity and interest in seabird conservation and management. In addition to many governmental agencies, there are five "seabird groups" around the world composed of interested professionals which have been organized to study and help conserve these important elements of marine wildlife. The Pacific Seabird Group focuses on our West Coast from California to Washington, plus Alaska, Hawaii, British Columbia, and Mexico. In California, state and federal governmental agencies, anglers and commercial fishermen, and marine bird conservationists are beginning to work together to help conserve and manage marine wildlife.

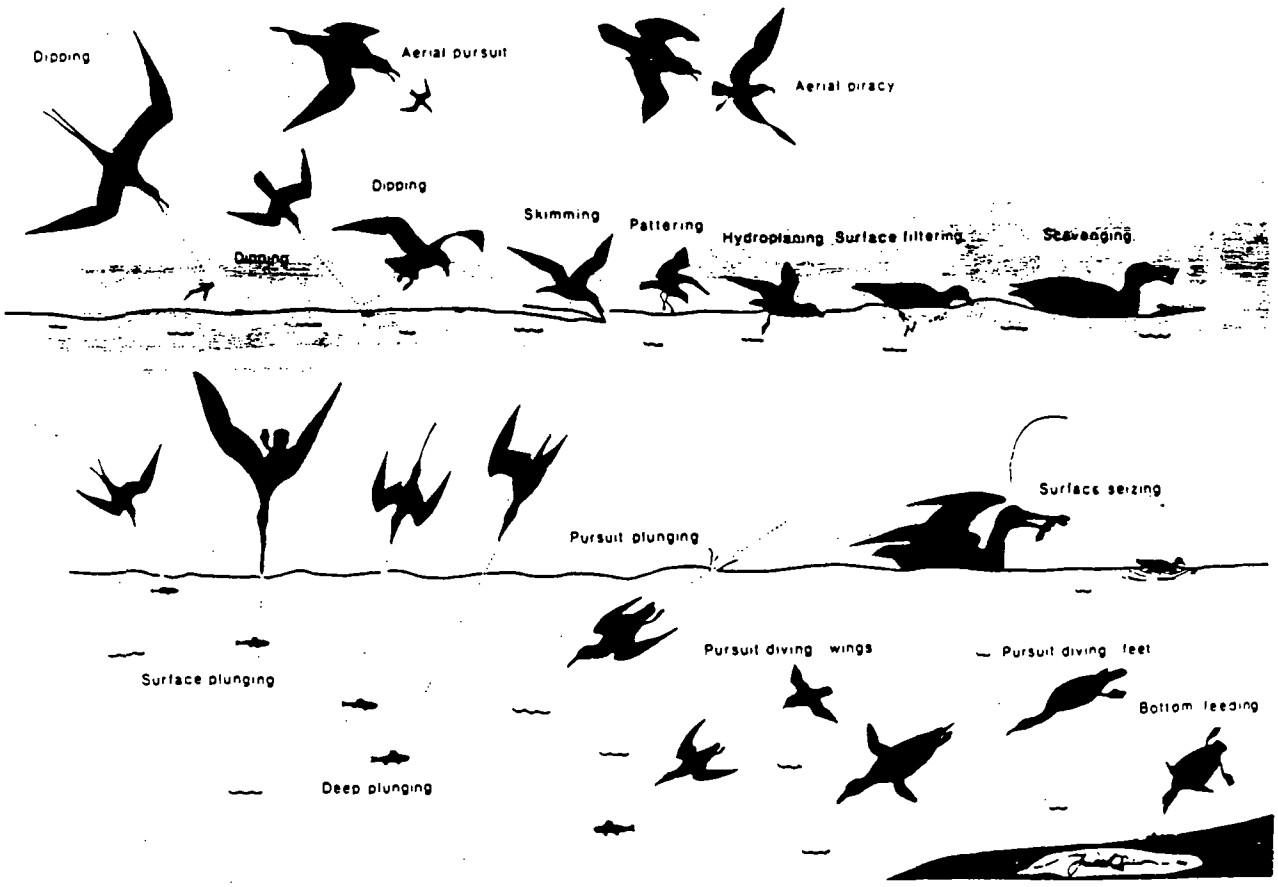
Seabird Ecology

Almost all important adaptations in body form and behavior of seabirds reflect specialization for either breeding or feeding. Methods of marine bird feeding depend on types of foods and where these foods are found in the water column. Seabirds are, therefore, influenced by the environmental factors which influence the marine environment. During the breeding season, seabirds are confined to feeding within a reasonable distance from their nesting islands. In addition to providing suitable nesting habit, nesting islands must be free of predators and disturbances. Outside the breeding season, when not constrained to tending offspring, many seabird species are highly mobile and can move long distances to find food. Other species may remain in areas of abundant and predictable food supplies, just like fishermen. Distribution at sea is heavily influenced by the physical oceanography of the area. For example, plankton feeders will be found where ocean currents favor growth and accumulation of planktonic species. Such areas, in turn, provide food for shoals of pelagic species such as northern anchovy, Pacific sardine, herring, mackerel, or juvenile demersal fishes such as rockfishes. These midwater fish in turn are preyed upon by fish-feeding seabirds. The species of fish is usually not as important as is the fact that the fish are available and abundant.

Some seabirds feed at the surface and others fly or paddle underwater to extend their reach lower into the water column. Some California species can dive to a depth of 330 feet. Water

SMB-26959

clarity influences which type of feeding method will be most successful. For example, clear, tropical waters typically best support species that catch fish by plunge-diving (boobies and pelicans). In contrast, northern waters are usually too turbid for aerial plungers to see prey, but are better suited to underwater swimmers or flyers (like the murres, auklets, and cormorants).



Seabird feeding methods in relation to depth of water column penetration and morphological variation of different species (described by N.P. Ashmole and drawn by J. Ahlquist, reprinted with permission from Academic Press).

While nesting, seabirds are more or less bound to a nest that requires protection from predators and parental care. The breeding season is the period of time it takes from courtship, nest-building, and egg-laying to the point of fledging, when young leave the nest or become independent. During breeding, seabirds are strongly influenced by local food supplies and, thus, the oceanographic and meteorological conditions. Reproductive success is influenced by the biomass, availability, and consistency of local food supplies. For instance, when El Niño weather patterns occur, seabirds reproduce poorly or not at all because prey resources are less abundant and available.

Since offshore islands with nearby, stable food supplies are in short supply for nesting seabirds in California, such birds are almost always found concentrated into tightly-packed nesting colonies, with different species usually segregated onto different kinds of micro-habitat. As a consequence, nesting colonies are vulnerable to destruction by mammalian predators such as foxes and raccoons. Therefore, nesting islands must be free from terrestrial predators and human disturbance to provide seabirds with successful nesting opportunities. Evolutionary development on islands lacking terrestrial predators has left many seabirds with no defenses against predators, except to abandon their colonies. Undisturbed roosting and loafing sites are also critical to seabirds. Tourism and introductions of rats, cats, dogs, pigs, goats, and other feral animals has repeatedly led to extermination of seabirds from islands that were formerly predator-free.

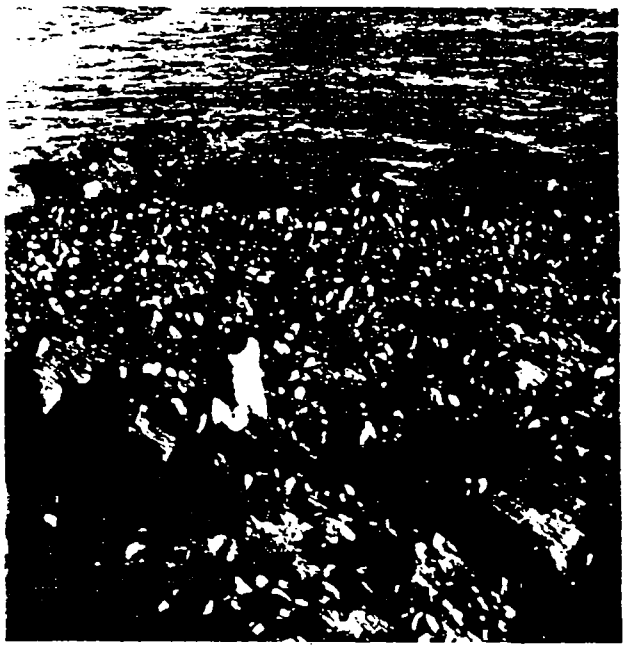
Management

Many agencies are involved in the management and conservation of marine birds, and many statutory and executive provisions contribute to their protection. In addition, California has one of the finest systems of sanctuaries and refuges for seabirds in the world. However, our coastal wetlands now comprise only a small percentage of their former extent, and these habitats are critical to many species of seabirds. Offshore waters are becoming increasingly occupied and utilized by people, yet many offshore islands and rocks are as close to their natural states as one might reasonably expect in our modern world.

Nonetheless, some of California's seabirds are threatened or endangered, and others may warrant such designation. Examples are the California least tern, the California brown

SMB-26960

pelican, the marbled murrelet, the Xantus' murrelet, and the ashy storm-petrel. The brown pelican may soon be downlisted because its populations are recovering; one of the few success stories in recent times.



Common murres and Brandt's cormorants on Flatiron Rock off Trinidad, north of Eureka.

Seabird populations have a number of characteristics in common which make them susceptible to harm from environmental changes:

1) Resident seabirds concentrate their nesting efforts over several months at small areas, and they traditionally use the same nesting areas year after year.

2) Some seabirds (pelicans, cormorants, gulls) concentrate in roosts or resting sites. Night roosts provide protection from predators and disturbances and may have beneficial thermal characteristics. Day roosts are located closer to food supplies and may have good plumage drying properties.

3) Many seabirds depend on concentrated food supplies, often commercially valuable fisheries resources. Marine fisheries biologists are working with marine wildlife biologists to balance recreational and commercial fisheries with other wildlife needs.

4) Many seabirds tend to be long-lived with low annual reproductive rates. Thus, seabirds cannot usually recover very rapidly from large impacts on their populations.

5) Seabirds are often components of assemblages with interdependent elements, which means that they are closely allied to other species in their system. Disruption of one or more interacting elements may affect the entire assemblage in some way.

Seabird and Fisheries Interactions

Seabird-fisheries interactions have been categorized as follows: 1) direct competition, with negative population implications either for fish or seabird populations; 2) mutualism, where the interaction is beneficial, or commensalism, where there is neither benefit nor detriment to the interaction; and 3) physical injury, where birds are killed or damaged by fishing activities, or bird activities damage operations or gear. Categories 1) and 3) describe conflicts in resource use that should be minimized. Multi-species or ecosystem management instead of management that is single-species oriented may be the key to minimizing such conflicts. The management plan of the Pacific Fishery Management Council (PFMC) for anchovies was one of the first in the nation to consider the multiple uses of the anchovy resource, including seabirds, marine mammals, and bait fisheries for sport fishermen. With the rapidly recovering Pacific sardine resource, the PFMC is revising its anchovy plan to include multi-species management of small pelagic fishes. Fishery management plans are beginning to include concepts such as reserves, multiple-needs, ecosystem balance, and thresholds of minimum resource abundance.

Pileup of brown pelicans, Heermann's gulls, and Brandt's cormorants feeding on anchovies at Shell Beach. Other individuals are roosting on nearby rocks.

The future of fishing gear/seabird interactions is also improving. Gill netting has been banned in many areas, and some fishermen have switched to other fishing methods that do not harm seabirds. Situations are more difficult to control when the commercial fishing occurs outside areas of state or federal jurisdiction. Interactions between recreational fisheries and marine wildlife also occur. While each individual interaction may involve only one angler and one bird, together they can have a significant effect on some seabird populations, especially threatened or endangered species. In many instances the best management approach is education.

Daniel W. Anderson
University of California, Davis

David G. Ainley
Point Reyes Bird Observatory

Harry R Carter
U.S. Fish and Wildlife Service

Kenneth T. Briggs
University of California, Davis

Alec D MacCall
National Marine Fisheries Service

SMB-26961

References

Cogswell, H. G. 1977. Water birds of California, University of California Press, Berkeley, CA. 399 pp.

Fisher, J., and R. M. Lockley. 1954. Seabirds. Houghton-Mifflin, Boston, MA. 320 pp.

Grant, P. 1986. Gulls: a guide to identification, second edition. Buteo Books, Vermillion, SD. 320 pp.

Haley, D. (ed.). 1984. Seabirds of eastern north Pacific and Arctic waters. Pacific Search Press, Seattle, WA. 214 pp.

Harrison, P. 1983. Seabirds: an identification guide. Houghton-Mifflin, Boston, MA. 448pp.

Lockley, R. M. 1974. Ocean wanderers. Stackpole Books, Harrisburg, PA. 188 pp.

Morgan, K. H., K. Vermeer, R. W. McKelvey. 1991. Atlas of pelagic birds of western Canada. Canadian Wildlife Service Occasional Paper 72:1-72.

National Geographic Society. 1987. Field guide to the birds of North America, second edition. National Geographic Society, Washington, DC. 464 pp.

Palmer, R. S. (ed.). 1962. Handbook of North American birds, volume I. Yale University Press, New Haven CT. 567 pp.

Spendelow, J. A., and S. R. Patton. 1988. National atlas of coastal waterbird colonies in the contiguous United States: 1976-82. U. S. Fish and Wildlife Service National Wetlands Research Center, Washington, DC. 326 pp.

Surveys and Status Reports

Ainley, D. G., and T. J. Lewis. 1974. The history of Farallon Island marine bird populations, 1854-1972. Condor 76:432-436.

Ainley, D. G., and G. L. Hunt, Jr. 1991. Status and conservation of seabirds in California. International Council for Bird Protection Technical Publication 11:103-114.

Carter, H. R., D. L. Jaques, G. J. McChesney, C. S. Strong, M. W. Parker, and J. E. Takekawa. 1990. Breeding populations of seabirds on the northern and central California coasts in 1989 and 1990. Unpublished Report, U. S. Fish and Wildlife Service, Dixon, CA. 443 pp.

Carter, H. R., G. J. McChesney, D. L. Jaques, C. S. Strong, M. W. Parker, J. E. Takekawa,

D. L. Jory, D. L. Whitworth, and D. B. Lewis. 1993. Breeding seabird populations of California, 1989-1991. U. S. Fish and Wildlife Service, Dixon, CA. In preparation. Everett, W. T., and D. W. Anderson. 1991. Status and conservation of the breeding seabirds on offshore Pacific islands of Baja California and the Gulf of California. International Council for the Protection of Birds Technical Publication 11:115-139.

Harrison, C. S. 1991. Seabirds of Hawaii: natural history and conservation. Cornell University Press, Ithaca, NY 288 pp.

Hunt, G. L., Jr., R. L. Pitman, and H. L. Jones. 1980. Distribution and abundance of seabirds breeding on the California Channel Islands. Pp. 443-459, *in*: Power, D. M. (ed.), The California Islands: proceedings of a multidisciplinary symposium. Santa Barbara Museum of Natural History, Santa Barbara, CA. 787 pp.

Sowls, A. L., A. R. DeGange, J. W. Nelson, and G. S. Lester. 1980. Catalogue of California seabird colonies. U. S. Fish and Wildlife Service, Biological Services Program FWS/OBS-80/37, Washington, DC. 371 pp.

Sowls, A. L., S. A. Hatch, and C. J. Lensink. 1978. Catalog of Alaskan seabird colonies. U. S. Fish and Wildlife Service, Biological Services Program FWS OBS.78/78, Washington, DC. 166 pp.

Speich, S. M., and T. R. Wahl. 1989. Catalogue of Washington seabird colonies. U. S. Fish and Wildlife Service Biological Report 88:1-510.

Seabird Ecology

Ainley, D. G. 1977. Feeding methods in seabirds: a comparison of polar and tropical nesting communities in the eastern Pacific Ocean. Proceedings S.C.A.R. Symposium on Antarctic Biology 3:669-685.

Ainley, D. G. 1980. Birds as marine organisms: a review. California Cooperative Ocean Fisheries Investigations Reports 21:48-52.

Ainley, D. G., and R. J. Boekelheide (eds.). 1990. Seabirds of the Farallon Islands: ecology, dynamics, and structure of an upwelling system community. Stanford University Press, Stanford, CA. 450 pp.

Ainley, D. G., H. R. Carter, D. W. Anderson, K. T. Briggs, M. C. Coulter, F. Cruz, J. B. Cruz, C. A. Valle, S. I. Fefer, S. A. Hatch, E. A. Schreiber, R. W. Schreiber, and N. G. Smith. 1988. Effects of the 1982-83 El Niño-Southern Oscillation on Pacific ocean bird populations. Proceedings of the International Ornithological Congress 19:1747-1758. Anderson, D. W., F. Gress, and K. F. Mais. 1982. Brown pelicans: influence of food supply on reproduction. Oikos 39:23-31.

Anderson, D. W. 1983. The seabirds. Pp. 246-264, 474-481, *in*: Case, T. J., and M. L. Cody (eds.), Island biogeography in the Sea of Cortez. University of California Press, Berkeley, CA. 508 pp.

Ashmole, N. P. 1971. Sea bird ecology and the marine environment. Pp. 223-286, *in*: Farner, D. S., and J. R. King (eds.), Avian Biology, volume 1. Academic Press, New York, NY. 586 pp.

Briggs, K. T., and E. W. Chu. 1986. Sooty shearwaters off California: distribution, abundance and habitat use. Condor 88:355-364.

Briggs, K. T., W. B. Tyler, D. B. Lewis, and D. R. Carlson. 1987. Bird communities at sea off California: 1975 to 1983. Studies in Avian Biology 11:1-74.

Burger, J., B. L. Olla, and H. E. Winn. 1980. Behavior of marine animals, volume 4: marine birds. Plenum Press, New York, NY. 515 pp.

Burger, J. 1988. Seabirds and other marine vertebrates: competition, predation, and other interactions. Columbia University Press, New York, NY. 339 pp.

Croxall, J. P. (ed.). 1987. Seabirds: feeding ecology and role in marine ecosystems. Cambridge University Press, New York, NY. 408 pp.

Furness, R. W., and P. Monaghan. 1987. Seabird ecology. Chapman and Hall, New York, NY. 164 pp.

Nelson, B. 1979. Seabirds: their biology and ecology. A & W Publishers, New York, NY. 224 pp.

Sealy, S. G. (ed.). 1990. Auks at sea. Studies in Avian Biology 14:1-180.

Warham, J. 1990. The petrels: their ecology and breeding systems. Academic Press, New York, NY. 440 pp.

Conservation and Management

Anderson, D. W., J. E. Mendoza, and J. O. Keith. 1976. Seabirds in the Gulf of California: a vulnerable, international resource. Natural Resources Journal 16:483-505.

Anderson, D. W., and F. Gress. 1981. The politics of pelicans. Pp. 117-143 *in*: Jackson, T. C., and D. Reische (eds.), Coast alert: scientists speak out. Coast Alliance Press, San Francisco, CA. 181 pp.

Bartonek, J. C., and D. N. Nettleship (eds.). 1979. Conservation of marine birds of northern North America. U. S. Fish and Wildlife Service Wildlife Research Report 11:1-315.

SMB-26962

Croxall, J. P., P. G. H. Evans, and R. W. Schreiber (eds.). 1984. Status and conservation of the world's seabirds. International Council for Bird Protection Technical Publication 2:1-778.

Croxall, J. P. (ed.). 1991. Seabird status and conservation: a supplement. International Council for Bird Protection Technical Publication 11:1-308.

Diamond, A. W., and F. L. Filion. 1987. The value of birds. International Council for Bird Protection 6:1-275.

Nettleship, D. N. 1991. Seabird management and future research. Colonial Waterbirds 14:77-84.

Sherman, K. 1991. The large marine ecosystem concept: research and management strategy for living marine resources. Ecological Applications 1:349-360.

U. S. Fish and Wildlife Service. 1980. California least tern recovery plan. U. S. Fish and Wildlife Service, Portland, OR. 58 pp.

U. S. Fish and Wildlife Service. 1982. California brown pelican recovery plan. U. S. Fish and Wildlife Service, Portland, OR. 179 pp.

Pollution and Other Perturbations

Anderson, D. W., and J. O. Keith. 1980. The human influence on seabird nesting success: conservation implications. Biological Conservation 18:65-80.

Anderson, D. W. 1988. Dose-response relationship between human disturbance and brown pelican breeding success. Wildlife Society Bulletin 16:339-345.

Manuwal, D. A. 1978. Effect of man on marine birds: a review. Pp. 140-160 *in*: C. M. Kirkpatrick (ed.), Wildlife and people. Purdue Research Association, West LaFayette, IN.

Page, G. W., H. R. Carter, and R. G. Ford. 1990. Numbers of seabirds killed or debilitated in the 1986 *Apex Houston* oil spill in central California. Studies in Avian Biology 14:164-174.

Takekawa, J. E., H. R. Carter, and T. E. Harvey. 1990. Decline of the common murre in California, 1980-1986. Studies in Avian Biology 14:149-163.

Seabirds and Fisheries

Anderson, D. W., F. Gress, K. F. Mais, and P. R. Kelly. 1980. Brown pelicans as anchovy stock indicators and their relationships to commercial fishing. California Cooperative Oceanic Fisheries Investigations Reports 21:54-61.

Furness, R. W., and R. T. Barrett. 1991. Seabirds and fish declines. National Geographic Research and Exploration 7:82-95.

Nettleship, D. N., G. A. Sanger, and P. F. Springer (eds.). 1985. Marine birds: their feeding ecology and commercial fisheries relationships. Canadian Wildlife Service Special Publication CW66-65, Ottawa, ON. 220 pp.

Radovich, J. 1981. The collapse of the California sardine fishery: what have we learned? Pp. 107-136 *in*: Glanz, M. H., and J. D. Thompson (eds.), Resource management and environmental uncertainty: lessons from coastal upwelling fisheries. Wiley and Sons, New York, NY. 491 pp.

