Community Climate Charts

What's up — or down — in your corner of the North?