Wahl, T. R., and D. Heinemann. 1979. Seabirds and fishing vessels: co-occurrences and attraction. Condor 81:390-396.

SMB-26963

ECONOMIC UTILIZATION OF OCEAN RESOURCES

Background

Economic as well as biological factors affect the utilization of California's living marine resources. A particularly notable economic phenomenon has been the increase in trade activity between the domestic seafood industry and its foreign counterparts. California's commercial landings are increasingly being marketed abroad, and California consumers are satisfying their cosmopolitan taste for seafood with an array of imported products.

The economic value of a commercial fishery is appropriately measured by the benefits that it provides to consumers and the net economic return (gross revenue minus costs) that it generates to businesses at the ex-vessel, wholesale and retail levels. This chapter's discussion of commercial landings considers only the ex-vessel component of value, and reflects gross rather than net economic return in that it ignores the cost of harvesting fish. Similarly, the discussion of seafood imports and exports includes only the wholesale component of value and ignores costs incurred by import/export businesses. These ex-vessel and wholesale values provide a useful but incomplete picture of the economic value of California's commercial fisheries.

All monetary estimates of value provided in this chapter have been corrected for inflation and are expressed in 1990-equivalent dollars.

Supply

Trends in Landings and Revenues. Seasonal and annual variations in commercial landings are affected by a variety of factors, including species abundance and availability, management restrictions, market demand, ex-vessel prices, harvesting and processing technology and weather. The picture is further complicated by the multispecies nature of many fishing operations (For instance, small combination boats target salmon and albacore with troll gear and crab with pot gear; round haul vessels target pelagic wetfishes, squid, bonito and bluefin tuna; trawlers target rockfish, sablefish, Pacific whiting, flatfish and shrimp). In multispecies fisheries, fishing strategies, and therefore, landings of each species are affected by the availability and profitability of all species targeted in the fishery. Trends in landings are properly viewed in the context of these contributing factors and the interactions among them.

The State of California requires poundage landed, price received, and other information, to be recorded on a "pink ticket" each time a commercial fishing vessel lands its catch at a California port. The landings described in this chapter are based on pink ticket data and reflect most of the harvest but exclude discards, live bait catch and capture of live specimens for aquarium use. In particular:

1) Commercial fishing operations often yield a bycatch of non-targeted species, which may be landed and sold or discarded at sea. Even targeted species may be discarded if, for instance, they are sub-legal or non-marketable in size, or part of a catch that exceeds a trip limit. Information on the level of discards and discard mortality is generally unavailable.

2) Live bait sold in the recreational fishery is generally not landed, since transactions between buyers and sellers of live bait take place at sea or from receivers that are tied up near the docks. Logbook data indicate that bait haulers harvest up to twelve million pounds of live bait per year, most of which consists of northern anchovy.

3) A variety of marine specimens are harvested live, for display in home and public aquariums. These include animals such as gobies, juvenile sheephead, juvenile leopard shark, and even "live rocks" (pieces of substrate with attached communities of living organisms). The harvest of such specimens, though not recorded on pink tickets, has likely increased in recent years, due to increases in domestic and foreign demand.

Total finfish and shellfish landings in California declined by almost half from 1970 to 1990, while total U.S. landings doubled over the same period. California's share of the U.S. harvest, which was 14 percent in 1970, declined to four percent by 1990. Ex-vessel revenues followed a similar pattern (Table 1).

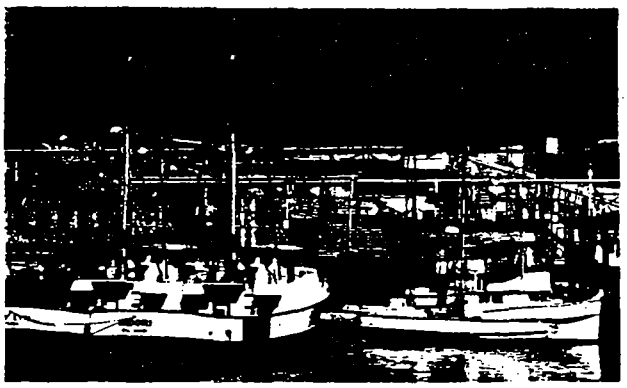
Table 1. Commercial landings (1,000 lbs. landed weight) and ex-vessel revenues ($1,000's) in 1990-equivalent dollars of finfish and shellfish in California and the United States in 1970, 1975, 1980, 1985 and 1990.

	Landings (1,000 pounds)	
Year	California	United States
1970	703,216	4,917,220
1975	861,315	4,877,443
1980	800,723	6,482,354
1985	356,960	6,257,642
1990	395,753	9,708,421
	Ex-Vessel Revenues ($1,000's)	
Year	California	United States
1970	290,551	2,065,417
1975	307,900	2,372,577
1980	501,121	3,548,572
1985	154,002	2,825,643
1990	158,851	3,572,437

The major reason for California's diminished profile was the nine-fold decline in tuna landings from 1970 to 1990 (see appendix for landings figures). The proportion of ex-vessel revenues from all species attributable to tuna decreased from 74 percent in 1970 to 17 percent in 1990 (Table 2). High interest rates, the relocation of tuna processing operations from California to American Samoa and Puerto Rico, and competition from imports of canned tuna packed in water created economic hardship for the fishing fleet. Tuna landings in California dropped precipitously as many of the superseiners transferred flags or converted to other fisheries.

SMB-26964

In 1970, California's top revenue-generating species were yellowfin ($141.1 million), skipjack ($40.7 million) and albacore ($26.4 million); together, these three tunas accounted for 72 percent of total revenues from all species. By 1990, the top revenue-generating species had become sea urchin ($24.7 million), yellowfin tuna ($19.7 million), rockfishes ($16.9 million), Dungeness crab ($16.3 million) and chinook salmon ($11.3 million), together accounting for 56 percent of total revenues from all species. California's commercial fishing industry, once dominated by the tuna fishery, has evolved into a more heterogeneous mix of smaller fisheries.



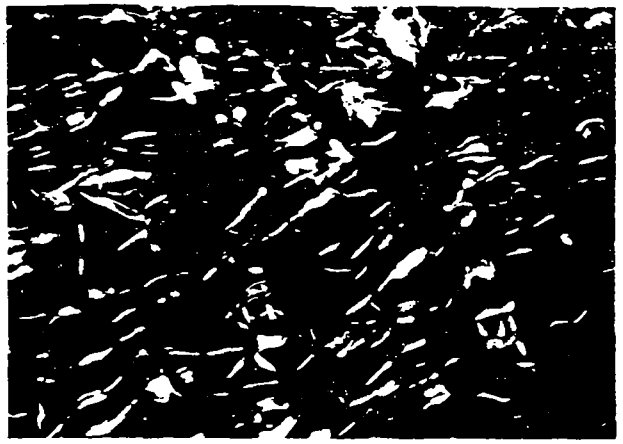
Commercial fishing vessel at San Pedro.

In addition to the tuna fishery, a number of other fisheries have also experienced a decline in recent years. For instance, both biological and economic factors (*e.g.*, habitat loss, competition from aquaculture) have contributed to the decline in salmon landings. Concerns about abalone stocks have prompted increasingly restrictive management measures to reduce fishing effort, and abalone harvest has declined despite a strong market. Anchovy landings have fallen dramatically since 1983, when the decline in the ex-vessel reduction price prompted the round haul fleet to redirect their fishing effort to higher-priced species such as mackerel and squid.

Landings and ex-vessel revenues attributable to species other than tuna increased from $74.7 million in 1970 to $131.9 million in 1990, indicating that declining harvests of some species have been more than offset by increases in others. For instance, mackerel landings increased dramatically in the late 1970's, when the Pacific mackerel population rebounded to levels of abundance not experienced since the early 1940's. Market demand for calamari has prompted the upward trend in squid landings, which reached a record high of 62.7 million pounds in 1990.

A number of major fisheries in California are driven by market demand in the Pacific Rim. For instance, the fishery for red sea urchins developed in the early 1970's, when California gained access to the Japanese market for "uni" (sea urchin gonads, also referred to as roe for marketing purposes). Currently, about 50 percent of all urchin roe imported by Japan originates in the U.S. and over 75 percent of the U.S. product originates in California. In addition to being marketed fresh in Japan, California uni is also sold in the growing domestic sushi market.

Pacific herring landings also increased significantly during the 1970's, as California fishermen obtained access to Asian



Market squid (*Loligo opalescens*) gathered under lights at right.

markets. The harvest is shipped frozen to South Korea, where the roe are stripped and sold as a delicacy in Japan. Although prices have declined and stabilized from the record high of 1980, the fishery generates higher ex-vessel revenues than any other pelagic wetfish species.

The expansion of California's groundfish fishery during the 1970's was fueled by expanding markets as well as improvements in harvesting and processing technology. Asia is the major market for thornyheads, sablefish and other groundfish species.

Many of California's fledgling fisheries are also driven by Asian markets. The hagfish fishery developed in response to a hagfish shortage in the Republic of Korea, where the meat is eaten and the skin made into leather goods. Herring roe on kelp is packed in brine on kelp fronds and marketed as a delicacy in Japan. Landings of sea cucumber (boiled, dried and salted for sale in foreign and domestic Asian markets) doubled between 1985 and 1990. An experimental fishery has recently developed for purple sea urchins for both the roe and live sea urchin markets in Japan. Live fish markets that cater to California's own Asian population have developed for spot prawns, cabezon, California sheephead, white croaker and other small fishes.

Part of the commercial fishing fleet owned by immigrant families from Vietnam at Moss Landing harbor.

A fishery which has been virtually inactive during 1970-1990, but has perhaps the greatest potential for development, is

SMB-26965

Pacific sardine. During the heyday of the sardine fishery (1934-1945), California landings averaged 1.1 billion pounds per year and accounted for almost 80 percent of total statewide landings of all species. The late 1940's signalled the beginning of what was to be a long term collapse of the fishery. Subsequent State restrictions on sardine harvest culminated in 1974 with a moratorium on all directed harvest and a small allowance for incidental take. The State lifted its moratorium in 1986 and currently allows modest levels of directed and incidental harvest. Once sufficiently recovered, the sardine population may be able to sustain an annual yield of 500 million pounds. Whether and when this actually occurs will depend on the timetable for recovery of the stock and development of markets for sardine products, both of which are highly uncertain at this time.

Table 2. Ex-vessel revenues (in 1990-equivalent dollars) from finfish and shellfish in California in 1970, 1975, 1980, 1985 and 1990, by species category ($1,000's).

Species	1970	1975	1980	1985	1990
CRUSTACEANS					
Dungeness Crab	13,432.5	6,781.6	15,496.8	10,844.0	16,273.8
Pac. Ocean Shrimp	1,910.6	1,615.5	3,464.8	1,442.2	4,184.1
Spiny Lobster	903.8	1,042.9	2,140.2	2,362.0	3,962.3
Rock Crab	201.1	642.6	1,219.1	1,867.2	1,813.9
Spot Prawn	55.2	488.8	718.8	401.0	1,526.0
Bay Shrimp	3.7	6.8	0.0	0.0	489.5
Ridgeback Prawn	0.0	38.9	321.8	669.0	152.5
Other	0.0	82.4	19.2	85.5	347.6
Total	16,506.9	10,699.5	23,380.7	17,670.9	28,749.7
TUNA					
Yellowfin	141,099.4	149,560.2	178,485.0	18,061.6	19,719.9
Bonito	2,194.3	9,463.6	4,511.5	712.3	1,934.8
Albacore	26,428.3	12,237.9	15,156.0	8,997.7	1,794.9
Bluefin	5,375.5	9,753.4	5,185.3	3,576.3	1,786.2
Skipjack	40,703.3	41,480.0	145,883.7	2,335.1	1,676.4
Other	11.5	291.8	2,055.2	1,102.1	83.7
Total	215,812.3	222,786.9	351,276.7	34,785.1	26,995.9
ECHINODERMS					
Sea Urchin	0.0	1,493.1	5,813.5	5,876.3	24,714.8
Other	0.0	0.0	8.6	18.3	35.9
Total	0.0	1,493.1	5,822.1	5,894.6	24,750.7
ROUNDFISH					
Rockfish:					
Thornyhead	0.0	0.0	1,228.0	1,971.7	4,575.0
Sculpin	156.3	172.7	80.9	37.2	165.9
Other	2,777.4	7,808.5	12,302.9	12,991.4	12,199.9
Subtotal	2,933.7	7,981.2	13,611.8	15,000.3	16,940.8
Sablefish	1,075.6	3,401.1	2,781.8	3,432.1	3,487.2
Pacific Whiting	0.7	4.9	172.7	479.4	777.7
Total	4,010.0	11,387.2	16,566.3	18,911.8	21,205.7
PELAGIC WETFISH					
Pacific Herring	124.0	533.7	26,514.7	7,325.2	7,014.0
Mackerel	6,503.3	4,149.8	15,440.4	9,511.5	5,775.8
Northern Anchovy	7,266.7	12,166.3	4,039.5	338.8	604.1
Pacific Sardine	341.2	0.7	6.7	1.7	178.6
Total	14,235.2	16,850.5	46,001.3	17,177.2	13,572.5
SALMON					
Chinook	N/A	N/A	N/A	N/A	11,299.7
Coho	N/A	N/A	N/A	N/A	621.4
Other	N/A	N/A	N/A	N/A	125.2
Total	17,183.7	16,936.6	21,233.4	14,239.9	12,046.3
FLATFISH					
Dover Sole	4,153.4	6,090.4	5,803.6	7,651.9	3,681.7
California Halibut	307.2	870.7	1,636.6	2,777.6	2,126.7
Petrale Sole	1,788.7	1,902.9	1,692.4	1,694.5	1,220.6
English Sole	1,090.4	1,936.7	2,125.0	970.9	682.6
Sanddab	236.8	459.2	665.4	449.2	437.0
Rex Sole	639.4	739.3	1,006.6	860.1	428.3
Sand Sole	78.2	94.0	217.5	217.8	156.7
Other	77.5	254.1	390.8	261.8	95.4
Total	8,371.6	12,347.3	13,537.9	14,883.8	8,829.0

SMB-26966

Table 2. (continued)

Species	1970	1975	1980	1985	1990
MOLLUSKS					
Market Squid	2,245.8	2,007.9	4,812.9	4,517.9	4,683.7
Abalone:					
Red	N/A	1,415.6	1,622.8	1,545.0	1,845.9
Black	N/A	555.1	971.7	956.2	381.1
Green	N/A	331.4	223.0	124.9	178.9
Pink	N/A	908.6	461.3	314.1	140.0
Other	N/A	165.4	8.4	16.2	1.9
Subtotal	3,191.7	3,376.1	3,287.2	2,956.4	2,547.8
Other	3,528.6	2,700.7	1,962.7	176.1	58.0
Total	8,966.1	8,084.7	10,062.8	7,650.4	7,289.5
SWORDFISH	1,798.8	3,392.9	4,983.4	16,336.3	7,140.0
NEARSHORE FISHES					
Lingcod	467.2	1,025.2	1,046.9	555.2	931.2
Calif. Sheephead	1.3	2.7	5.2	22.8	456.4
White Croaker	150.2	226.4	484.3	639.2	341.2
White Seabass	1,300.9	1,613.3	1,903.6	294.6	287.0
Other	400.2	357.4	587.8	431.0	300.9
Total	2,319.8	3,225.0	4,027.8	1,942.8	2,316.7
HAGFISH	0.0	0.0	0.0	0.0	2,118.2
SHARKS/RAYS/SKATES					
Mako Shark	N/A	N/A	157.8	234.7	741.8
Common Thresher Shark	N/A	N/A	1,960.2	2,200.5	641.3
Pacific Angel Shark	N/A	N/A	47.3	700.9	164.7
Soupfin Shark	N/A	N/A	126.7	257.6	102.7
Other	N/A	N/A	1,307.6	298.4	155.6
Total	182.9	318.5	3,599.6	3,692.1	1,806.1
HERRING ROE ON KELP	0.0	0.0	0.0	0.0	1,525.4
SMELTS	269.1	201.6	226.2	310.0	235.0
SUBTOTAL	289,656.4	307,723.8	500,718.2	153,494.9	158,580.7
OTHER	894.1	175.8	403.2	506.6	270.6
GRAND TOTAL	290,550.5	307,899.6	501,121.4	154,001.5	158,851.3

Imports and Exports. The U.S. has experienced a persistent trade deficit with regard to seafood products. The value of U.S. imports of edible fishery products more than doubled from $2.4 billion in 1970 to $5.2 billion in 1990. Exports, although significantly lower in value than imports, increased almost tenfold from $0.3 billion in 1970 to $2.8 billion in 1990 (Table 3).

California's seafood trade deficit is disproportionately large. In 1990, the value of imported seafood products exceeded the value of exported products by two to one for the U.S. as a whole (Table 4) and by almost eight to one for California (Tables 5 and 6). About 28 percent ($1.5 billion) of the imported value of fishery products in 1990 entered the U.S. at a California port. By comparison, California's share of U.S. exports in 1990 was a relatively modest seven percent ($0.2 billion).

The past two decades have seen the development of a global market for fishery products and the increasing prominence of Pacific Rim countries as trading partners. Whereas 29 percent of the value of U.S. exports involved trade with Asia in 1970, this proportion had increased to 71 percent by 1990 (Table 3). Our major trading partners in 1990 were Japan ($1,785.9 million) and Canada ($313.6 million). The import picture is more diverse. In 1990, Asia and North America each accounted for about one-third of the value of U.S. imports (Table 3). More than half of U.S. imports in 1990 originated from the following five countries: Canada ($1,174.5 million), Thailand ($592.2 million), China ($399.4 million), Ecuador ($340.6 million) and Mexico ($278.9 million).

The species composition of imports and exports differs somewhat between California and the U.S. as a whole. Shrimp accounted for 52 percent of the value of foreign imports into California (Table 4) and 31 percent of imports into the U.S. (Table 6) in 1990. Fresh and frozen salmon accounted for percent of the total value of U.S. exports (Table 6) but only four percent of the value of California's exports (Table 5). Fresh sea urchin was California's major exported product in 1990, accounting for 23 percent of the value of all seafood exported from the State (Table 5).

The seafood industry in California has created business opportunities for numerous processors, importers, brokers, traders and distributors. While the import/export figures (Tables 4 and 5) are indicative of the size of the seafood market in California, the complex and circuitous interactions among

SMB-26967

middlemen make it difficult to trace imports and exports to their final destination. Imports are not necessarily consumed in the state of entry. For instance, some seafood imports that enter the U.S. at Nogales, Arizona and Honolulu, Hawaii likely end up in California markets. In addition, it is not safe to assume that exports from a state were necessarily produced within that state. For instance, much of the abalone exported from California is harvested in Mexico and funneled to other countries via California.

Despite the difficulty of determining exactly how much of the seafood imported into the U.S. ends up in California markets, available information suggests that Californians rely heavily on imports to satisfy their substantial demand for seafood. By one estimate, less than 10 percent of the seafood sold in California is derived from California fisheries; 13 percent comes from Pacific Northwest and Alaska fisheries, and most of the remainder consists of foreign imports.

Table 3. Value in 1990-equivalent dollars of U.S. imports/exports of edible fishery products by continent of origin/destination in 1970, 1975, 1980, 1985 and 1990 ($1,000's).

IMPORTS FROM:	1970	1975	1980	1985	1990
Asia	587,756	696,697	993,671	1,374,528	1,954,106
North America	971,795	1,391,666	1,798,200	1,732,183	1,729,076
South America	220,344	312,849	474,884	707,176	764,016
Europe	304,309	614,229	612,851	762,636	487,013
Australia	183,455	160,851	258,673	274,233	262,376
Africa	106,531	145,092	116,266	86,141	36,578
TOTAL	2,374,190	3,321,384	4,254,545	4,936,897	5,233,165

EXPORTS TO:	1970	1975	1980	1985	1990
Asia	85,140	190,190	706,158	881,539	1,983,666
Europe	112,769	263,625	393,907	150,043	425,523
North America	86,077	185,623	273,014	166,517	343,980
Australia	4,409	7,196	37,318	25,392	20,493
Africa	1,283	1,482	10,551	1,794	3,611
South America	1,614	1,399	13,522	1,872	2,177
TOTAL	291,292	649,515	1,434,470	1,227,157	2,779,450

Table 4. Value of 20 top imports of edible fish and fish products into California from foreign countries in 1990 ($1,000's).[1]

Product Category	Value
Shrimp, frozen	774,940
Misc., frozen	129,912
Lobster, frozen	91,178
Tuna, canned	76,547
Tuna, prepared	64,387
Mollusk, frozen	45,299
Abalone, prepared	35,209
Misc., fresh	23,377
Mollusk, live	19,291
Shrimp, canned	18,263
Squid, frozen	15,770
Oyster, canned	14,828
Crab, canned	13,667
Sardine, prepared	13,003
Tuna, fresh	11,941
Misc., prepared	10,799
Salmon, fresh	10,524
Crab, frozen	8,880
Clams, canned	7,724
Crustacean, frozen	7,715
Other	97,746
TOTAL	1,491,000

[1]Source: Unpublished data from U.S. Bureau of the Census.

Table 5. Value of 20 top exports of edible fish and fish products from California to foreign countries in 1990 ($1,000's).[1]

Product Category	Value
Sea urchin, fresh	44,436
Abalone, prepared	30,392
Misc., frozen	15,750
Cod, frozen	11,235
Roe, frozen	9,695
Lobster, frozen	9,383
Shrimp, frozen	7,344
Misc., dried	7,257
Squid, frozen	6,793
Herring, frozen	6,726
Salmon, frozen	5,928
Squid, prepared	4,772
Tuna, fresh	3,012
Clams, frozen	2,263
Mollusk, prepared	2,175
Salmon, canned	1,900
Crab, frozen	1,868
Salmon, fresh	1,855
Shrimp, canned	1,491
Sablefish, frozen	1,470
Other	17,255
TOTAL	193,000

[1]Source: Unpublished data from U.S. Bureau of the Census.

SMB-26968

Table 6. Value of U.S. exports, imports and net exports of fishery products in 1990, by product category ($1,000's).

Product Category	Exports	Imports	Net Exports
FRESH & FROZEN:			
Shrimp	112,212	1,639,181	-1,526,969
Fillets	66,320	809,932	-743,612
Lobster	82,622	439,972	-357,350
Tuna	45,085	339,300	-294,215
Blocks	214,679	373,292	-158,613
Scallop	19,518	130,453	-110,935
Groundfish[1]	298,568	79,987	218,581
Salmon	666,583	252,880	413,703
Other Fish and Shellfish	814,885	456,311	358,574
Total	2,320,472	4,521,308	-2,200,836
CANNED:			
Salmon	104,277	4,241	100,036
Tuna	13,211	293,873	-280,662
Other	68,140	244,510	-176,370
Total	185,628	542,624	-356,996
CAVIAR & ROE	223,836	15,007	208,829
CURED	32,831	118,581	-85,750
OTHER	16,683	35,645	-18,962
GRAND TOTAL	2,779,450	5,233,165	-2,453,715

[1]"Groundfish" includes all fresh and frozen product forms (except fillets and blocks) of cod, haddock, hake, pollock, sablefish and flatfish. "Fillets"and "Blocks" cover a variety of species, including groundfish.

Demand

During 1986-1988, U.S. consumption of fish and shellfish averaged 45.2 pounds per capita (live weight equivalent). Similar consumption rates can be found in Western Europe and Canada. Consumption rates in northern Europe and industrialized Asian countries are two to four times the U.S. average, while consumption rates in Mexico and other less industrialized countries tend to fall below the U.S. average (Table 7).

Consumption of commercial finfish and shellfish in the U.S. (edible meat) increased from about 24.0 billion pounds in 1970 to 38.8 billion pounds in 1990. The reasons for this are twofold: a 23 percent increase in the U.S. population and a 31 percent increase in per capita consumption, from 11.8 pounds in 1970 to 15.5 pounds in 1990. About two-thirds of total consumption is accounted for by fresh and frozen products (Table 8).

Assuming that per capita seafood consumption in California is equal to the national averages described in Table 8, total consumption in California (edible meat) is estimated to have increased from approximately 2.4 billion pounds in 1970 to 4.5 billion pounds in 1990. These, however, should be considered conservative estimates, since the strong seafood preferences exhibited by sizeable segments of California's population (e.g., upscale health-conscious consumers, Asian immigrants) suggest that per capita consumption in California likely exceeds the national average.

Table 7. Annual per capita consumption of fish and shellfish in selected countries, 1986-88 average (pounds live weight equivalent).

Country	Pounds Live Weight
Iceland	203.7
Japan	157.0
Portugal	132.5
Hong Kong	112.2
Republic of Korea	109.3
Norway	97.7
Spain	83.8
France	63.9
Canada	59.3
Peru	51.4
United States	**45.2**
United Kingdom	42.3
German Democratic Republic	33.5
Mexico	21.6
People's Republic of China	17.6
Brazil	14.6

Table 8. U.S. annual per capita consumption of commercial fish and shellfish by product category in 1970, 1975, 1980, 1985 and 1990 (pounds edible meat).

Product Category	1970	1975	1980	1985	1990
Fresh and Frozen	6.9	7.5	7.9	9.8	10.1
Canned	4.5	4.3	4.3	5.0	5.1
Cured	0.4	0.4	0.3	0.3	0.3
TOTAL	11.8	12.2	12.5	15.1	15.5

Outlook

California's commercial fishing industry, once dominated by the tuna fishery, has evolved into a more heterogeneous mix of smaller fisheries. Many of these fisheries have developed in response to demand in Pacific Rim countries (most notably Japan). Future fishery development in the State will depend largely on the ability of the industry to compete in the global seafood market. This ability will depend, not only on the quantity and quality of domestically caught seafood, but also on success in overcoming barriers to trade.

The dory fleet at Newport Beach where fishermen have marketed their catch directly to consumers for many decades.

SMB-26969

Commercially caught seafood must also compete with aquaculture products for the consumer's dollar. Aquaculture contributes significantly to the worldwide trade in seafood products. While the competition offered by farm-raised imports (particularly salmon and shrimp) probably reduces the ex-vessel prices received by U.S. fishermen, it also provides benefits to U.S. consumers in the form of lower seafood prices.

In addition to market pressures, California's commercial fisheries face growing competition from other users, including sport anglers and marine mammals (most notably sea otters and sea lions), for limited marine resources. Activities that alter the marine environment (such as oil and gas development, discharge of sewage, thermal and chemical wastes, diversion of water from instream to agricultural and other uses, dredging of harbors, elimination of wetlands, and other forms of coastal development) also affect the abundance of marine resources.

Seafood safety is also an important health and economic issue. Quality control from harvest to market, and adequate inspection, provide important safeguards. However, even isolated instances of tainted seafood can erode consumer confidence, with significant repercussions for the entire industry.

Cynthia Thomson
National Marine Fisheries Service

John Dentler
National Marine Fisheries Service

SMB-26970

APPENDIX

HISTORICAL REVIEW OF LANDINGS, 1916-1969 AND 1970-1991

Unless noted otherwise, the data used in this historical review comes from the California Department of Fish and Game. The 1916-1969 data are reproduced directly from the 1971 edition of *California's Living Marine Resources and Their Utilization.*

The reader should be aware that over the years reporting categories and practices have changed. For the 1970-1991 historical review we have included most important species which have reliable landings figures. Most changes in reporting practices occurred in 1977 and 1987 when more species were reported individually (sharks, rockfish, surfperches, salmon, etc.). For groups of species which are likely to be incorrectly recorded, such as the rockfishes, smelts and surperches, we have aggregated the landings figures for 1970-1991. The complete landings figures are available from the California Department of Fish and Game.

SMB-26971

KELP HARVEST IN TONS

Year	Open Beds	Leased Beds	Total Tons
1916	134,537.00	----	134,537.00
1917	394,974.00	----	394,974.00
1918	395,098.00	----	395,098.00
1919	16,673.00	----	16,673.00
1920	25,464.00	----	25,464.00
*			
1931	----	260.00	260.00
1932	301.61	10,013.08	10,314.69
1933	52.75	21,568.65	21,621.40
1934	1,827.21	14,052.57	15,879.78
1935	----	30,601.83	30,601.83
1936	14,336.70	34,980.34	49,317.04
1937	9,613.79	34,340.65	43,953.35
1938	18,284.06	29,413.25	47,697.31
1939	25,546.30	31,189.70	56,736.00
1940	33,322.20	25,682.20	59,004.40
1941	36,103.00	19,614.00	55,717.00
1942	44,880.11	17,017.65	61,897.76
1943	19,547.44	28,410.86	47,958.30
1944	22,710.50	30,319.40	53,029.90
1945	37,541.30	21,639.90	59,181.20
1946	60,384.00	30,683.60	91,068.50
1947	46,028.80	28,207.80	74,236.60
1948	50,966.10	27,675.00	78,641.10
1949	56,076.00	27,270.00	83,346.00
1950	49,955.00	50,647.00	100,602.00
1951	30,318.00	84,442.00	114,760.00
1952	37,906.00	72,252.50	110,158.50
1953	37,172.50	89,476.50	126,649.00
1954	40,269.00	65,946.50	106,215.50
1955	38,992.00	85,071.00	124,063.00
1956	35,476.50	82,339.00	117,815.50
1957	32,810.75	61,396.50	94,207.25
1958	41,105.75	72,955.75	114,061.50
1959	42,289.65	47,309.45	89,599.10
1960	61,914.95	58,384.85	120,299.80
1961	71,952.70	57,303.30	129,256.00
1962	86,227.70	54,005.10	140,232.80
1963	57,517.00	63,514.80	121,031.80
1964	35,592.90	91,660.85	127,253.75
1965	33,464.10	101,664.90	135,129.00
1966	11,100.70	108,363.20	119,463.90
1967	9,531.00	122,164.00	131,495.00
1968	20,388.20	114,465.15	134,853.35
1969	10,028.70	121,210.50	131,239.20

* No data available 1921-1930.

TOTAL YEARLY LANDINGS AND SHIPMENTS IN POUNDS

Year	California landings*	Shipments other than tuna†	Total landings and shipments other than tuna	Tuna shipments‡	Grand total
1916	95,002,695	----	95,002,695	----	95,002,695
1917	209,876,670	----	209,876,670	----	209,876,670
1918	261,134,265	----	261,134,265	----	261,134,265
1919	266,270,133	107	266,270,240	----	266,270,240
1920	222,004,376	951	222,004,376	----	222,004,376
1921	135,346,435	1,391	135,347,826	----	135,347,826
1922	182,343,333	----	182,343,333	----	182,343,333
1923	253,874,581	----	253,874,581	----	253,874,581
1924	340,445,919	----	340,445,919	----	340,445,919
1925	437,502,232	----	437,502,232	----	437,502,232
1926	394,964,393	----	394,964,393	----	394,964,393
1927	487,088,551	----	487,088,551	77,592	487,166,143
1928	578,887,037	857,306	579,744,343	3,782,408	583,526,751
1929	850,953,251	----	850,953,251	5,900,804	856,854,055
1930	695,147,535	32,105	695,179,640	7,009,155	702,188,795
1931	495,448,900	----	495,448,900	6,940,975	502,389,875
1932	552,617,747	----	552,617,747	3,521,316	556,139,063
1933	817,715,982	----	817,715,982	4,089,034	821,805,016
1934	1,384,827,500	----	1,384,827,500	5,970,654	1,390,798,154
1935	1,442,032,007	----	1,442,032,007	5,984,564	1,448,016,571
1936	1,760,370,876	----	1,760,370,876	4,529,014	1,764,899,890
1937	1,351,256,911	----	1,351,256,911	11,726,806	1,362,983,717
1938	1,300,257,401	----	1,300,257,401	10,338,267	1,310,595,668
1939	1,479,045,931	----	1,479,045,931	7,488,975	1,486,534,906
1940	1,293,981,291	----	1,293,981,291	3,536,372	1,297,517,663
1941	1,527,760,007	----	1,527,760,007	1,132,184	1,528,892,191
1942	1,172,943,617	----	1,172,943,617	470,506	1,173,414,123
1943	1,234,049,119	----	1,234,049,119	----	1,234,049,119
1944	1,456,919,970	----	1,456,919,970	2,535,547	1,459,455,517
1945	1,216,391,831	----	1,216,391,831	108,758	1,216,500,589
1946	919,822,188	----	919,822,188	----	919,822,188
1947	795,172,919	----	795,172,919	326,160	795,499,079
1948	899,070,526	73,467	899,143,993	1,322,926	900,466,919
1949	1,132,620,348	1,293,855	1,133,914,203	1,424,487	1,135,338,690
1950	1,344,358,573	6,399,233	1,350,757,806	15,918,589	1,366,676,395
1951	865,749,226	4,638,919	870,388,145	33,726,242	904,114,387
1952	658,838,075	5,192,573	661,030,648	33,965,725	694,996,373
1953	547,602,957	8,040,854	555,643,811	63,075,605	618,919,416
1954	625,835,447	1,677,816	627,513,263	85,897,121	713,410,384
1955	603,117,051	2,735,682	605,852,733	104,860,721	710,713,454
1956	678,552,376	2,398,474	680,950,850	91,600,457	772,551,307
1957	628,003,175	3,858,296	631,861,471	106,688,913	738,550,384
1958	676,170,923	3,071,482	679,242,405	153,676,658	832,919,063
1959	529,242,200	1,321,722	530,563,922	182,859,114	713,423,036
1960	543,402,951	1,535,272	544,938,223	149,724,849	694,663,072
1961	599,263,509	2,164,041	601,427,550	123,825,921	725,253,471
1962	521,439,230	1,077,215	522,516,445	140,590,162	663,106,607
1963	509,718,393	744,927	510,463,320	82,435,547	592,898,867
1964	493,140,709	1,250,354	494,391,063	96,739,561	591,130,624
1965	453,268,232	----	453,268,232	91,211,669	544,479,901
1966	458,440,080	----	458,440,080	133,093,337	591,533,417
1967	803,893,182	----	803,893,182	85,134,479	589,027,661
1968	445,307,390	----	445,307,390	121,906,187	567,213,577
1969	576,735,857	----	576,735,857	96,057,454	672,793,311

* California landings include some shipments of species other than tuna for the period 1916 through 1947.
† Shipments other than tuna are incomplete prior to 1948, minimal from 1948 through 1964, and unavailable from 1965 through 1968.
‡ Tuna shipments do not balance to figures given in the tuna tables because shipments of bigeye and unclassified tuna are included here.

YEARLY LANDINGS IN POUNDS
Crustaceans

Year	Market crab	Rock crab	Spiny lobster	Bay shrimp	Ocean shrimp	Spot prawn
1916	1,296,912	....	250,632	411,847	....	....
1917	2,580,840	....	355,259	605,004	....	....
1918	1,619,280	....	195,750	722,178	....	....
1919	1,304,904	....	256,894	747,023	....	....
1920	1,220,568	....	247,156	817,091	....	....
1921	800,952	....	334,271	907,467	....	1,006
1922	860,328	....	276,310	990,349	....	....
1923	1,075,800	....	384,381	1,113,358	....	....
1924	1,506,816	....	294,356	1,551,086	....	....
1925	3,234,312	....	432,059	1,460,234	....	....
1926	3,296,280	....	442,198	1,431,511	....	....
1927	2,960,712	....	508,123	1,897,365	....	....
1928	3,574,464	270	355,800	2,280,871	....	....
1929	1,792,776	....	396,764	3,054,748	....	....
1930	1,992,384	12	374,460	2,687,831	....	8,736
1931	2,231,384	56	383,697	1,584,783	....	4,114
1932	2,433,987	145	319,307	2,681,807	....	982
1933	3,208,494	14,818	380,014	2,087,052	....	798
1934	3,768,081	21,570	360,051	1,783,663	....	910
1935	3,680,188	12,817	371,661	3,445,091	....	2,351
1936	2,311,802	16,202	414,183	2,240,849	....	1,861
1937	1,027,753	1,710	393,242	1,108,761	....	3,041
1938	3,873,600	3,847	308,378	1,847,926	....	3,285
1939	3,953,361	3,984	376,928	1,175,979	....	4,271
1940	3,151,014	3,460	281,102	1,080,190	....	2,361
1941	4,260,340	2,645	357,334	952,152	....	5,387
1942	2,414,110	80	168,641	800,958	....	....
1943	2,315,338	....	298,377	253,215	....	43
1944	2,934,776	540	512,490	291,974	....	....
1945	4,334,383	12,188	478,819	382,147	....	1,452
1946	9,624,368	11,600	600,272	432,145	....	5,178
1947	10,733,398	15,244	593,401	841,086	....	1,687
1948	11,892,891	20,938	563,520	926,707	....	2,771
1949	11,115,476	18,630	834,558	800,441	....	3,952
1950	11,704,648	20,007	933,449	913,181	....	5,790
1951	11,568,353	22,592	824,611	931,323	....	2,604
1952	12,997,451	16,977	807,070	913,008	205,485	3,016
1953	8,278,519	40,300	749,245	732,308	287,410	2,723
1954	7,829,651	39,058	901,293	744,768	296,797	2,695
1955	6,119,320	54,051	858,416	682,731	838,656	1,182
1956	14,320,549	59,171	735,809	718,908	1,108,519	1,233
1957	19,118,484	151,131	647,281	192,814	1,370,641	767
1958	17,282,766	160,902	632,018	45,955	1,728,680	911
1959	17,262,261	129,534	505,947	35,011	1,785,228	....
1960	14,876,148	120,903	351,032	1,580	2,026,787	147
1961	11,711,327	151,782	412,453	2,050	2,002,700	....
1962	3,222,580	200,304	515,816	1,075	1,782,955	694
1963	1,931,461	240,811	584,102	1,225	2,093,063	8,445
1964	1,815,363	263,885	446,655	....	1,100,147	5,775
1965	4,803,000	328,680	480,325	10,765	1,422,304	697
1966	12,376,390	330,843	489,088	4,165	1,190,197	3,575
1967	11,716,488	324,386	449,874	19,771	1,412,513	2,690
1968	16,015,581	351,657	312,483	10,465	2,274,770	7,239
1969	7,938,990	504,076	309,472	8,041	2,947,563	5,073

YEARLY LANDINGS IN POUNDS
Mollusks

Year	Abalone	Eastern oyster	Pacific oyster	Squid
1916	762,001	1,969,519	....	275,620
1917	637,780	816,276	....	439,438
1918	602,919	1,360,685	....	361,714
1919	759,203	1,615,425	....	3,698,242
1920	806,716	1,121,160	....	508,199
1921	1,481,170	767,124	....	432,559
1922	1,523,394	743,352	....	209,641
1923	1,555,134	688,103	....	1,180,446
1924	2,241,812	526,775	....	6,831,029
1925	2,352,861	569,003	....	1,891,220
1926	2,060,770	610,422	....	3,135,561
1927	2,816,530	554,921	....	6,014,113
1928	2,066,243	726,298	....	1,351,992
1929	3,438,858	437,215	....	4,660,572
1930	3,176,813	582,367	....	10,969,462
1931	3,262,160	456,255	....	1,738,621
1932	2,817,345	290,571	....	4,229,743
1933	2,756,188	340,003	68,702	824,543
1934	3,223,492	518,600	50,240	1,530,150
1935	3,870,921	346,682	299,375	815,944
1936	3,302,105	318,012	310,683	945,439
1937	2,863,175	364,049	680,081	501,662
1938	2,121,468	280,742	1,207,421	1,599,319
1939	1,804,440	130,684	1,659,355	1,162,056
1940	1,724,084	113,360	1,292,505	1,800,632
1941	1,002,330	102,040	1,717,781	1,431,130
1942	164,462	92,426	609,233	943,783
1943	680,274	79,878	741,105	9,164,361
1944	1,630,402	106,896	636,686	10,936,595
1945	2,429,312	65,581	909,738	15,225,664
1946	2,095,762	84,603	88,006	38,024,528
1947	2,669,285	133,779	46,035	14,542,649
1948	3,195,852	331,238	166,524	19,255,687
1949	3,599,998	46,535	235,134	6,859,129
1950	3,954,791	117,079	143,612	5,906,335
1951	4,084,190	178,716	133,700	12,382,869
1952	4,784,033	163,485	190,638	3,670,023
1953	4,720,350	129,733	161,520	8,017,114
1954	4,099,625	124,928	460,920	8,155,105
1955	4,185,875	140,918	1,635,067	14,271,968
1956	4,284,063	142,181	6,101,220	19,483,984
1957	5,421,914	119,834	11,067,640	12,449,121
1958	4,224,018	32,087	9,590,062	7,457,418
1959	4,501,827	8,733	13,759,192	19,653,013
1960	4,266,408	2,072	10,686,856	2,501,520
1961	4,553,766	105,726	10,047,650	10,285,791
1962	4,183,181	95,100	11,043,732	9,368,149
1963	4,333,879	*13,502	*1,255,515	11,560,854
1964	4,079,223	4,910	1,354,737	16,433,024
1965	4,576,084	7,982	1,054,810	18,610,893
1966	4,963,556	12,925	787,502	19,025,879
1967	4,421,581	12,710	729,431	19,601,922
1968	4,474,842	16,166	645,553	24,932,713
1969	3,658,078	16,952	696,093	20,779,382

* Beginning in 1963 oyster landings have been reported as the weight of the packed meats rather than as weight in the shell.

YEARLY LANDINGS AND SHIPMENTS IN POUNDS
Albacore tuna

Year	California waters	North of state	South of state	Total landings	Shipments	Total pounds
1916	22,899,309	....	....	22,899,309	....	22,899,309
1917	30,556,242	....	....	30,556,242	....	30,556,242
1918	7,263,895	....	1,527	7,265,422	....	7,265,422
1919	13,553,025	....	77,874	13,630,899	....	13,630,899
1920	18,876,647	....	....	18,876,647	....	18,876,647
1921	15,274,528	....	2,199	15,276,727	....	15,276,727
1922	13,231,823	....	....	13,231,823	....	13,231,823
1923	12,488,199	....	26,634	12,514,833	....	12,514,833
1924	17,280,340	....	415,018	17,695,362	....	17,695,362
1925	21,684,942	....	521,981	22,206,923	....	22,206,923
1926	2,469,861	....	60	2,469,921	....	2,469,921
1927	4,455,372	....	123,995	4,579,367	77,592	4,656,959
1928	283,321	....	....	283,321	3,782,408	4,065,729
1929	269,056	....	45	269,101	5,841,229	6,110,330
1930	283,117	....	....	283,117	7,005,568	7,288,685
1931	37,322	....	....	37,322	6,939,079	6,976,401
1932	619,694	....	....	619,694	2,467,521	3,087,215
1933	467	....	....	467	2,793,068	2,794,452
1934	119,829	....	....	119,829	4,167,467	4,287,296
1935	2,386,249	....	61,279	2,447,528	3,231,265	5,678,793
1936	945,595	....	....	945,595	1,510,409	2,456,004
1937	2,020,016	....	....	2,020,016	2,723,093	4,743,709
1938	4,789,880	1,995,101	20,919	6,814,900	6,759,735	13,574,635
1939	8,264,109	1,732,006	4,187	10,000,362	6,422,872	16,423,234
1940	2,387,254	1,552,504	880	3,940,038	3,137,096	7,078,334
1941	3,016,065	325,144	....	3,341,209	973,299	4,314,508
1942	7,998,144	....	2,623,216	10,621,360	470,506	11,091,866
1943	11,886,148	....	9,498,716	21,384,864	....	21,384,864
1944	8,679,273	....	9,774,659	18,453,932	2,535,547	20,989,479
1945	8,777,991	232,850	12,214,180	21,225,021	108,758	21,333,779
1946	9,116,647	2,434	8,958,818	18,077,899	....	18,077,899
1947	7,395,785	13,867	5,762,119	13,171,751	255,530	13,427,281
1948	10,499,390	55,167	25,901,589	36,456,146	1,153,643	37,609,789
1949	20,417,078	46,030	23,541,172	44,006,280	284,040	44,290,320
1950	38,139,296	30,396	23,575,512	61,745,204	4,378,420	66,123,624
1951	13,284,600	9,150	17,621,586	30,915,342	17,520,891	48,436,233
1952	23,103,074	3,389	26,697,061	49,803,524	22,525,248	72,328,772
1953	13,297,627	47,468	20,490,810	33,835,905	46,186,816	80,022,721
1954	14,289,095	....	11,818,195	26,107,290	38,466,383	64,573,673
1955	9,312,029	....	19,690,209	29,002,298	44,844,675	73,846,973
1956	15,874,652	115,985	21,064,574	37,055,211	20,322,775	57,377,986
1957	22,613,429	....	20,911,816	43,525,245	39,564,027	83,089,272
1958	25,387,030	1,075,988	724,753	27,187,777	27,485,321	54,673,098
1959	32,522,331	218,133	....	32,740,464	29,741,982	62,482,446
1960	32,056,980	69,104	2,986,543	35,112,627	36,339,548	71,452,175
1961	20,594,360	143,709	8,388,175	29,123,244	30,291,007	59,414,251
1962	32,046,366	....	4,576,009	36,622,375	36,731,754	73,354,129
1963	41,925,739	....	6,933,839	48,859,578	16,945,225	65,804,803
1964	33,807,847	....	8,683,164	42,551,011	32,169,953	74,720,964
1965	19,650,865	230,603	3,136,818	23,217,984	44,807,150	68,025,134
1966	16,141,399	672,854	1,374,959	18,189,212	55,719,626	73,908,838
1967	15,184,473	2,387,979	285,471	17,857,923	53,889,762	71,747,685
1968	11,617,055	2,779,876	680,229	15,077,159	61,022,572	76,099,731
1969	11,162,742	3,026,404	533,249	14,722,395	56,333,031	71,055,426

YEARLY LANDINGS AND SHIPMENTS IN POUNDS
Bluefin tuna

Year	California waters	North of state	South of state	Total landings	Shipments	Total pounds
1919	14,990,860	....	....	14,990,860	....	14,990,860
1920	10,530,272	....	....	10,530,272	....	10,530,272
1921	1,971,813	....	....	1,971,813	....	1,971,813
1922	2,811,283	....	....	2,811,283	....	2,811,283
1923	3,218,090	....	....	3,218,090	....	3,218,090
1924	3,241,110	....	....	3,241,110	....	3,241,110
1925	3,803,677	....	....	3,803,677	....	3,803,677
1926	6,526,533	....	....	6,526,533	....	6,526,533
1927	4,898,386	....	79	4,898,465	....	4,898,465
1928	13,700,870	....	....	13,700,870	....	13,700,870
1929	7,476,370	....	50,487	7,526,857	....	7,526,857
1930	16,598,892	....	5,322,390	21,921,282	....	21,921,282
1931	2,356,775	....	1,177,255	3,534,030	....	3,534,030
1932	460,044	....	611,162	1,071,206	1,053,795	2,125,001
1933	324,218	....	236,276	560,492	889,336	1,449,828
1934	18,291,721	....	66,107	18,357,828	....	18,357,828
1935	18,495,813	....	6,677,270	25,173,083	146,531	25,319,614
1936	13,808,578	....	5,116,305	18,924,883	745,052	19,669,935
1937	10,822,071	....	1,871,851	12,693,922	524,062	13,217,984
1938	16,512,262	....	1,218,769	17,728,031	4,328	17,732,359
1939	9,318,934	....	2,516,737	11,835,671	44	11,835,715
1940	18,849,968	....	1,120,300	19,970,268	....	19,970,268
1941	8,848,147	....	670,865	9,519,012	....	9,519,012
1942	10,331,506	....	2,513,058	12,844,564	....	12,844,564
1943	7,563,887	....	2,614,881	10,178,768	....	10,178,768
1944	16,083,584	....	4,259,966	20,343,550	....	20,343,550
1945	14,100,476	....	6,493,833	20,594,309	....	20,594,309
1946	15,518,212	....	6,513,590	22,031,802	....	22,031,802
1947	14,755,661	....	6,082,012	20,837,673	....	20,837,673
1948	1,693,760	....	4,835,047	6,528,807	168,180	6,696,987
1949	2,266,236	....	2,123,235	4,389,471	....	4,389,471
1950	9,339	....	2,729,624	2,738,963	107,878	2,846,841
1951	837,209	....	3,025,209	3,862,418	2,112	3,864,530
1952	907,215	....	3,669,470	4,576,685	....	4,576,685
1953	3,903,642	....	5,868,973	9,772,615	62,447	9,835,062
1954	5,647,672	....	15,377,248	21,024,920	771,147	21,795,967
1955	2,477,735	....	11,131,442	13,609,177	343,346	13,952,523
1956	2,612,046	....	10,013,922	12,625,968	162,875	12,788,843
1957	10,462,564	....	9,851,982	20,314,546	323,024	20,637,570
1958	15,609,801	....	15,109,431	30,719,232	757,976	31,477,208
1959	13,073,729	....	2,169,236	15,242,965	554,738	15,797,703
1960	4,339,031	....	7,613,480	11,952,511	1,463,900	13,416,411
1961	13,762,432	....	7,120,218	20,882,650	1,272,540	22,155,190
1962	17,039,651	....	14,160,300	31,199,951	1,919,778	33,119,729
1963	7,130,960	....	23,222,449	30,353,409	2,348,392	32,701,801
1964	4,655,330	....	18,515,928	23,171,258	3,660,681	26,831,939
1965	2,274,674	....	13,653,486	15,928,160	806,346	16,734,506
1966	2,202,585	....	32,617,821	34,820,406	3,118,804	37,939,210
1967	1,791,634	47,532	11,896,429	13,735,595	....	13,735,595
1968	3,737,291	1,125	9,297,859	12,936,275	80,098	13,016,373
1969	798,058	....	14,436,672	15,234,730	372,589	15,607,319

YEARLY LANDINGS AND SHIPMENTS IN POUNDS

Skipjack tuna

Year	California waters	South of state	Total landings	Shipments	Total pounds
1918	3,022,964	..	3,022,964	....	3,022,964
1919	6,880,312	12,115	6,892,427	....	6,892,427
1920	7,942,188	15,089	7,957,277	....	7,957,277
1921	1,134,853	140	1,134,993	....	1,134,993
1922	10,104,563	1,753,270	11,857,833	....	11,857,833
1923	4,579,077	6,883,445	11,462,522	....	11,462,522
1924	1,349,513	2,424,545	3,774,058	....	3,774,058
1925	8,755,478	5,466,975	14,222,453	....	14,222,453
1926	14,217,018	6,734,330	20,951,348	....	20,951,348
1927	5,802,598	28,003,362	33,805,960	....	33,805,960
1928	4,394,938	11,551,972	15,946,910	....	15,946,910
1929	8,032,077	18,974,936	27,007,013	59,575	27,066,588
1930	3,015,275	17,470,312	20,485,587	....	20,485,587
1931	11,965,616	4,541,145	16,506,761	....	16,506,761
1932	375,042	21,261,535	21,636,577	....	21,636,577
1933	10	16,687,298	16,687,308	405,733	17,093,041
1934	....	14,830,194	14,830,194	1,579,245	16,409,439
1935	1,907,916	15,289,270	17,197,186	2,606,768	19,803,954
1936	8,456,781	18,549,354	27,006,105	2,264,925	29,271,030
1937	1,884,148	45,219,944	47,104,092	7,594,903	54,698,995
1938	2,816	22,650,815	22,653,631	3,499,343	26,152,974
1939	3,718,641	27,402,250	30,120,891	1,066,059	31,186,950
1940	2,985,111	53,665,044	56,650,155	260,367	56,910,522
1941	4,214,373	21,371,095	25,585,468	121,596	25,707,064
1942	217,838	38,517,390	38,735,228	....	38,735,228
1943	17,904	28,875,880	28,893,784	....	28,893,784
1944	43,676	29,993,560	30,037,236	....	30,037,236
1945	93,078	33,254,818	33,347,896	....	33,347,896
1946	1,747,060	39,340,934	41,087,994	....	41,087,994
1947	893,046	51,567,122	52,460,168	....	52,460,168
1948	319,194	58,451,409	58,770,603	1,103	58,771,706
1949	26,677	78,495,241	78,521,918	52,739	78,574,657
1950	12,421	124,766,998	124,779,419	3,261,659	128,041,078
1951	590	115,886,258	115,886,848	2,750,824	118,637,672
1952	534	84,528,703	84,529,297	4,362,370	88,891,667
1953	1,307	122,304,876	122,300,183	8,347,730	130,653,019
1954	14,399	153,741,791	153,756,190	15,707,756	169,463,946
1955	1,246	101,889,720	101,890,966	18,634,023	120,524,989
1956	875	120,152,347	120,153,222	15,842,212	135,995,434
1957	353,455	90,194,258	90,547,713	20,888,590	111,436,303
1958	2,488,907	120,278,637	122,767,544	25,300,712	148,158,256
1959	1,365,207	97,100,450	98,465,657	47,728,534	146,194,191
1960	24,199	46,279,405	46,303,694	28,494,941	74,798,635
1961	578	65,402,282	65,402,860	21,344,772	86,747,632
1962	....	92,721,036	92,721,036	6,338,433	99,059,469
1963	2,224,116	94,395,828	96,619,944	9,664,889	106,284,833
1964	3,988	66,054,966	66,058,954	6,495,326	72,554,280
1965	40	84,241,655	84,241,695	5,677,518	89,919,213
1966	173,781	50,915,480	51,089,261	14,136,271	65,225,532
1967	116,902	110,839,399	110,956,301	4,002,499	114,958,800
1968	410,713	58,823,928	59,234,641	1,439,186	60,673,827
1969	74,160	45,840,325	45,914,485	2,765,596	48,680,081

YEARLY LANDINGS AND SHIPMENTS IN POUNDS

Yellowfin tuna

Year	California waters	South of state	Total landings	Shipments	Total pounds
1919	348,081	....	348,081	....	348,081
1920	1,477,905	487,119	1,965,024	....	1,965,024
1921	1,200,600	96,851	1,297,451	....	1,297,451
1922	1,205,023	6,200,256	7,405,279	....	7,405,279
1923	428,896	10,408,029	10,836,925	....	10,836,925
1924	680,759	2,382,639	3,063,398	....	3,063,398
1925	2,963,620	10,274,278	13,237,898	....	13,237,898
1926	2,695,502	9,869,484	12,564,986	....	12,564,986
1927	595,247	25,338,719	25,933,966	....	25,933,966
1928	84,626	32,168,580	32,253,206	....	32,253,206
1929	199,444	37,245,480	37,444,924	....	37,444,924
1930	35,553	56,616,628	56,654,181	3,587	56,657,768
1931	154,024	36,425,456	36,579,480	1,896	36,581,376
1932	165,323	36,758,087	36,923,410	....	36,923,410
1933	6,867	51,068,763	51,075,630	....	51,075,630
1934	19,514	60,893,646	60,913,160	223,942	61,137,102
1935	529,001	71,765,126	72,294,127	....	72,294,127
1936	767,231	77,585,413	78,352,644	8,628	78,361,272
1937	187,732	91,334,726	91,522,458	884,148	92,406,606
1938	10,566	78,277,578	78,288,144	74,861	78,363,005
1939	457,405	109,960,396	110,417,801	....	110,417,801
1940	237,627	113,522,373	113,759,900	138,309	113,898,209
1941	1,799	76,562,732	76,564,531	37,289	76,701,820
1942	1,215	41,465,299	41,466,514	....	41,466,514
1943	2,058	49,259,270	49,261,328	....	49,261,328
1944	45,373	63,098,518	63,143,891	....	63,143,891
1945	4,959	87,326,481	87,331,440	....	87,331,440
1946	32,653	127,214,022	127,246,675	....	127,246,675
1947	3,234	150,385,520	150,388,754	70,630	150,459,384
1948	593	191,723,388	191,723,981	....	191,723,981
1949	9,884	184,514,502	184,524,386	1,087,708	185,612,094
1950	1,461	182,314,373	182,315,834	8,130,632	190,446,466
1951	63	160,246,175	160,246,238	13,422,415	173,668,653
1952	....	178,439,583	178,439,583	7,078,107	185,517,690
1953	102	132,086,244	132,086,346	8,458,606	140,544,952
1954	....	119,401,795	119,401,795	29,701,898	149,103,693
1955	....	122,291,864	122,291,864	40,526,143	162,818,007
1956	120	149,280,874	149,280,994	54,604,513	203,885,507
1957	70,853	136,884,984	136,955,837	46,085,798	182,041,635
1958	417,710	123,001,684	123,419,394	94,655,755	218,075,149
1959	81,676	108,288,171	108,369,847	102,622,211	210,992,058
1960	10,482	189,296,372	189,306,854	83,341,244	272,648,098
1961	....	191,854,056	191,854,056	70,456,206	262,310,262
1962	40	124,020,715	124,020,755	94,128,155	218,148,910
1963	60,220	109,522,946	109,583,166	52,743,056	162,326,222
1964	84	149,020,029	149,020,113	53,835,616	202,855,729
1965	....	156,553,451	156,553,451	39,881,904	196,435,355
1966	2,385	132,592,138	132,594,523	57,250,249	189,844,772
1967	....	140,356,083	140,356,083	26,895,452	167,251,535
1968	98,492	152,928,017	153,026,509	59,211,941	212,238,450
1969	717	204,161,220	204,161,937	36,584,573	240,746,510

SMB-26975

YEARLY LANDINGS IN POUNDS
Pacific bonito

Year	California waters	South of state	Total pounds
1916	465,691	14,715	480,406
1917	889,376	----	889,376
1918	2,265,047	176,667	2,441,714
1919	2,908,745	600,353	3,509,098
1920	672,393	201,255	873,648
1921	241,859	82,878	324,737
1922	894,292	63,650	957,942
1923	478,771	636,476	1,115,247
1924	842,906	202,187	1,045,282
1925	782,868	96,298	879,166
1926	2,942,906	178,698	3,121,604
1927	1,121,476	596,532	1,718,008
1928	1,336,719	770,370	2,107,089
1929	593,588	2,324,658	2,918,544
1930	2,866,496	1,297,764	5,164,260
1931	3,014,135	65,538	3,079,673
1932	1,676,487	1,185,799	2,862,286
1933	1,967,244	284,955	2,252,199
1934	3,003,048	199,646	3,202,694
1935	2,263,740	5,632,744	7,896,484
1936	2,216,679	4,999,237	7,215,916
1937	5,707,212	2,100,858	7,808,070
1938	4,684,570	3,155,423	7,839,993
1939	6,007,240	3,221,626	9,918,875
1940	3,553,121	1,738,019	5,291,140
1941	7,850,496	3,057,106	10,907,602
1942	860,833	789,856	1,650,689
1943	801,535	1,480,764	2,282,299
1944	326,175	492,696	818,871
1945	330,664	2,374,517	2,714,181
1946	582,948	5,042,700	5,625,648
1947	384,327	13,312,856	13,697,183
1948	214,992	8,920,134	9,135,126
1949	99,244	1,730,297	1,829,541
1950	33,456	662,158	695,614
1951	54,047	722,756	776,803
1952	7,504	2,135,013	2,142,517
1953	19,069	3,083,578	3,102,647
1954	218,701	2,100,359	2,319,060
1955	40,354	96,636	136,990
1956	22,491	105,123	127,614
1957	110,174	108,975	219,149
1958	4,804,784	742,022	5,546,806
1959	3,003,058	8,558	3,011,616
1960	1,219,682	30,862	1,250,544
1961	8,439,400	73,572	8,512,972
1962	2,071,998	62,904	2,134,902
1963	4,013,505	9,017	4,022,522
1964	2,606,411	5,858	2,612,269
1965	5,632,399	5,941	5,638,340
1966	18,308,175	840,319	19,148,494
1967	17,841,537	3,377,894	21,219,431
1968	14,903,357	18,572	14,921,929
1969	13,174,505	4,027,342	17,201,847

YEARLY LANDINGS IN POUNDS
Salmon

Year	Coastal ports	Sacramento area ports	Coastal rivers	Total pounds
1916	5,592,216	3,450,786	1,896,692	10,939,594
1917	6,0[illegible]5,997	3,975,487	999,097	11,060,581
1918	5,033,346	6,938,029	1,221,813	13,093,188
1919	7,208,382	4,529,222	1,408,123	13,145,727
1920	6,066,190	3,860,312	1,207,317	11,133,819
1921	4,483,105	2,511,127	996,700	7,990,932
1922	4,338,317	1,765,066	1,131,741	7,235,124
1923	3,736,924	2,243,945	1,109,391	7,090,260
1924	6,374,573	2,640,110	1,000,886	10,015,269
1925	5,481,536	2,778,846	1,265,371	9,525,753
1926	3,863,677	1,261,776	958,626	6,084,079
1927	4,021,600	920,786	889,343	5,511,929
1928	3,444,306	553,777	480,483	4,478,566
1929	4,033,640	581,497	429,714	5,044,871
1930	4,085,650	1,213,698	703,546	6,002,894
1931	3,686,841	941,605	686,065	5,294,511
1932	2,649,204	1,264,987	703,990	4,618,181
1933	3,657,661	454,253	446,520	4,558,434
1934	3,921,530	397,572	----	4,319,102
1935	4,773,112	888,868	----	5,661,980
1936	4,093,475	949,179	----	5,042,654
1937	5,934,996	974,871	----	6,909,867
1938	2,170,921	1,668,376	----	3,839,297
1939	2,238,755	496,933	----	2,735,688
1940	5,160,393	1,515,588	----	6,675,981
1941	2,946,030	844,963	----	3,790,993
1942	4,063,306	2,552,944	----	6,616,250
1943	5,285,527	1,295,424	----	6,580,951
1944	7,021,848	3,265,143	----	10,286,991
1945	7,912,754	5,467,960	----	13,380,714
1946	7,196,527	6,463,245	----	13,659,772
1947	8,104,297	3,380,484	----	11,484,781
1948	5,860,915	1,939,801	----	7,800,716
1949	5,531,021	899,090	----	6,430,111
1950	5,867,346	1,202,890	----	7,070,236
1951	5,849,530	1,343,171	----	7,192,701
1952	6,536,890	738,081	----	7,274,971
1953	7,136,223	869,696	----	8,005,919
1954	8,599,579	900,961	----	9,500,540
1955	9,656,996	2,320,746	----	11,977,742
1956	10,274,902	1,139,585	----	11,414,487
1957	5,176,909	321,824	----	5,498,733
1958	3,656,641	----	----	3,656,641
1959	6,768,699	463	----	6,769,162
1960	6,221,445	----	----	6,221,445
1961	8,637,907	----	----	8,637,907
1962	6,672,861	----	----	6,672,861
1963	7,859,186	----	----	7,859,186
1964	9,481,215	----	----	9,481,215
1965	9,737,775	----	----	9,737,775
1966	9,446,995	----	----	9,446,995
1967	7,401,729	----	----	7,401,729
1968	6,951,931	----	----	6,951,931
1969	6,150,906	----	----	6,150,906

YEARLY LANDINGS IN POUNDS AND TONS
Anchovy, Pacific Herring and Sardine

Year	Anchovy		Pacific herring		Sardine*	
	Pounds	Tons	Pounds	Tons	Pounds	Tons
1916	531,209	266	2,928,591	1,464	15,648,839	7,824
1917	528,753	264	7,435,997	3,718	104,103,331	52,052
1918	868,161	434	7,938,280	3,969	157,652,811	78,826
1919	1,609,548	805	4,289,899	2,145	153,877,179	76,939
1920	569,774	285	274,364	137	118,520,914	59,260
1921	1,946,881	973	542,124	271	59,332,305	29,666
1922	652,516	326	341,621	171	93,399,900	46,700
1923	307,074	154	383,950	192	158,159,356	79,080
1924	346,961	174	435,620	218	242,685,958	121,343
1925	93,071	46	865,774	433	315,294,986	157,648
1926	60,157	30	453,607	227	286,741,250	143,371
1927	368,201	184	1,168,321	584	342,275,269	171,138
1928	357,470	179	1,139,682	570	420,269,665	210,135
1929	382,445	191	957,563	479	651,771,904	325,886
1930	319,861	160	717,634	359	502,062,747	251,031
1931	307,494	154	685,759	343	364,351,801	182,176
1932	299,217	150	765,724	383	422,609,716	211,305
1933	317,292	159	601,445	301	626,397,481	313,199
1934	257,505	129	801,601	401	1,119,931,099	559,966
1935	178,970	90	928,880	464	1,095,758,848	547,879
1936	195,122	98	840,530	420	1,463,543,700	731,772
1937	226,229	113	631,330	316	1,071,490,625	535,745
1938	735,144	368	504,884	252	1,023,389,489	511,695
1939	2,147,901	1,074	302,242	151	1,160,793,581	580,397
1940	6,317,797	3,159	453,193	227	905,973,403	452,987
1941	4,105,382	2,053	789,783	395	1,262,480,393	631,240
1942	1,694,290	847	190,815	95	969,747,099	484,874
1943	1,570,803	785	630,358	315	972,269,915	486,135
1944	3,891,029	1,946	422,290	211	1,147,207,882	573,604
1945	1,616,880	808	460,465	230	846,062,774	422,531
1946	1,921,627	961	481,776	241	510,759,173	255,380
1947	18,940,521	9,470	1,654,850	827	255,513,948	127,757
1948	10,835,930	5,418	8,000,492	4,000	262,037,087	131,018
1949	3,322,273	1,661	379,311	190	633,379,791	316,690
1950	4,878,687	2,439	1,425,351	713	714,523,781	357,261
1951	6,954,852	3,477	4,923,655	2,462	328,900,731	164,450
1952	55,782,870	27,891	9,495,386	4,748	14,330,420	7,165
1953	85,835,478	42,918	7,801,928	3,901	9,468,892	4,734
1954	42,410,364	21,205	911,906	456	136,504,017	68,252
1955	44,691,582	22,346	1,946,821	973	145,607,749	72,804
1956	56,920,585	28,460	1,735,776	868	69,554,345	34,777
1957	40,547,526	20,274	1,188,080	594	45,862,106	22,931
1958	11,602,724	5,801	2,399,730	1,200	207,445,837	103,723
1959	7,173,739	3,587	1,727,013	864	74,366,856	37,183
1960	5,058,603	2,529	1,800,672	900	57,532,719	28,766
1961	7,711,573	3,856	1,401,248	701	43,169,064	21,584
1962	2,764,003	1,382	1,305,569	653	15,362,952	7,682
1963	4,570,380	2,285	630,087	315	7,131,221	3,566
1964	4,975,089	2,488	349,270	175	13,137,483	6,569
1965	5,733,024	2,866	516,319	258	1,924,319	962
1966	62,280,236	31,140	241,973	121	878,359	439
1967	69,609,377	34,805	271,902	136	148,766	74
1968	31,076,116	15,538	357,869	179	124,088	62
1969	135,277,718	67,639	170,532	85	105,273	53

* Includes Reduction Ships.

SEASONAL LANDINGS IN TONS
Sardines

Season*	Reduction ships	San Francisco area	Monterey area	Los Angeles area	San Diego area	Total tons
1916-17	----	----	7,710	17,380	2,440	27,530
1917-18	----	70	23,810	41,340	7,360	72,580
1918-19	----	450	35,750	32,530	6,810	75,540
1919-20	----	1,000	43,040	16,580	6,410	67,030
1920-21	----	230	24,960	11,740	1,520	38,450
1921-22	----	80	16,290	19,220	910	36,500
1922-23	----	110	29,210	33,170	2,620	65,110
1923-24	----	190	45,920	35,040	2,780	83,930
1924-25	----	560	67,310	96,330	8,820	173,020
1925-26	----	560	69,010	61,990	5,710	137,270
1926-27	----	3,820	81,860	64,720	2,110	152,210
1927-28	----	16,690	98,020	67,900	4,650	187,260
1928-29	----	13,520	120,290	119,250	1,420	254,480
1929-30	----	21,960	160,050	140,540	2,620	325,170
1930-31	10,960	25,970	109,620	38,490	80	185,120
1931-32	31,040	21,607	69,078	42,656	264	164,645
1932-33	58,790	18,634	89,599	83,605	82	250,690
1933-34	67,820	36,336	152,480	125,047	1,746	383,429
1934-35	112,040	68,477	230,884	178,818	4,865	595,054
1935-36	150,830	76,147	184,470	138,400	10,651	560,498
1936-37	235,610	141,099	206,706	138,115	4,594	726,124
1937-38	67,580	133,718	104,936	109,947	383	416,564
1938-39	43,890	201,200	180,994	146,403	2,800	575,287
1939-40	----	212,453	227,874	96,827	112	537,266
1940-41	----	118,092	166,698	175,592	1,202	460,584
1941-42	----	186,589	250,287	148,912	1,585	587,373
1942-43	----	115,884	184,399	201,510	2,868	504,661
1943-44	----	126,512	213,616	135,311	2,690	478,129
1944-45	----	136,598	237,246	178,294	2,767	554,905
1945-46	----	84,103	145,619	173,110	951	403,683
1946-47	----	2,869	31,391	194,774	4,768	233,802
1947-48	----	94	17,830	101,184	2,463	121,341
1948-49	----	112	47,862	131,830	3,922	183,726
1949-50	----	17,442	131,769	186,433	3,281	338,925
1950-51	----	12,727	33,699	303,782	2,910	353,088
1951-52	----	83	15,897	111,774	1,351	129,104
1952-53	----	----	49	5,635	27	5,711
1953-54	----	----	58	4,111	323	4,492
1954-55	----	----	656	67,099	510	68,465
1955-56	----	----	518	73,943	----	74,461
1956-57	----	----	63	33,564	16	33,643
1957-58	----	----	17	22,255	----	22,272
1958-59	----	----	24,701	79,264	6	103,971
1959-60	----	----	16,109	21,146	1	37,256
1960-61	----	----	2,340	26,436	102	28,878
1961-62	----	----	2,231	23,295	2	25,528
1962-63	----	----	1,211	2,961	----	4,172
1963-64	----	----	1,015	1,895	32	2,942
1964-65	----	----	308	5,717	78	6,103
1965-66	----	----	151	535	33	719
1966-67	----	----	23	311	10	344
1967-68	----	----	10	61	----	71
1968-69	----	----	----	41	11	52

* Season June through the following May.

SMB-26977

YEARLY LANDINGS IN POUNDS AND TONS
Mackerel

Year	Jack mackerel		Pacific mackerel		Unclassified mackerel		Total	
	Pounds	Tons	Pounds	Tons	Pounds	Tons	Pounds	Tons
1916	....	..	....	..	1,113,998	557	1,113,998	557
1917	....	..	....	..	3,345,563	1,673	3,345,563	1,673
1918	....	..	....	..	4,005,906	2,003	4,005,906	2,003
1919	....	..	....	..	2,654,596	1,327	2,654,596	1,327
1920	....	..	....	..	2,997,308	1,499	2,997,308	1,499
1921	....	..	....	..	2,914,613	1,457	2,914,613	1,457
1922	....	..	....	..	2,466,702	1,233	2,466,702	1,233
1923	....	..	....	..	3,553,954	1,777	3,553,954	1,777
1924	....	..	....	..	3,227,300	1,614	3,227,300	1,614
1925	....	..	....	..	3,506,103	1,753	3,506,103	1,753
1926	235,151	118	3,610,098	1,805	....	..	3,845,249	1,923
1927	462,539	231	4,728,903	2,364	....	..	5,191,442	2,596
1928	538,416	269	35,251,298	17,626	....	..	35,789,744	17,895
1929	698,290	349	57,973,952	28,987	....	..	58,672,242	29,336
1930	368,828	184	16,531,364	8,266	....	..	16,900,192	8,450
1931	563,108	282	14,254,081	7,127	....	..	14,817,189	7,409
1932	536,400	268	12,473,746	6,237	....	..	13,010,185	6,505
1933	1,010,850	505	69,613,680	34,807	....	..	70,624,530	35,312
1934	1,581,274	791	113,818,585	56,924	....	..	115,420,859	57,715
1935	9,983,924	4,992	146,427,202	73,214	....	..	156,411,126	78,206
1936	4,599,382	2,300	100,542,214	50,271	....	..	105,141,596	52,571
1937	6,541,026	3,270	60,936,701	30,468	....	..	67,477,727	33,739
1938	4,133,918	2,067	79,848,015	39,924	....	..	83,981,933	41,991
1939	3,760,155	1,880	80,909,374	40,455	....	..	84,669,529	42,335
1940	1,432,637	716	120,504,412	60,252	....	..	121,937,049	60,968
1941	2,068,685	1,034	78,167,200	39,084	....	..	80,235,885	40,118
1942	5,348,501	2,674	52,553,663	26,277	....	..	57,902,164	28,951
1943	12,698,974	6,350	75,214,799	37,607	....	..	87,913,773	43,957
1944	12,777,077	6,388	83,656,900	41,828	....	..	96,433,977	48,217
1945	9,032,987	4,516	53,716,765	26,858	....	..	62,749,752	31,375
1946	15,093,321	7,547	53,875,327	26,938	....	..	68,968,648	34,484
1947	129,048,807	64,524	46,478,362	23,239	....	..	175,526,869	87,763
1948	72,898,335	36,449	39,385,801	19,693	....	..	112,284,136	56,142
1949	51,250,088	25,625	49,771,273	24,886	....	..	101,021,361	50,511
1950	133,255,782	66,628	32,649,969	16,325	....	..	165,905,721	82,953
1951	89,838,095	44,919	33,518,520	16,759	....	..	123,356,615	61,678
1952	146,521,673	73,261	20,604,761	10,302	....	..	167,126,434	83,563
1953	55,750,855	27,875	7,502,181	3,751	....	..	63,253,036	31,626
1954	17,333,381	8,667	25,392,804	12,696	....	..	42,726,185	21,363
1955	35,754,707	17,877	23,310,302	11,655	....	..	59,065,009	29,533
1956	75,762,110	37,881	50,013,009	25,006	....	..	125,775,119	62,888
1957	82,011,785	41,006	62,043,775	31,022	....	..	144,055,560	72,028
1958	22,065,801	11,033	27,648,485	13,824	....	..	49,714,286	24,857
1959	37,507,227	18,754	37,602,134	18,801	....	..	75,109,361	37,555
1960	74,945,453	37,473	36,808,690	18,404	....	..	111,754,143	55,877
1961	97,600,304	48,803	44,110,194	22,055	....	..	141,716,498	70,858
1962	89,978,933	44,990	48,578,820	24,289	....	..	138,557,753	69,279
1963	95,442,284	47,721	40,242,676	20,121	....	..	135,684,960	67,842
1964	89,692,911	44,846	26,827,881	13,414	....	..	116,520,792	58,260
1965	66,666,380	33,333	7,050,059	3,525	....	..	73,716,439	36,858
1966	40,802,400	20,401	4,620,504	2,315	....	..	45,401,913	22,716
1967	38,180,547	19,090	1,166,697	583	....	..	39,347,154	19,674
1968	55,667,682	27,834	3,133,446	1,567	....	..	58,801,128	29,400
1969	51,921,162	25,960	2,357,194	1,179	....	..	54,278,356	27,139

YEARLY LANDINGS IN POUNDS
California barracuda

Year	California waters	South of state	Total pounds
1916	2,226,993	460,369	2,687,362
1917	2,965,388	94,955	3,060,323
1918	3,885,691	951,593	4,837,284
1919	4,038,852	1,786,105	5,824,957
1920	4,585,388	3,615,947	8,201,335
1921	4,588,900	3,036,262	7,625,162
1922	4,721,448	1,528,770	6,250,218
1923	5,135,824	2,064,751	7,200,575
1924	4,733,779	2,394,744	7,128,523
1925	5,976,453	2,059,996	8,036,449
1926	2,945,189	2,077,295	5,022,484
1927	4,355,583	1,844,156	6,199,739
1928	4,385,214	2,067,242	6,452,456
1929	3,925,899	1,302,711	5,228,610
1930	3,513,608	1,250,158	4,763,766
1931	3,336,065	841,473	4,177,538
1932	2,505,101	421,674	2,926,775
1933	2,912,152	160,810	3,072,962
1934	1,601,264	581,558	2,182,822
1935	2,003,947	613,877	2,617,824
1936	2,247,858	729,984	2,977,842
1937	1,799,045	1,139,445	2,938,490
1938	1,260,790	1,269,022	2,529,812
1939	2,967,780	1,124,274	4,092,054
1940	2,545,661	1,169,171	3,714,832
1941	2,971,349	1,230,579	4,201,928
1942	2,243,163	1,211,374	3,454,537
1943	2,382,884	1,392,454	3,775,338
1944	2,317,430	1,330,878	3,648,308
1945	1,744,560	2,128,697	3,873,257
1946	1,637,346	1,469,678	3,107,024
1947	1,695,867	969,878	2,665,745
1948	1,100,081	1,025,656	2,125,737
1949	903,674	1,554,110	2,457,684
1950	890,435	1,367,980	2,258,415
1951	670,015	1,436,913	2,106,928
1952	747,667	1,346,539	2,094,206
1953	565,942	872,904	1,438,846
1954	485,946	1,076,793	1,562,739
1955	322,831	818,128	1,140,959
1956	50,153	702,374	752,527
1957	387,143	295,523	682,666
1958	753,266	161,993	915,259
1959	1,110,409	42,192	1,152,601
1960	1,147,831	81,837	1,229,668
1961	478,362	231,017	709,379
1962	521,769	224,707	746,476
1963	347,354	31,360	378,714
1964	251,025	83,115	334,140
1965	273,003	89,055	362,058
1966	233,319	85,797	319,116
1967	281,224	31,960	313,184
1968	114,534	25,966	140,500
1969	70,833	3,760	74,593

SMB-26978

YEARLY LANDINGS IN POUNDS
California yellowtail

Year	California waters	South of state	Total pounds
1916	1,137,253	16,141	1,153,394
1917	2,736,906	9,089	2,745,995
1918	11,375,426	139,946	11,515,372
1919	4,871,763	133,502	5,005,265
1920	2,496,537	218,400	2,704,937
1921	2,189,626	351,170	2,490,796
1922	3,111,131	303,292	3,414,423
1923	3,068,506	1,094,012	4,062,608
1924	2,863,012	1,851,137	4,714,149
1925	2,586,631	593,270	3,179,891
1926	3,173,424	1,849,690	5,023,114
1927	1,435,456	2,789,397	4,224,853
1928	1,297,037	1,386,477	2,683,514
1929	849,948	2,225,319	3,075,264
1930	1,214,969	3,555,797	4,770,766
1931	1,690,680	835,173	2,525,853
1932	1,024,086	772,278	1,796,364
1933	1,233,286	2,665,602	3,898,888
1934	210,590	2,136,571	2,347,161
1935	582,589	7,566,129	8,148,718
1936	253,723	9,838,747	10,092,470
1937	223,983	5,147,492	5,371,475
1938	246,238	6,566,080	6,812,318
1939	262,524	2,603,764	2,866,288
1940	329,036	5,627,768	5,956,804
1941	95,924	9,734,766	9,830,690
1942	55,017	2,671,252	2,726,269
1943	33,350	4,901,520	4,934,879
1944	28,464	2,928,707	2,957,171
1945	23,416	3,510,637	3,534,052
1946	31,285	4,530,298	4,561,583
1947	103,706	9,849,148	9,952,854
1948	246,553	10,138,141	10,384,694
1949	15,907	7,301,833	7,317,740
1950	5,727	3,524,174	3,529,901
1951	14,454	4,655,282	4,669,736
1952	51,116	9,395,863	9,446,979
1953	14,379	5,198,004	5,212,383
1954	11,846	1,644,932	1,656,778
1955	5,570	158,752	164,322
1956	18,598	352,289	370,887
1957	150,898	358,053	508,951
1958	105,486	64,144	169,630
1959	207,187	24,097	231,284
1960	156,515	92,118	248,633
1961	80,689	300,080	380,769
1962	37,066	151,355	188,421
1963	25,443	44,283	69,726
1964	25,878	84,221	110,099
1965	12,522	115,283	127,805
1966	35,880	209,327	245,207
1967	13,179	137,489	150,668
1968	22,460	140,717	163,177
1969	11,744	222,411	234,155

YEARLY LANDINGS IN POUNDS
White seabass

Year	California waters	South of state	Total pounds
1916	477,091	321,024	798,115
1917	869,187	30,810	899,997
1918	1,458,667	154,853	1,613,520
1919	2,380,713	74,654	2,455,367
1920	2,375,646	252,462	2,628,108
1921	2,069,414	500,075	2,569,489
1922	2,195,831	736,220	2,932,051
1923	1,781,970	591,877	2,373,847
1924	938,760	550,829	1,489,589
1925	890,437	994,672	1,885,109
1926	1,477,789	738,613	2,216,402
1927	806,559	1,466,848	2,273,407
1928	824,879	475,335	1,300,214
1929	955,656	606,576	1,562,232
1930	1,239,285	387,137	1,626,422
1931	1,058,162	341,251	1,399,413
1932	667,363	137,433	804,796
1933	828,129	334,950	1,163,079
1934	468,299	382,898	851,197
1935	648,900	417,519	1,066,419
1936	564,956	243,137	808,093
1937	263,195	336,224	599,419
1938	289,987	356,660	626,647
1939	806,604	187,792	994,396
1940	811,307	104,409	915,716
1941	832,454	75,842	908,296
1942	356,655	197,200	553,855
1943	370,178	121,005	500,183
1944	254,070	139,918	393,988
1945	380,468	147,262	527,730
1946	472,204	144,272	616,476
1947	692,814	390,709	1,083,023
1948	789,691	324,599	1,114,290
1949	945,502	464,097	1,409,599
1950	1,123,463	407,911	1,531,374
1951	955,428	577,827	1,533,255
1952	692,292	454,811	1,147,103
1953	471,206	402,087	873,293
1954	434,354	771,757	1,206,111
1955	544,953	369,912	914,865
1956	413,956	667,267	1,081,223
1957	1,261,955	245,140	1,507,095
1958	2,750,652	99,111	2,849,763
1959	3,385,791	37,562	3,423,353
1960	1,086,895	149,303	1,236,198
1961	458,491	235,733	694,224
1962	208,867	365,541	574,408
1963	372,479	518,741	891,220
1964	550,817	840,264	1,391,081
1965	577,607	850,538	1,428,145
1966	674,545	663,305	1,337,850
1967	507,588	715,171	1,222,759
1968	210,050	651,830	861,880
1969	250,906	847,802	1,098,708

YEARLY LANDINGS IN POUNDS
Giant sea bass

Year	California waters	South of state	Total pounds
1916	129,414	24,026	153,440
1917	152,570	5,810	158,380
1918	210,432	38,363	248,795
1919	126,997	58,273	185,270
1920	89,869	58,168	148,037
1921	67,196	40,235	127,431
1922	83,668	13,662	97,354
1923	75,740	151,256	226,995
1924	88,677	142,727	231,404
1925	102,904	86,168	189,072
1926	120,070	257,864	377,934
1927	182,726	284,869	467,595
1928	204,862	177,253	382,115
1929	184,093	240,293	404,386
1930	187,473	206,536	394,009
1931	254,017	248,047	502,064
1932	231,203	242,643	473,846
1933	119,582	333,441	453,023
1934	53,752	807,746	861,498
1935	17,223	614,536	631,759
1936	19,854	378,741	398,595
1937	20,412	695,172	715,584
1938	34,848	372,978	407,826
1939	32,964	427,979	460,943
1940	42,784	323,899	366,683
1941	37,801	371,736	409,537
1942	13,717	365,063	378,780
1943	19,271	681,584	700,855
1944	18,478	416,402	434,880
1945	10,481	319,687	330,168
1946	26,325	406,236	432,561
1947	18,922	225,382	244,304
1948	16,637	171,374	188,011
1949	17,221	97,180	114,401
1950	11,903	138,893	150,796
1951	8,590	268,894	277,484
1952	5,272	308,222	313,494
1953	7,823	404,156	411,979
1954	5,835	344,441	350,276
1955	7,663	357,824	365,487
1956	39,610	291,708	331,318
1957	9,302	233,051	242,353
1958	9,962	206,065	216,027
1959	10,085	230,824	240,909
1960	20,505	221,125	241,690
1961	12,509	327,854	340,363
1962	8,188	438,021	446,209
1963	13,960	289,619	303,579
1964	14,018	208,697	222,715
1965	13,053	338,697	351,750
1966	7,486	333,481	340,967
1967	11,893	218,711	230,604
1968	14,919	143,502	158,421
1969	7,084	147,077	154,761

YEARLY LANDINGS IN POUNDS
Sole *

Year	Dover	English	Petrale	Rex	Sand	Unclassified	Total pounds
1916	----	----	----	----	----	6,407,186	6,407,186
1917	----	----	----	----	----	8,728,429	8,728,429
1918	----	----	----	----	----	7,027,767	7,027,767
1919	----	----	----	----	----	5,528,685	5,528,685
1920	----	----	----	----	----	3,821,748	3,821,748
1921	----	----	----	----	----	4,870,870	4,870,870
1922	----	----	----	----	----	7,043,336	7,043,336
1923	----	----	----	----	----	7,086,035	7,086,035
1924	----	----	----	----	----	8,838,351	8,838,351
1925	----	----	----	----	----	8,762,535	8,762,535
1926	----	----	----	----	----	8,649,870	8,649,870
1927	----	----	----	----	----	10,479,765	10,479,765
1928	----	----	----	----	----	10,281,719	10,281,719
1929	----	----	----	----	----	11,706,761	11,706,761
1930	----	----	----	----	----	10,924,085	10,924,085
1931	----	----	1,375,535	831,240	----	7,206,107	9,412,882
1932	----	----	1,227,223	555,568	----	7,108,059	8,890,840
1933	----	----	953,424	559,743	----	6,797,928	8,311,095
1934	----	5,280,154	2,456,989	716,498	----	514,962	8,967,603
1935	----	6,035,966	1,988,326	631,432	----	508,540	9,164,263
1936	----	6,286,867	1,126,527	515,648	----	395,966	8,325,008
1937	----	5,760,060	1,802,721	481,497	----	297,944	8,302,222
1938	----	4,953,934	2,026,166	515,254	----	242,293	7,737,647
1939	----	6,270,424	2,558,461	667,496	----	248,411	9,744,792
1940	----	5,056,535	1,575,489	593,359	----	162,622	7,388,005
1941	----	3,278,638	893,426	371,130	----	82,661	4,625,855
1942	----	2,020,662	611,880	387,545	----	136,070	3,155,757
1943	----	3,092,170	918,925	495,672	----	275,612	4,782,379
1944	----	3,066,865	1,123,986	413,286	----	96,237	4,700,374
1945	----	5,857,240	1,232,801	442,179	----	250,482	7,782,702
1946	----	7,176,727	2,666,285	570,418	----	151,263	10,564,693
1947	----	8,379,502	2,947,177	842,968	----	103,047	12,333,694
1948	7,234,436	8,171,645	5,089,684	893,248	----	265,924	21,654,939
1949	7,890,073	5,713,258	4,952,186	982,307	----	191,691	19,729,485
1950	9,548,379	6,080,693	4,366,598	1,068,456	----	812,382	23,876,508
1951	8,621,238	5,631,659	2,726,304	1,013,890	----	179,369	18,172,460
1952	11,748,215	4,911,468	2,893,813	1,185,451	----	70,563	20,809,316
1953	8,904,367	4,099,106	3,350,163	1,020,877	34,542	36,958	17,446,013
1954	9,930,438	3,748,245	4,171,901	1,183,538	75,844	72,056	19,181,722
1955	8,185,501	4,134,779	3,619,530	1,094,437	92,572	19,425	17,146,244
1956	8,268,424	3,826,397	2,830,158	1,147,523	77,357	22,852	16,172,611
1957	7,932,137	4,819,872	3,486,819	1,234,494	86,081	28,252	17,527,635
1958	8,053,040	5,150,234	3,157,678	1,422,891	24,435	15,214	17,823,492
1959	7,327,420	4,617,491	2,632,461	1,443,005	95,765	21,197	16,137,329
1960	9,184,814	2,375,383	2,475,661	1,107,372	73,401	228,066	15,444,760
1961	7,826,617	3,645,918	3,390,739	1,208,829	77,130	34,484	16,183,717
1962	8,581,091	4,206,048	3,041,164	1,408,245	196,565	68,444	17,501,557
1963	9,781,732	4,254,545	3,317,948	1,565,672	231,208	43,415	19,294,520
1964	9,265,238	4,592,782	2,697,670	1,410,647	336,197	47,265	18,349,769
1965	10,759,963	4,892,391	2,662,257	1,490,475	310,444	43,016	20,158,546
1966	10,311,633	4,844,868	2,927,190	1,635,399	235,691	25,957	19,980,738
1967	7,215,037	5,821,909	2,768,537	1,766,038	305,897	31,712	17,909,130
1968	8,535,521	5,811,436	2,946,805	1,930,583	211,376	29,614	19,465,137
1969	12,918,982	3,804,047	2,867,064	2,259,165	203,764	17,100	22,070,122

* Prior to 1931, all soles were combined as one group; individual species were tabulated separately when they became sufficiently important.

YEARLY LANDINGS IN POUNDS
Flatfish other than sole

Year	California halibut	Pacific halibut	Arrowtooth flounder*	Starry flounder	Sanddab	Turbot
1916	4,052,173	70,344	....	453,916	2,228,734	2,608
1917	4,379,312	131,585	....	1,151,878	2,631,862	1,327
1918	4,624,216	129,472	....	818,535	1,781,509	3,664
1919	4,698,123	161,375	....	435,731	709,738	2,115
1920	4,279,582	168,208	....	481,587	721,810	855
1921	3,653,861	141,896	....	293,656	784,011	219
1922	3,254,505	148,979	....	539,220	1,170,979	1,834
1923	2,229,381	197,486	....	808,961	1,363,911	1,011
1924	2,576,882	132,016	....	379,770	1,699,832	1,868
1925	2,452,561	161,310	....	594,420	1,953,847	3,926
1926	1,349,031	238,689	....	667,711	1,143,935	1,365
1927	1,303,589	568,672	....	590,064	892,718	3,950
1928	1,187,681	278,840	....	399,880	1,108,764	9,234
1929	1,102,873	750,624	....	580,752	1,051,868	1,323
1930	1,097,760	413,958	....	391,096	616,349	7,345
1931	969,773	790,384	....	169,806	672,805	18,284
1932	948,702	645,828	....	843,806	665,345	23,422
1933	989,649	321,664	....	457,998	562,994	49,815
1934	1,037,008	1,022,965	....	537,164	767,025	72,548
1935	1,575,863	872,971	....	656,113	675,597	72,287
1936	1,582,907	530,457	....	621,186	621,675	116,275
1937	1,207,235	316,841	....	974,770	516,195	75,990
1938	1,076,229	421,910	....	642,812	639,328	85,896
1939	991,621	402,250	....	739,311	821,204	104,585
1940	948,457	309,491	....	804,089	779,078	62,124
1941	706,650	234,762	....	601,577	442,467	26,940
1942	760,539	238,988	....	370,125	253,540	6,571
1943	1,111,998	281,121	....	505,399	505,338	38,047
1944	1,485,463	250,946	....	366,520	551,289	72,825
1945	1,748,621	290,136	....	337,543	592,062	159,870
1946	2,457,187	403,070	....	509,448	679,073	49,847
1947	1,787,901	282,100	....	527,072	701,413	101,784
1948	1,306,629	130,589	....	405,251	804,695	114,701
1949	1,256,435	167,347	....	356,374	722,183	95,605
1950	1,092,748	201,900	74,309	913,765	690,621	128,080
1951	868,201	86,749	69,801	1,128,892	543,821	110,164
1952	525,402	242,581	112,913	597,477	659,874	81,895
1953	530,315	98,219	88,367	502,526	690,443	69,158
1954	661,331	90,662	550,457	500,550	753,471	175,918
1955	509,742	81,942	748,249	650,180	781,564	100,498
1956	455,659	39,158	1,070,597	375,400	789,280	83,294
1957	376,815	28,206	933,715	504,461	692,083	96,055
1958	267,446	8,271	643,880	471,202	406,438	72,533
1959	354,242	8,345	787,254	1,046,926	466,684	139,225
1960	376,263	4,916	1,007,679	259,038	348,373	62,436
1961	654,554	3,961	160,659	315,337	562,964	71,367
1962	863,086	3,546	53,326	338,192	679,911	80,383
1963	1,120,369	4,508	17,345	521,310	555,783	96,819
1964	1,276,105	3,040	9,735	420,986	580,526	93,280
1965	1,243,718	5,019	11,595	378,369	470,041	78,531
1966	1,011,412	671	3,503	380,628	720,101	83,327
1967	838,058	498	6,041	870,707	687,168	72,853
1968	671,654	127	13,400	856,157	714,622	69,504
1969	274,277	86	9,980	374,840	696,482	25,033

* Arrowtooth flounder were tabulated with unclassified sole prior to 1950.
† The drop in landings after 1960 reflects a change in reporting animal food landings.

YEARLY LANDINGS IN POUNDS
Fishes

Year	Cabezon	White croaker*	Pacific hake	Lingcod	Rockfish	Sablefish
1916	569	779,287	189,219	617,236	4,918,952	83,623
1917	434	835,259	254,331	930,519	7,774,026	909,816
1918	167	1,014,820	193,018	913,836	8,242,754	498,937
1919	....	609,178	133,181	1,063,136	6,398,109	334,950
1920	....	461,459	141,981	687,954	5,633,077	781,032
1921	....	391,085	90,218	425,843	4,761,658	1,022,612
1922	....	581,863	74,516	568,481	4,312,014	268,554
1923	....	411,564	78,969	467,347	5,096,622	538,292
1924	....	384,217	60,780	400,432	4,742,885	933,310
1925	3,352	536,654	22,017	683,130	5,488,621	722,472
1926	....	484,921	58,235	649,902	7,540,969	178,642
1927	762	529,267	84,653	556,308	6,390,604	992,654
1928	2,628	441,758	109,648	853,537	6,419,909	916,955
1929	1,196	476,497	145,669	1,167,120	6,036,409	1,439,408
1930	1,046	457,167	56,088	1,388,172	7,225,424	1,359,147
1931	1,115	414,034	12,501	1,229,088	7,277,688	1,021,215
1932	4,678	447,531	29,001	899,912	5,636,319	975,373
1933	4,265	564,274	37,539	1,088,955	4,787,774	1,332,573
1934	5,265	634,345	56,901	857,600	4,603,536	2,117,046
1935	10,537	768,676	72,843	1,017,455	4,831,174	2,848,672
1936	18,468	652,134	50,791	758,547	4,603,904	1,035,530
1937	8,189	645,759	63,454	968,258	4,291,214	733,499
1938	5,425	493,209	38,428	648,004	3,637,137	415,836
1939	4,023	542,901	13,661	576,972	3,333,126	767,044
1940	3,392	412,228	18,049	692,243	3,570,636	573,785
1941	13,346	325,155	15,044	529,772	3,405,622	536,540
1942	2,312	284,225	41,981	314,334	1,423,440	1,972,522
1943	7,532	396,633	10,505	719,318	2,762,192	3,205,374
1944	3,906	367,701	4,751	746,039	5,422,230	4,116,451
1945	4,417	459,515	2,415	758,395	13,266,076	6,264,397
1946	7,860	437,023	550	1,156,127	11,161,222	2,656,873
1947	4,526	458,686	876	1,940,747	8,498,584	602,110
1948	8,202	643,123	4,600	2,056,088	6,507,205	2,088,439
1949	16,073	764,429	1,635	1,656,184	5,962,267	1,743,372
1950	21,679	750,732	500	1,918,905	8,116,102	1,584,301
1951	23,875	682,269	24,972	1,672,114	10,993,502	2,585,513
1952	34,586	3,273,702	6,145	1,366,279	10,727,521	1,343,867
1953	13,365	1,201,134	103,926	952,103	12,228,663	1,655,653
1954	6,262	913,802	611,622	947,383	12,640,729	2,357,531
1955	6,944	819,488	956,845	984,926	12,681,697	2,065,737
1956	12,415	889,870	1,376,317	931,311	14,913,815	2,868,407
1957	13,206	535,362	1,150,006	1,639,654	16,091,279	2,199,782
1958	19,612	770,534	1,135,138	1,599,515	17,842,163	1,732,992
1959	9,508	1,534,382	1,097,069	1,406,297	15,281,282	1,938,356
1960	3,067	1,078,119	325,088	1,207,129	13,713,886	2,419,024
1961	4,952	889,164	13,275	1,439,943	10,830,762	1,616,528
1962	2,474	687,633	78,530	1,112,204	9,834,393	2,016,237
1963	2,811	551,059	139,699	1,133,008	11,749,460	1,809,349
1964	5,281	838,584	111,529	836,377	8,117,912	2,463,452
1965	7,436	1,135,866	119,255	812,690	9,392,424	2,863,550
1966	12,599	790,997	69,002	800,303	10,063,592	3,215,939
1967	14,284	498,378	14,430	938,655	9,798,951	3,798,493
1968	20,106	941,304	6,494	1,094,054	9,444,396	3,219,455
1969	25,837	525,514	27,047	1,113,508	9,227,451	4,156,816

* White croaker includes queenfish.
† The drop in landings after 1960 reflects a change in reporting animal food landings.

YEARLY LANDINGS IN POUNDS
Fishes

Year	Sculpin	Shark	California sheephead	Smelt	Swordfish	Whitebait smelt
1916	8,014	36,247	3,549	991,509	----	161,797
1917	17,425	287,872	5,906	984,270	----	123,079
1918	28,237	403,093	22,978	796,984	18,442	135,857
1919	25,432	612,683	17,972	756,980	18,252	5,915
1920	35,674	811,349	14,567	744,187	12,513	678
1921	58,380	539,333	23,925	765,073	14,803	5,229
1922	42,121	282,018	18,205	830,140	23,256	84,007
1923	60,466	360,363	31,628	806,380	11,691	67,818
1924	109,070	392,634	24,267	721,912	31,833	122,483
1925	223,104	372,222	48,811	751,669	27,045	70,968
1926	108,068	506,723	138,927	883,123	45,543	85,557
1927	113,457	325,683	159,397	965,921	130,288	134,149
1928	97,083	623,816	372,677	926,116	426,001	135,180
1929	107,797	833,985	288,422	933,095	693,081	243,119
1930	88,610	647,297	243,689	1,054,665	562,729	174,917
1931	91,688	596,134	198,347	1,074,810	340,769	141,495
1932	85,503	850,888	89,591	899,216	661,470	133,540
1933	64,160	471,030	58,609	729,702	850,699	95,751
1934	65,939	526,280	143,852	732,191	263,958	105,982
1935	69,549	555,256	188,022	875,480	669,283	164,345
1936	110,417	471,861	128,577	841,231	577,402	197,738
1937	137,312	914,205	81,466	682,070	625,307	86,177
1938	165,386	7,504,329	72,031	567,861	722,478	108,724
1939	128,628	9,227,750	71,361	474,936	594,360	166,883
1940	122,133	7,660,030	62,352	449,360	887,168	127,449
1941	95,287	7,617,334	49,119	452,739	916,739	131,102
1942	44,332	3,551,566	50,258	443,939	445,908	159,258
1943	42,550	3,729,334	151,048	1,566,273	336,386	141,367
1944	57,270	2,613,431	168,653	1,541,044	751,596	269,425
1945	94,656	2,438,096	249,584	2,369,580	363,093	291,152
1946	145,129	1,608,846	267,125	793,336	863,494	344,477
1947	127,048	2,637,926	193,489	713,310	1,009,957	326,616
1948	155,076	2,480,555	100,227	782,096	1,113,808	222,499
1949	148,367	1,550,992	63,524	715,616	198,361	241,764
1950	139,523	717,247	66,209	590,968	26,494	207,607
1951	101,437	842,324	61,410	1,095,665	228,034	182,054
1952	83,610	823,238	36,231	646,679	265,690	152,115
1953	119,628	449,753	35,426	670,116	142,831	179,292
1954	134,310	770,337	29,184	609,082	23,055	267,426
1955	108,056	876,201	13,182	780,172	134,659	214,558
1956	100,232	1,086,314	6,575	466,333	275,174	148,820
1957	73,268	728,900	11,030	371,472	376,986	243,600
1958	64,872	491,713	11,366	549,864	471,775	306,805
1959	37,342	602,191	10,233	551,945	448,220	274,408
1960	29,203	694,191	4,740	429,299	324,784	168,458
1961	26,718	623,072	12,602	491,265	368,855	335,852
1962	57,951	753,177	20,327	339,498	39,057	188,357
1963	75,521	665,367	28,011	358,456	98,074	148,080
1964	94,225	646,560	17,914	414,039	183,023	191,215
1965	82,730	648,265	12,153	368,951	327,174	148,596
1966	108,499	653,790	15,984	522,457	468,772	162,259
1967	82,650	596,898	19,628	591,975	305,067	199,694
1968	125,175	499,947	12,750	443,062	199,398	238,061
1969	115,471	478,235	13,285	413,401	1,031,583	161,449

YEARLY LANDINGS IN POUNDS
Perch and perch-like fishes

Year	Opaleye	Halfmoon	Blacksmith	Sargo	Perch	Total pounds
1916	----	----	----	----	221,186	221,186
1917	----	----	----	----	252,503	252,503
1918	----	----	----	----	203,420	203,420
1919	----	----	----	----	192,481	192,481
1920	----	----	----	----	186,381	186,381
1921	----	----	----	----	253,199	253,199
1922	----	----	----	----	243,776	243,776
1923	----	----	----	----	359,682	359,682
1924	----	----	----	----	305,726	305,726
1925	----	----	----	----	272,351	272,351
1926	----	----	----	----	208,910	208,910
1927	----	----	----	----	262,893	262,893
1928	----	30,104	----	----	236,974	267,078
1929	----	16,308	----	----	311,194	327,502
1930	----	36,765	----	----	267,972	304,737
1931	17,913	24,692	----	260	223,092	265,957
1932	16,279	21,547	----	----	207,222	244,046
1933	4,272	8,880	----	503	214,511	228,166
1934	3,896	28,394	----	334	192,596	225,220
1935	1,424	33,432	----	5,226	241,525	281,607
1936	1,781	42,166	----	515	207,280	251,742
1937	1,778	34,333	100	2,069	210,309	249,589
1938	100	27,501	----	5	155,815	183,421
1939	20	----	----	773	139,394	140,187
1940	39	192	----	435	57,977	58,643
1941	----	----	----	220	25,832	26,052
1942	66	----	----	----	58,018	58,084
1943	17	----	----	----	113,018	113,035
1944	7	----	----	2,305	146,546	148,858
1945	----	----	----	1,384	217,486	218,870
1946	----	----	----	196	192,430	192,626
1947	1,519	----	----	44	289,182	290,745
1948	564	614	----	1,899	302,087	305,164
1949	954	----	----	31	326,336	327,321
1950	6,278	1,604	----	27	242,364	250,263
1951	1,006	384	----	1,580	237,331	240,171
1952	525	----	83,811	----	213,357	297,693
1953	392	----	14,200	----	281,998	296,590
1954	9,164	50,007	----	2,040	118,499	179,710
1955	6,117	34,410	----	695	136,554	177,776
1956	3,433	15,108	----	----	187,681	206,222
1957	5,198	12,872	----	----	245,699	263,769
1958	2,351	4,455	3	1,740	189,679	198,228
1959	4,866	3,639	----	35	212,853	221,393
1960	1,208	2,904	----	222	164,273	168,607
1961	2,337	5,907	----	44	118,245	126,533
1962	1,674	8,536	20	59	165,115	175,404
1963	4,278	8,683	2,900	171	172,884	189,016
1964	2,001	10,043	145,143	11	133,115	290,313
1965	3,149	10,518	117,785	128	187,730	319,310
1966	19,432	9,530	8,920	1,120	160,381	197,383
1967	17,298	25,431	7,620	41	202,513	252,903
1968	11,173	49,617	137,634	46	168,040	366,510
1969	15,929	27,028	246,517	----	156,528	446,002

NUMBER OF FISH BY SPECIES, ANGLER DAYS, ANGLERS, AND ANGLER HOURS REPORTED AND NUMBER OF MOBILE BOATS REPORTING CALIFORNIA PARTYBOAT FLEET, 1947–1969

Species	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Albacore	11,445	15,414	22,002	118,087	75,921	187,267	23,363	20,008	78,688	65,814	41,540	6,482	39	76,075	184,891	229,314	158,372	112,358	99,771	74,680	96,497	129,710	18,887
Barracuda, California	677,449	384,056	306,423	256,367	289,545	336,862	170,550	282,552	154,962	87,603	577,184	782,723	1,195,585	755,408	391,884	335,507	483,699	303,070	443,304	892,697	470,480	372,246	358,518
Bass, giant sea	160	439	213	179	201	92	135	102	162	74	151	203	184	228	310	390	598	353	580	548	622	496	653
Bass, kelp, sand	682,789	630,223	796,959	619,397	781,609	536,075	711,395	876,607	497,343	470,362	609,071	653,671	428,426	478,656	613,604	789,149	1,219,344	1,103,394	1,230,313	1,278,939	1,003,911	1,317,963	1,216,175
Bass, striped	†	†	†	†	†	†	†	†	†	†	†	†	†	*30,856	*42,357	*39,682	*58,851	34,163	16,488	44,869	23,794	23,058	20,091
Bonito, Pacific	30,496	14,819	5,372	2,359	14,475	7,649	6,321	70,078	22,409	61,404	258,555	422,568	776,386	1,199,919	849,426	798,725	775,719	1,298,804	806,322	614,415	349,952	1,102,936	1,130,241
Cabezon	9,886	14,590	14,126	15,971	18,029	10,847	9,650	13,132	12,366	18,193	14,479	9,909	5,329	2,516	2,639	4,538	9,726	6,491	7,575	10,293	5,419	4,319	4,583
Croaker, white	58,034	89,825	121,053	76,765	62,945	77,948	57,606	66,964	27,349	16,289	8,648	20,000	6,895	8,633	21,782	27,256	37,225	23,269	21,448	17,285	20,590	10,906	15,273
Croaker, yellowfin	8,166	3,667	3,032	999	663	708	1,367	2,411	595	1,099	275	95	132	275	325	778	562	993	1,386	1,619	615	211	1,351
Dolphinfish	15	--	--	1	--	2	--	12	--	2	2,805	--	4	1	3	--	139	4	341	48	198	929	170
Flatfish, miscellaneous	13,012	16,513	21,168	29,437	48,998	35,677	64,872	48,410	39,136	23,912	19,300	9,265	7,755	5,835	9,316	8,958	8,005	14,449	15,755	20,238	21,282	22,666	23,485
Halibut, California	101,436	143,462	104,639	85,935	59,295	34,158	34,292	80,074	35,802	21,601	10,795	16,192	25,365	48,310	108,011	118,966	125,669	141,465	118,213	88,726	63,582	51,663	27,631
Lingcod	22,011	24,406	26,131	23,863	24,052	17,389	13,011	22,940	29,113	37,649	38,012	39,801	31,206	28,232	23,466	25,399	27,513	25,263	33,260	44,676	43,559	42,449	32,693
Mackerel, jack	4,505	2,351	2,932	557	202	4,395	196,280	19,407	39,473	23,493	6,878	27,807	11,820	8,537	28,891	9,029	9,342	6,577	25,619	19,027	10,236	13,589	11,272
Mackerel, Pacific	148,041	203,012	95,158	66,969	47,188	76,568	61,467	315,037	151,018	121,136	151,960	136,607	88,952	70,370	113,088	110,738	146,560	101,219	151,896	205,090	108,366	78,933	120,036
Marlin	37	58	28	115	58	57	4	9	6	32	22	84	349	9	8	2	37	48	46	40	81	60	66
Rockfish	193,652	410,005	570,037	670,104	721,808	705,761	600,480	1,149,307	1,737,707	2,030,708	1,395,151	1,561,132	1,177,979	1,015,673	898,641	956,438	962,659	966,801	1,347,430	1,688,718	1,891,057	2,102,859	1,978,981
Sablefish	9,159	3,546	45	90	581	87	6,487	36,724	15,992	5,177	271	39	9	39	622	2,231	1,232	4,722	8,601	21,693	6,388	4,099	2,118
Salmon	5,018	11,209	23,057	56,337	71,970	80,472	98,723	119,911	128,978	114,505	44,701	52,676	55,945	37,941	42,065	87,612	72,457	92,021	51,677	70,151	84,946	127,594	111,389
Sculpin	26,062	52,554	37,030	53,419	35,721	39,068	28,952	33,462	28,613	36,558	13,473	13,743	11,477	15,111	26,672	33,314	53,890	73,844	71,888	69,851	63,280	59,863	63,011
Seabass, white	20,721	24,078	65,545	54,718	44,367	41,043	28,182	41,588	30,103	19,755	19,030	34,039	10,593	15,697	14,082	14,564	19,800	14,901	9,775	3,972	3,385	4,138	4,056
Steelhead, California	13,001	17,261	15,440	14,291	20,416	16,481	17,349	21,499	14,102	14,789	15,105	18,120	17,146	11,541	15,210	13,488	18,443	26,822	41,651	52,967	42,676	33,075	49,626
Sturgeon	‡	‡	†	‡	‡	‡	‡	--	--	2	--	--	2	--	1	1	3	832	1,731	1,874	2,258	1,653	1,911
Tuna, Bluefin	2,194	104	1,941	27	7,142	145	4,276	966	8,179	34,187	6,428	884	1,330	97	2,268	2,453	737	693	92	1,998	3,166	1,231	1,170
Tuna, Yellowfin	137	18	11	0	56	34	--	--	1	78	325	13	4	2,124	21	3	80	103	101	241	10,801	8,499	4,210
Tuna, skipjack	698	400	9	31	132	38	279	50	10	13	6,453	491	514	378	11	40	8,149	3,961	2,142	1,012	1,656	4,250	9,998
Whitefish, ocean	5,160	14,124	14,576	14,925	8,828	10,003	4,963	9,952	9,508	7,951	4,389	6,143	5,608	5,850	6,647	6,157	6,231	6,949	13,810	15,587	18,184	22,155	36,474
Yellowtail, California	6,948	13,028	17,710	6,971	23,721	59,263	27,702	40,872	36,468	29,198	242,686	123,384	457,350	254,969	42,367	21,826	45,705	39,104	18,367	80,163	31,392	58,019	79,202
All others	11,194	20,437	13,879	13,432	12,658	22,044	16,452	22,653	15,800	18,349	11,808	14,749	12,191	7,754	13,225	13,437	28,049	31,503	94,976	57,003	53,758	128,583	348,671
Total	2,070,432	2,110,019	2,339,794	2,190,413	2,350,644	2,306,133	2,280,158	3,274,837	3,113,883	3,262,995	3,490,885	3,950,880	4,328,575	4,090,034	3,453,633	3,655,993	4,278,502	4,434,176	4,634,558	5,408,420	4,444,161	5,731,201	5,725,575
Number angler days	359,436	407,787	469,915	544,264	556,949	588,087	502,146	532,190	496,286	523,063	530,175	515,152	557,154	516,265	495,805	#	#	#	#	#	#	#	#
Number anglers	§	§	§	§	§	§	§	§	§	§	§	§	§	637,498	503,916	595,806	643,155	695,373	688,103	857,000	780,102	819,651	802,811
Number angler hours	§	§	§	§	§	§	§	§	§	§	§	§	§	2,710,890.2	2,861,600.2	2,903,001.6	3,193,687.7	3,478,965.9	3,486,217.5	4,193,764.5	3,880,630.4	4,294,901.0	4,034,065.9
Number boats statewide	343	430	464	596	502	593	599	612	550	515	454	382	396	402	384	358	377	373	303	407	397	412	406

* Ocean and San Francisco Bay catch (Sacramento-San Joaquin Delta catches not included until 1964).
† Catch statistics maintained elsewhere until 1960—See Chadwick, 1962.
‡ Fishery closed 1917–1953.
§ Not available until 1960. Must be estimated 1947–1959.
# This statistic discontinued in 1962.

SMB-26983

INSHORE BAIT LANDINGS IN POUNDS

Species	1963	1964	1965	1966	1967	1968	1969
Clam							
Freshwater	151,878	214,383	442,548	524,982	500,055	406,996	671,156
Jackknife	73,060	72,500	65,972	62,302	53,168	55,585	67,164
Purple	----	4,386	10,768	16,799	25,110	24,008	12,953
Unclassified	----	----	764	1,035	2,908	773	517
Crab							
Sand	4,673	5,130	6,795	8,394	8,303	7,738	4,019
Shore	----	----	----	26	38	6	5
Mudsucker	9,861	7,306	91,384	175	4,742	282	4,278
Mussels	105,118	67,827	69,403	102,644	95,110	91,472	101,668
Perch, Shiner	----	----	----	40	60	188	93
Sculpin, Staghorn	----	681	511	2,061	1,158	1,829	1,237
Shrimp							
Bay	----	----	6,695	28,119	37,586	47,201	61,040
Ghost	8,190	4,899	4,578	7,780	2,884	7,748	8,839
Red	4,056	2,446	4,667	2,356	1,561	5,113	4,568
Miscellaneous	4,064	645	12	----	----	----	----
Total	360,900	379,983	704,097	754,713	732,683	648,939	937,584

SMB-26984

KELP HARVEST IN TONS

		Total Tons
1970	1970	127,039
1971	1971	155,559
1972	1972	162,511
1973	1973	153,080
1974	1974	170,181
1975	1975	171,597
1976	1976	158,371
1977	1977	130,597
1978	1978	169,029
1979	1979	171,020
1980	1980	147,636
1981	1981	73,064
1982	1982	86,503
1983	1983	5,271
1984	1984	46,479
1985	1985	87,300
1986	1986	56,832
1987	1987	93,264
1988	1988	90,615
1989	1989	132,760
1990	1990	151,439
1991	1991	127,505

YEARLY COMMERCAL LANDINGS IN POUNDS
Crustaceans

	Bay Shrimp	Dungeness Crab	Pacific Ocean Shrimp	Ridgeback Prawn	Rock Crab	Sheep (Spider) Crab	Spiny Lobster	Spot Prawn
1970	65,761	15,413,589	4,047,589	-----	539,579	1,032	225,399	22,259
1971	59,721	9,662,265	3,080,583	-----	542,732	-----	224,486	11,773
1972	73,067	1,563,006	2,489,970	-----	843,530	-----	398,217	20,970
1973	62,308	1,022,873	1,239,976	-----	935,788	-----	233,179	24,384
1974	79,797	685,000	2,387,366	4,015	864,033	52	190,950	218,167
1975	99,708	3,934,663	4,998,369	28,522	1,201,867	-----	201,412	173,498
1976	98,789	15,726,774	3,500,788	3,130	1,227,766	-----	292,534	112,069
1977	82,797	33,647,863	15,871,332	2,972	1,083,015	-----	251,568	53,838
1978	81,715	9,362,197	13,887,379	45,716	956,874	1,919	360,986	67,547
1979	92,213	12,978,505	5,182,703	356,715	953,590	14,402	419,529	83,778
1980	127,968	15,934,778	3,868,214	281,661	1,083,957	9,869	416,249	213,826
1981	178,363	10,435,441	4,164,495	192,637	1,375,227	10,914	478,863	370,536
1982	211,697	6,973,679	4,543,806	129,402	1,277,872	16,495	524,710	302,268
1983	148,115	5,301,828	1,132,742	153,779	1,397,109	47,108	525,087	109,096
1984	142,012	5,340,088	1,628,992	589,998	1,676,298	56,338	444,998	50,464
1985	132,578	6,210,272	3,381,117	896,816	1,739,835	41,777	447,848	63,941
1986	107,304	7,758,277	6,757,818	670,573	2,097,408	34,678	488,804	102,486
1987	103,088	6,857,118	8,023,390	241,872	1,567,138	99,556	449,778	88,535
1988	132,951	11,297,300	11,236,298	142,694	1,237,934	107,609	610,859	166,670
1989	122,599	5,717,145	13,351,218	165,527	1,302,687	70,066	742,571	189,878
1990	151,382	10,367,719	8,700,916	90,842	1,784,135	93,451	705,341	317,655
1991	140,725	4,246,029	10,364,782	128,732	1,594,010	99,269	589,240	311,431

SMB-26985

YEARLY COMMERCAL LANDINGS IN POUNDS
Mollusks

	Black Abalone	Green Abalone	Pink Abalone	Red Abalone	White Abalone	Total Abalone 1	Market Squid	Octopus	Pacific Oyster 2	Sea Snail
1970	-----	-----	-----	-----	-----	2,900,813	24,590,865	3,926	1,119,484	-----
1971	-----	-----	-----	-----	-----	2,945,318	31,517,408	1,804	978,826	-----
1972	1,014,892	424,828	403,709	1,104,462	143,819	3,093,644	20,159,312	10,582	885,001	-----
1973	1,912,949	156,804	371,352	663,919	83,112	3,193,120	12,061,632	23,348	726,875	593
1974	1,145,396	121,563	455,324	751,060	113,765	2,595,040	28,904,678	32,538	799,742	4,509
1975	687,428	170,927	458,235	742,769	71,821	2,138,460	23,621,984	23,233	799,885	4,782
1976	356,751	120,489	431,143	739,621	81,907	1,732,819	20,306,005	81,618	716,356	13,724
1977	463,301	97,457	318,494	537,450	17,603	1,436,153	28,243,779	34,411	929,544	16,658
1978	419,976	93,042	287,335	489,147	3,648	1,295,033	37,798,628	38,990	1,025,127	21,027
1979	330,928	61,327	156,383	439,469	502	992,499	43,407,642	105,157	1,144,623	
1980	518,548	63,181	138,906	516,731	1,076	1,238,988	33,917,646	129,804	939,455	-----
1981	520,948	63,950	94,127	430,315	167	1,109,651	51,829,718	84,751	1,061,983	33,872
1982	633,307	88,645	86,178	431,285	908	1,240,579	35,953,265	88,917	999,388	30,044
1983	484,310	56,861	67,152	231,210	482	840,112	4,020,353	34,813	1,047,075	36,714
1984	436,294	31,910	57,030	299,759	449	826,672	1,243,458	15,521	1,253,680	32,954
1985	359,835	23,952	68,623	368,782	1,654	762,070	22,652,461	15,260	1,209,093	34,100
1986	267,452	25,750	51,830	263,302	876	615,037	46,908,622	13,457	1,130,540	18,139
1987	309,727	28,965	31,539	391,278	2	763,056	44,056,904	16,448	1,138,237	29,724
1988	201,604	23,498	19,003	324,635	2	568,826	82,080,486	27,578	1,172,024	29,173
1989	218,489	19,723	22,469	469,407	22	730,890	90,152,660	50,338	1,457,781	22,067
1990	91,379	27,089	23,226	379,143	17	521,071	62,714,437	35,142	1,557,951	24,768
1991	26,226	8,154	12,780	328,466	4	376,980	82,426,950	32,782	1,550,274	25,848

YEARLY COMMERCAL LANDINGS IN POUNDS
Echinoderms

	Red Sea Urchin	Sea Cucumber
1970	-----	-----
1971	200	-----
1972	76,457	-----
1973	3,594,695	-----
1974	7,107,815	-----
1975	7,567,154	-----
1976	11,106,426	-----
1977	16,536,295	-----
1978	14,427,547	8,780
1979	20,558,950	69,438
1980	22,167,108	23,060
1981	26,433,986	-----
1982	19,441,151	139,487
1983	17,756,472	163,495
1984	14,978,869	52,354
1985	19,998,191	-----
1986	34,134,025	77,967
1987	46,061,653	107,678
1988	51,987,994	159,106
1989	51,188,502	160,011
1990	45,269,659	147,284
1991	41,938,120	581,974

1 Prior to 1972 Abalone landings were aggregated.

2 Weight in packed meats.

SMB-26986

YEARLY COMMERCAL LANDINGS IN POUNDS
Fish

	Anchovy	Anchovy for Live Bait	Barracuda	Bonito	Cabezon	White Croaker	Arrowtooth Flounder	Starry Flounder 1	Flyingfish	Grenadiers	Hagfish	Hake	California Halibut	Herring	Lingcod	Louvar	Jack Mackerel
1970	192,485,074	-----	24,588	9,192,304	10,698	564,871	6,120	-----	78,631	-----	-----	9,775	257,444	315,968	1,531,399	-----	47,746,509
1971	89,705,068	-----	17,264	20,268,984	4,518	334,395	2,661	-----	160,266	-----	-----	34,685	336,871	240,936	2,097,949	-----	59,882,985
1972	138,201,573	-----	13,915	22,312,627	5,853	373,410	163,947	-----	128,889	64,023	-----	10,525	309,245	125,448	3,246,186	-----	51,117,573
1973	265,271,871	-----	37,605	30,787,731	4,554	227,096	236,244	-----	160,981	70,860	-----	34,175	273,526	2,819,467	3,559,621	-----	20,615,827
1974	165,433,480	-----	36,498	18,817,766	14,901	514,317	210,510	-----	72,726	72,003	-----	32,210	306,479	5,260,274	3,824,107	-----	25,457,593
1975	317,021,422	-----	58,597	31,873,688	7,332	577,785	70,714	-----	91,254	98,714	-----	38,508	508,913	2,433,676	3,190,195	-----	36,779,231
1976	249,838,707	-----	162,091	8,896,859	19,166	497,961	185,228	-----	98,176	92,053	-----	28,521	628,400	4,819,691	3,120,220	-----	44,893,081
1977	222,953,334	9,078,000	77,119	22,547,605	12,150	588,531	222,300	-----	84,000	102,323	-----	86,813	467,862	11,653,280	1,694,539	-----	100,326,000
1978	25,258,916	11,470,000	48,437	7,882,396	28,781	422,288	206,603	-----	182,715	71,262	-----	747,709	441,440	9,860,119	2,015,460	-----	68,912,000
1979	107,396,181	5,134,000	37,327	3,960,071	50,327	716,315	238,203	-----	61,931	79,798	-----	1,836,264	665,546	9,385,489	3,161,120	-----	36,600,000
1980	94,677,748	9,594,000	66,553	14,242,114	60,146	1,064,141	122,820	-----	61,333	101,868	-----	1,527,992	726,852	17,771,444	2,810,797	-----	44,856,000
1981	115,317,479	10,546,000	67,594	16,615,051	53,460	978,734	105,550	-----	54,388	72,438	-----	1,467,276	1,262,265	13,142,305	2,839,852	-----	31,346,000
1982	92,923,977	8,428,000	73,394	6,062,617	62,214	1,331,801	106,414	2,551	153,246	98,383	-----	2,251,253	1,214,375	23,377,749	3,036,923	-----	58,220,000
1983	9,759,200	8,560,000	21,256	8,154,181	20,515	783,153	54,405	104,066	38,893	169,370	-----	2,160,904	1,130,581	17,690,601	1,976,790	-----	40,544,000
1984	6,368,620	8,950,000	28,660	6,179,690	14,741	1,491,487	71,409	468,753	19,950	82,653	-----	5,147,912	1,107,332	8,482,074	2,095,429	18,009	23,536,000
1985	3,584,565	9,308,000	68,025	6,089,254	22,506	1,437,132	83,297	383,797	53,185	133,933	-----	6,604,729	1,256,375	17,602,208	1,531,569	-----	20,636,000
1986	3,384,779	7,964,000	56,143	532,778	16,000	1,245,317	41,452	276,110	62,132	136,351	-----	6,574,845	1,184,090	16,883,098	1,153,820	-----	24,418,000
1987	3,063,684	7,880,000	113,258	11,140,031	6,884	912,963	100,182	210,976	179,528	127,104	-----	9,959,960	1,188,881	18,563,149	1,858,678	11,674	26,110,000
1988	3,258,034	9,350,000	138,067	8,682,920	12,746	1,133,763	79,997	217,402	107,032	262,779	690,655	14,401,883	1,114,559	19,050,726	1,938,700	10,917	22,758,000
1989	5,399,826	10,136,000	133,262	2,406,757	25,012	1,027,804	62,465	135,945	107,369	100,622	2,642,540	16,088,904	1,213,193	20,494,006	2,790,853	8,196	43,640,000
1990	7,073,116	10,672,000	169,931	9,577,955	25,996	774,869	119,468	80,397	83,889	176,963	4,894,473	12,166,681	924,448	16,393,533	2,345,841	14,105	10,920,000
1991	8,848,805	10,720,000	341,646	562,060	16,293	995,435	345,090	102,938	77,638	156,290	303,228	15,196,946	1,041,167	16,196,408	1,735,834	6,147	3,736,000

1 Aggregated under unspecified flounders until 1982.

SMB-26987

YEARLY COMMERCAL LANDINGS IN POUNDS
Fish

	Pacific Mackerel	Opah	Blackgill Rockfish *	Bocaccio/ Chilipepper Rockfish 1	Widow Rockfish 2	Total Rockfish	Sablefish	Salmon, all 3	Sanddabs	Sardine	Sardine for Live Bait	Scorpionfish	Giant Seabass	White Seabass	Pacific Angel Shark	Blue Shark	Common Thresher
1970	621,919	-----	-----	-----	-----	10,686,844	4,428,077	6,611,322	678,505	442,319	-----	154,961	129,541	1,101,445	-----	-----	-----
1971	155,847	-----	-----	-----	-----	11,168,746	4,424,463	8,116,878	785,401	297,886	-----	131,144	117,258	823,884	-----	-----	-----
1972	108,078	-----	-----	-----	-----	16,421,252	8,395,714	6,423,289	920,822	372,230	-----	132,016	95,313	777,388	-----	-----	-----
1973	56,848	-----	-----	-----	-----	22,052,455	8,550,071	9,668,984	904,001	151,599	-----	158,860	90,837	808,905	-----	-----	-----
1974	133,446	-----	-----	-----	-----	21,498,984	12,038,542	8,749,414	975,276	14,050	-----	157,833	80,439	752,496	-----	-----	-----
1975	287,121	-----	-----	-----	-----	23,624,150	14,131,964	6,925,082	1,015,557	5,300	-----	173,452	59,291	1,182,410	-----	-----	-----
1976	353,729	2,458	-----	-----	-----	24,603,179	13,331,261	7,786,288	1,293,872	16,190	-----	173,675	56,128	1,058,673	-----	-----	-----
1977	11,950,000	-----	-----	-----	-----	20,900,305	13,315,975	5,928,633	809,615	4,576	-----	116,734	49,363	1,199,644	366	-----	129,522
1978	25,080,000	-----	-----	-----	-----	20,510,364	17,715,724	6,810,990	743,206	1,920	-----	71,209	66,227	1,160,755	82,383	-----	302,073
1979	60,942,000	-----	-----	8,935,837	-----	28,568,319	28,573,600	8,749,778	1,322,739	20,572	-----	32,745	40,942	1,205,666	128,295	-----	735,743
1980	65,290,000	-----	-----	10,115,735	-----	36,146,801	10,284,930	6,023,229	1,280,474	46,839	26,000	59,168	38,623	997,412	112,051	192,130	1,806,007
1981	83,826,000	2,989	-----	7,831,367	4,967,944	40,094,541	14,727,481	6,046,164	942,163	32,554	12,000	56,284	37,903	776,033	268,640	203,074	1,974,037
1982	62,550,000	69,347	-----	10,604,864	22,642,385	53,785,436	20,996,253	8,001,858	1,057,614	4,010	84,000	62,264	6,999	70,795	318,960	57,838	2,397,171
1983	71,764,000	179,914	-----	9,841,652	7,634,619	40,537,722	14,613,392	2,414,883	565,839	1,384	426,000	31,719	3,740	77,964	360,323	13,983	1,726,646
1984	93,062,000	516,126	-----	7,196,636	5,928,425	36,300,158	10,633,321	2,982,656	553,068	2,598	118,000	24,984	11,118	118,099	633,273	3,864	1,659,104
1985	76,300,000	394,873	-----	6,299,317	6,524,827	32,898,526	11,305,795	4,644,406	971,417	12,876	26,000	34,501	11,809	125,380	1,248,487	2,385	1,540,799
1986	91,006,000	218,769	284,633	6,766,491	5,266,591	31,209,380	13,585,936	7,604,146	981,297	856,444	38,000	15,544	12,953	106,671	1,241,130	3,316	606,595
1987	91,780,000	92,493	455,718	5,029,313	4,684,568	30,147,834	9,585,601	9,302,399	1,175,880	968,776	576,000	28,823	12,037	116,490	940,187	3,410	525,104
1988	94,576,000	67,868	647,758	4,023,966	3,739,741	26,366,333	8,360,454	14,760,502	1,164,144	2,619,999	110,000	29,869	12,337	107,619	491,348	7,147	536,711
1989	79,640,000	116,966	575,215	4,110,006	3,458,063	28,480,931	8,715,410	5,818,273	1,408,187	1,844,620	222,000	17,639	8,760	116,023	268,252	13,521	649,984
1990	82,278,000	103,606	510,557	3,853,439	4,177,310	30,629,038	8,042,899	4,439,403	1,433,861	3,668,983	1,198,000	8,407	7,259	133,692	250,850	43,675	461,606
1991	68,248,000	81,678	618,703	4,122,938	2,536,781	24,130,839	7,300,661	3,701,677	1,232,085	16,727,151	600,000	1,452	11,741	163,803	181,765	1,200	758,266

* Aggregated as rockfish prior to 1986.

1 Aggregated as rockfish prior to 1979.

2 Aggregated as rockfish prior to 1981.

3 Includes all species of salmon.

SMB-26988

YEARLY COMMERCAL LANDINGS IN POUNDS

Fish

	Leopard Shark	Shortfin Mako Shark	Soupfin Shark	Unspecified Shark [1]	Sheephead	Jacksmelt/ Topsmelt Silversides	Skates	Smelt, all	Dover Sole	English Sole	Petrale Sole	Rex Sole	Sand Sole	Unspecified Sole	Total Surfperch	Swordfish	Thornyhead
1970	-----	-----	-----	420,318	3,805	-----	102,982	811,364	15,160,886	3,282,316	3,415,708	1,741,479	193,291	19,751	241,409	944,745	-----
1971	-----	-----	-----	421,335	8,854	-----	61,233	495,153	14,248,719	2,964,015	3,704,384	1,467,875	292,417	15,495	184,938	154,418	-----
1972	-----	-----	-----	400,769	7,084	-----	118,386	703,656	22,081,697	3,001,965	3,575,245	1,661,610	389,152	30,057	272,913	265,982	-----
1973	-----	-----	-----	418,694	3,072	-----	133,433	1,307,180	22,485,725	3,209,733	2,876,989	1,584,734	240,342	24,399	138,000	613,544	-----
1974	-----	-----	-----	497,359	3,721	-----	86,158	768,844	19,087,485	3,813,499	3,430,685	1,381,737	239,948	32,464	148,086	649,502	-----
1975	-----	-----	-----	533,954	6,031		135,291	648,325	22,688,520	4,314,262	3,269,998	1,646,421	181,647	45,022	113,757	865,536	-----
1976	-----	-----	-----	862,204	8,325	11,256	161,137	627,416	22,756,812	4,282,998	2,977,557	2,012,820	249,497	45,458	142,037	83,623	-----
1977	-----	19,911	162,166	1,070,685	6,409	42,766	161,426	878,206	21,923,851	3,403,057	2,200,713	1,548,006	243,765	61,212	110,233	511,388	3,236,741
1978	-----	-----	176,070	1,184,411	11,144	8,686	275,057	372,317	20,770,086	3,974,782	2,634,044	1,537,347	249,515	59,833	174,064	2,604,233	2,929,147
1979	-----	35,334	276,428	1,157,227	8,819	60,121	309,521	546,843	23,394,091	5,006,960	3,061,810	1,914,805	670,464	20,039	201,160	586,529	4,095,940
1980	-----	155,336	192,336	1,423,633	9,105	33,685	155,216	560,437	18,046,924	4,573,524	2,350,525	1,899,609	356,781	99,580	162,952	1,197,187	3,398,388
1981	-----	277,345	264,938	909,596	12,910	16,683	631,420	425,506	20,418,283	3,773,262	1,775,054	1,727,754	439,843	57,972	182,675	1,142,897	3,876,483
1982	-----	533,839	250,504	449,024	11,776	88,770	287,808	698,396	22,089,490	3,221,471	1,741,721	1,466,411	327,835	69,852	367,704	1,691,161	4,457,691
1983	-----	330,260	177,770	433,410	12,634	87,864	185,690	310,726	18,913,890	2,607,636	1,287,287	1,410,762	238,859	33,930	211,556	2,675,218	3,732,113
1984	-----	242,837	278,541	314,251	25,098	49,881	116,293	482,563	21,563,432	2,098,964	1,301,912	1,252,976	142,825	164,985	182,120	4,393,278	4,670,270
1985	-----	226,695	277,740	277,951	28,500	8,563	195,837	1,075,513	26,499,393	2,341,942	1,888,394	1,979,244	283,474	169,411	122,078	5,196,685	6,485,657
1986	74,741	473,684	212,279	201,201	29,252	4,902	150,125	633,716	24,365,419	2,385,989	1,600,400	1,856,179	354,366	143,691	124,983	3,845,932	6,494,560
1987	55,371	612,020	201,489	167,867	243,711	1,115	169,712	928,798	23,723,648	2,914,768	1,815,856	1,818,777	336,259	78,856	145,751	2,741,015	6,508,187
1988	41,737	489,217	140,366	44,236	29,345	9,358	127,861	867,271	18,071,140	2,351,350	1,752,940	1,854,324	247,980	56,520	107,284	2,484,428	9,956,776
1989	50,459	388,322	165,324	22,775	33,039	5,751	174,659	745,147	17,027,320	2,321,586	1,853,165	1,651,684	244,099	46,357	118,010	2,861,277	11,846,487
1990	41,295	577,128	125,726	18,111	123,526	3,590	143,754	900,527	13,933,132	1,967,050	1,495,680	1,226,691	207,539	27,282	137,745	1,871,535	11,884,714
1991	47,742	322,097	105,010	10,704	191,774	4,786	113,222	1,345,154	17,021,228	1,789,777	1,619,211	1,369,558	144,706	59,787	104,778	1,564,946	6,313,169

[1] All shark landings aggregated until 1977.

SMB-26989

YEARLY COMMERCAL LANDINGS IN POUNDS
Fish

	Albacore Tuna	Bigeye Tuna	Bluefin Tuna	Skipjack Tuna	Yellowfin Tuna	Turbot	Whitefish, Ocean	Yellowtail
1970	29,931,714	18,460	8,655,295	76,480,634	231,956,638	28,067	1,778	184,223
1971	36,116,734	1,806,038	17,250,966	101,377,638	150,941,111	24,882	3,706	390,520
1972	21,001,214	191,476	24,877,721	35,944,884	241,704,982	18,123	2,569	258,071
1973	8,640,832	905,193	20,187,207	29,809,281	232,793,961	36,400	1,584	235,622
1974	11,806,150	290,139	11,605,792	59,975,341	246,110,479	20,681	2,359	204,957
1975	15,412,778	385,472	16,360,774	73,810,130	234,252,185	27,697	-----	210,411
1976	27,759,376	1,859,966	18,789,445	122,694,052	276,064,610	29,590	-----	475,931
1977	15,904,840	3,340,145	6,939,994	81,620,289	195,596,189	19,985	-----	1,814,650
1978	21,549,428	2,788,328	9,561,343	137,185,991	191,100,304	21,902	2,371	460,782
1979	8,442,098	1,567,136	13,273,516	94,796,032	165,845,675	42,657	-----	427,612
1980	11,958,760	2,008,087	5,371,000	174,406,052	190,185,117	21,238	-----	365,176
1981	20,584,321	2,574,736	1,912,748	127,578,862	167,751,112	33,776	-----	347,297
1982	9,436,938	2,133,648	5,301,256	92,381,839	136,176,299	47,358	-----	75,109
1983	16,545,410	47,130	1,682,296	99,196,795	122,885,366	46,803	-----	171,956
1984	26,126,747	277,364	1,400,998	68,896,983	77,299,186	23,053	-----	132,165
1985	14,197,002	14,624	7,173,299	6,562,190	33,123,315	29,729	-----	259,759
1986	7,248,173	63,316	10,431,044	3,000,340	47,436,173	19,847	-----	57,746
1987	3,511,503	648,508	1,814,041	12,619,100	51,149,000	42,582	7,036	56,866
1988	2,669,538	14,172	1,771,706	19,539,462	43,033,185	23,810	3,099	85,131
1989	1,918,914	1,374	2,246,118	9,932,415	38,834,297	30,574	3,175	28,329
1990	1,902,318	4,766	2,040,073	4,472,810	18,759,062	20,164	6,074	40,267
1991	1,493,811	16,092	228,896	7,511,801	9,209,749	20,574	5,027	21,560

TOTAL YEARLY COMMERCIAL LANDINGS AND SHIPMENTS IN POUNDS

	Total Landings (pounds)	Dollar Value
1970	703,215,504	86,253,713
1971	582,295,875	86,266,200
1972	638,241,215	95,044,984
1973	718,004,675	104,510,026
1974	672,344,243	128,191,987
1975	861,314,856	126,740,644
1976	900,967,215	182,789,254
1977	856,144,240	188,289,507
1978	670,053,674	216,743,141
1979	702,242,452	214,698,939
1980	800,722,903	315,932,739
1981	790,345,980	286,606,524
1982	696,874,526	233,273,606
1983	521,966,215	189,379,911
1984	450,848,999	168,326,050
1985	356,960,048	126,783,211
1986	416,390,311	168,553,504
1987	443,382,318	205,131,634
1988	495,692,537	201,002,420
1989	487,902,000	180,847,008
1990	395,754,431	158,851,000
1991	371,457,600	139,418,144

SMB-26990

NUMBER OF FISH BY SPECIES, NUMBER OF ANGLERS, CATCH PER ANGLER, AND THE NUMBER OF COMMERCIAL PASSENGER-CARRYING FISHING VESSELS (CPFV) REPORTING, 1970-1990.

SPECIES	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
ALBACORE	112,106	160,361	86,890	9,858	12,814	81,362	84,973	70,274	92,646	10,196	21,309	26,648	36,690	17,161	211,285	172,493	27,322	7,046	559	29,728	3,816
BARRACUDA, CALIFORNIA	373,801	50,474	38,343	92,483	55,284	26,289	107,557	48,701	73,174	69,434	27,909	69,926	73,135	81,909	87,414	75,448	88,118	137,913	148,058	137,222	196,030
BASS, GIANT SEA	487	508	264	816	419	228	561	205	140	574	653	221	45	13	97	81	74	41	41	73	109
BASS, KELP & SAND	922,260	948,121	642,681	656,195	618,034	499,691	635,821	308,089	476,982	462,980	585,432	739,562	587,349	463,270	359,913	572,620	700,602	734,365	770,780	815,065	863,692
BASS, STRIPED	15,260	13,381	31,690	20,120	41,561	17,561	10,677	8,263	2,608	7,370	1,391	2,985	3,646	14,206	13,524	9,686	8,572	8,858	10,415	2,167	2,356
BONITO	651,898	152,795	418,984	472,451	141,619	80,438	197,382	161,962	315,643	338,476	560,508	654,051	218,478	348,050	377,678	120,139	340,480	517,523	250,495	339,382	263,007
CABEZON	6,372	4,611	11,452	7,551	6,964	6,433	6,445	5,620	8,887	5,469	6,208	5,030	5,247	3,758	1,759	1,760	4,386	4,773	5,418	6,353	6,713
CROAKER, WHITE	18,519	21,112	28,811	20,158	27,531	27,456	21,165	20,122	17,630	11,834	27,461	9,228	10,162	7,738	4,649	3,166	11,981	3,225	121,478	15,062	4,861
CROAKER, YELLOWFIN	770	2,230	597	627	176	1,300	278	139	285	199	123	337	549	112	587	234	295	289	875	4,274	661
DOLPHIN FISH	103	188	206	5,941	1,967	604	6,509	4,300	2,330	9,184	8,840	1,281	1,099	4,992	6,532	1,307	1,866	3,518	3,349	2,341	31,548
FLATFISH, UNSPECIFIED	43,698	22,115	23,057	29,728	37,415	25,006	18,684	13,330	13,361	15,980	17,710	11,766	12,453	7,772	11,896	11,362	12,793	10,311	16,644	28,697	14,585
HALFMOON	160,712	318,060	150,637	168,438	46,736	132,858	35,965	50,675	44,970	100,092	73,881	57,768	66,329	27,659	29,429	8,948	67,296	32,296	84,609	74,031	47,963
HALIBUT, CALIFORNIA	29,968	10,398	8,140	9,632	10,292	9,118	10,075	6,982	5,409	6,329	6,517	11,440	11,804	5,682	3,209	7,090	7,848	7,560	11,926	9,116	6,658
LINGCOD	61,833	65,239	100,965	80,778	79,685	88,976	80,863	46,521	65,869	75,826	89,349	65,604	49,791	30,543	23,797	20,603	25,585	42,504	66,567	76,517	59,845
MACKEREL, JACK	15,725	10,611	5,913	15,789	12,467	5,677	5,504	8,789	5,237	2,957	4,166	2,984	4,404	5,308	13,261	6,825	4,390	3,056	21,883	4,422	8,059
MACKEREL, PACIFIC	129,770	224,223	345,882	199,104	102,619	129,944	51,441	484,722	940,204	1,272,038	1,315,971	1,007,198	914,238	630,006	604,334	695,708	605,716	517,166	412,924	363,700	472,006
MARLIN, UNSPECIFIED	52	32	12	34	29	5	10	33	13	34	58	67	33	65	287	68	43	168	134	40	105
ROCKFISH, UNSPECIFIED	2,663,882	2,222,943	3,034,930	3,370,356	4,045,122	3,916,085	3,597,114	3,216,071	2,955,435	3,713,670	3,322,952	3,315,718	3,089,655	2,346,270	2,015,791	2,043,129	1,802,607	1,699,034	1,892,277	2,191,495	2,275,806
SABLEFISH	2,630	7,057	4,830	12,457	41,625	23,704	3,688	3,306	3,719	19,933	26,479	5,571	1,578	15	568	3,928	7,430	3,375	2,804	1,744	533
SALMON, UNSPECIFIED	98,301	130,812	151,595	124,676	107,942	73,857	66,099	56,157	45,646	69,904	64,500	65,629	102,576	55,560	71,491	108,343	88,679	126,202	111,375	111,114	88,331
SCORPIONFISH, SPOTTED	82,522	84,913	65,886	83,475	85,956	81,438	47,524	73,214	44,114	64,226	95,615	73,362	67,339	50,834	46,538	66,762	72,675	59,125	132,520	163,552	160,948
SEABASS, WHITE	4,359	5,265	3,858	7,083	4,003	3,158	2,671	2,096	433	1,352	1,002	887	1,899	1,003	973	1,045	1,634	616	2,383	1,365	2,563
SHEEPHEAD, CALIFORNIA	30,464	30,300	33,541	46,334	30,379	30,496	32,926	28,513	34,409	31,995	34,368	46,479	37,242	68,972	38,522	35,934	36,707	21,072	31,701	23,612	34,374
STURGEON, UNSPECIFIED	1,165	912	976	642	577	501	572	337	645	587	365	295	614	750	530	765	952	418	386	437	181
TUNA, BLUEFIN	1,833	749	1,470	5,347	5,765	3,348	2,040	1,838	479	1,087	729	542	665	1,912	2,834	4,980	693	1,859	321	6,519	3,756
TUNA, YELLOWFIN	3,840	6,622	849	1,783	2,524	2,356	4,437	7,689	6,708	4,042	11,217	4,559	2,035	116,298	8,648	3,898	5,505	14,794	20,065	19,076	49,118
TUNA, SKIPJACK	15,561	62	281	855	1,345	455	5,400	21,423	10,520	487	3,891	435	32	103,040	30,357	238	2,249	8,181	1,898	19,736	16,305
WHITEFISH, OCEAN	40,990	29,800	42,362	24,632	23,301	35,165	38,363	61,058	38,006	36,957	28,810	24,378	22,604	22,095	64,241	84,381	73,919	34,967	59,682	44,777	44,789
YELLOWTAIL, CALIFORNIA	97,376	44,608	50,031	221,287	121,149	19,742	28,962	34,141	58,528	71,483	44,246	88,911	37,308	178,688	96,018	45,509	42,005	58,537	68,020	61,746	69,805
ALL OTHER FISH	35,560	29,360	26,343	25,958	26,313	30,300	25,787	14,913	12,320	25,963	26,289	20,674	11,646	31,235	46,241	43,246	32,609	24,060	76,273	40,187	34,500
TOTAL NUMBER OF FISH	5,630,835	4,604,152	5,462,405	5,923,478	5,691,603	5,354,051	5,149,493	4,849,472	5,256,351	6,630,658	6,407,949	6,314,534	5,370,645	4,624,996	4,172,303	4,149,696	4,075,121	4,102,852	4,325,890	4,593,550	4,763,023
NUMBER OF ANGLERS	837,327	728,126	792,618	880,100	809,100	748,052	725,674	716,536	732,460	786,347	761,958	830,653	775,973	691,792	701,737	711,787	660,294	678,594	706,286	689,422	765,431
NUMBER OF BOATS REPORT	387	-	439	467	370	371	367	328	317	335	303	291	310	322	323	313	302	287	313	308	309
CATCH / ANGLER	6.72	6.32	6.89	6.73	7.03	7.16	7.00	6.77	7.18	8.43	8.41	7.60	6.92	6.69	5.95	5.83	6.17	6.05	6.12	6.66	6.22

SMB-26991

INDEX

Abalone 33, 180
Agar 5
Albacore 136
Anchovy 81
Angel Shark 46
Arrowtooth Flounder 105
Atlantic Salmon 189
Banded Chione Clam 26
Bank Rockfish 129
Barracuda 157
Barred Sand Bass 151
Barred Surfperch 172
Basking Shark 55
Bat Ray 56
Bay Shrimp 12
Big Skate 57
Black Abalone 33
Black and Yellow Rockfish 130
Blackcod 108
Black Perch 172
Black Rockfish 117
Blackgill Rockfish 120
Blue Rockfish 118
Blue Shark 53
Blue Whale 213
Bluefin Tuna 138
Rocaccio 120
Bonito 143
Bottlenose Dolphin 215
Box Crab 192
Brown Rock Crab 18
Brown Rockfish 127
Butter Sole 105
Butter Clam 32
Butterfish 108
C-O Turbot 105
Cabezon 160
Calico Surfperch 173
California Sea Lion 208
California Skate 57
Canary Rockfish 129
Carrageenan 5
Chilipepper 122
Chimaera 197
China Rockfish 130
Chinook Salmon 60, 190
Chub Mackerel 91
Chum Salmon 60
Clams 26, 27, 29, 31, 32
Coho Salmon 60, 189
Common Dolphin 214
Common Littleneck Clam 26
Copper Rockfish 128
Corbina 168
Coronado Sea Urchin 42
Cow Shark 54
Crab 14, 15, 18, 20
Croakers 168, 170
Curlfin Turbot 105
Dall's Porpoise 216
Delta Smelt 75
Diamond Turbot 105
Dolphins 211
Dover Sole 97
Dungeness Crab 15
Dwarf Perch 172
Eastern Oyster 183
Electric Ray 58
Elephant Seal 210
English Sole 99
Eulachon 75
European Oyster 184
Fantail Sole 105
Fat Gaper Clam 31
Fin Whale 213
Flat Abalone 35
Flounder 103, 105
Fur Seals 209, 210
Gaper Clam 31
Giant Red Sea Cucumber 44
Giant Sea Bass 153
Gopher Rockfish 130
Grass Rockfish 130
Gray Whale 214
Green Abalone 33, 180
Grenadier 198
Grunion 78
Guadalupe Fur Seal 210
Guitarfish 58
Hagfish 196
Hake 109
Halfmoon 177
Halibut 94, 105
Harbor Porpoise 216
Harbor Seal 209
Herring 86
Hornyhead Turbot 105
Humpback Whale 212
Island Seaperch 171
Jack Mackerel 89
Jacksmelt 78
Japanese Littleneck Clam 26
Kellet's whelk 193
Kelp 2
Kelp Bass 150
Kelp Greenling 164
Kelp Perch 172
Kelp Rockfish 130
Killer Whale 214
Kingfish 170
Leopard Shark 48
Lingcod 161
Littleneck Clams 26
Lobster 22
Longfin Sanddab 104
Longfin Smelt 75
Longnose Skate 57
Longspine Thornyhead 132
Louvar 113
Mackerel 89, 91
Mackerel Shark 55
Manila Clam 26
Marine Birds 222
Market Squid 36
Marlin 146
Minke Whale 213
Mussels 181
Native Oyster 183
Night Smelt 75
Northern Fur Seal 209
Northern Right-Whale Dolphin 215
Ocean Shrimp 8
Ocean Sunfish 202
Ocean Whitefish 201
Octopus 194
Olive Rockfish 123
Olympic Oyster 183
Opah 112
Opaleye 177
Oriental Shrimp 13
Oysters 183
Pacific Gaper Clam 31
Pacific Halibut 105
Pacific Mackerel 91
Pacific Oyster 184
Pacific Sanddab 104
Pacific White-sided Dolphin 215
Pelagic Red Crabs 195
Petrale Sole 100
Pile Perch 173
Pink Abalone 33, 180
Pink Salmon 60
Pink Seaperch 172
Pinniped 208
Pinto Abalone 35
Pismo Clam 27
Porpoises 211
Prawn 10, 11
Purple Sea Urchin 41
Queenfish 170
Rainbow Perch 172
Ratfish 197
Rays 56
Razor Clam 29
Red Abalone 33, 180

SMB-26992

Red Algae 5
Red Rock Crab 18
Red Sea Urchin 41
Redtail Surfperch 174
Reef Perch 172
Rex Sole 102
Ridgeback Prawn 11
Risso's Dolphin 215
Rock Crab 18
Rock Scallops 187
Rock Sole 105
Rockfishes 114
Rough-sided Littleneck Clam 26
Round Stingray 58
Rubberlip Seaperch 174
Sablefish 107
Salmon 60, 188
Salmon Shark 55
Sand Basses 151
Sand Crab 14
Sand Sole 105
Sandabs 104
Sardine 83
Saury 199
Scorpionfish 133
Sea Bass 153, 165
Sea Cucumbers 44
Sea Lions 208
Sea Otter 216
Sea Urchin 41
Seabass 165
Seabirds 221
Sevengill Shark 54
Sharks 46
Sharpnose Seaperch 172
Sheep Crab 20
Sheephead 175
Shiner Perch 171
Short-finned Pilot Whale 214
Shortbelly Rockfish 126
Shortfin Mako 51
Shortspine Thornyhead 132
Shovelnose Guitar Fish 56
Shrimp 8, 12
Silver Seaperch 172
Silversides 78
Sixgill Shark 54
Skates 56
Skipjack Tuna 140
Slender Sole 105
Smelt 75
Smooth Chione Clam 26
Sockeye Salmon 60
Sole 97, 99, 100, 102, 105
Speckled Sanddab 104
Spider Crab 21
Spiny Lobster 22
Spot Prawn 10
Spotfin Croaker 168
Spotfin Surfperch 172
Spotted Sand Bass 151
Spotted Turbot 105
Squid 36
Starry Flounder 103
Steelhead 67, 189
Steller Sea Lion 208
Striped Bass 72
Striped Marlin 146
Striped Seaperch 174
Sturgeon 70
Sunfish 202
Surf Smelt 75
Surfperches 171
Swordfish 148
Thin-shelled Littleneck Clam 26
Thornyheads 132
Threaded Abalone 35
Thresher Shark 49
Topsmelt 78
Treefish 130
Tuleperch 171
Tuna 136
Turbot 105
Vermilion Rockfish 123
Wagasaki Smelt 75
Walleye Surfperch 175
Warty Sea Cucumber 44
Washington Clam 32
Wavy Chione Clam 26
Whales 211
Whelk 193
White Abalone 34
White Croaker 170
White Sea Urchin 42
White Seabass 165
White Seaperch 171
White Shark 55
White Sturgeon 70
Whitebait Smelt 75
Whitefish 201
Whiting 109
Widow Rockfish 125
Yellow Rock Crab 18
Yellowfin Croaker 168
Yellowfin Tuna 140
Yellowtail 155

SMB-26993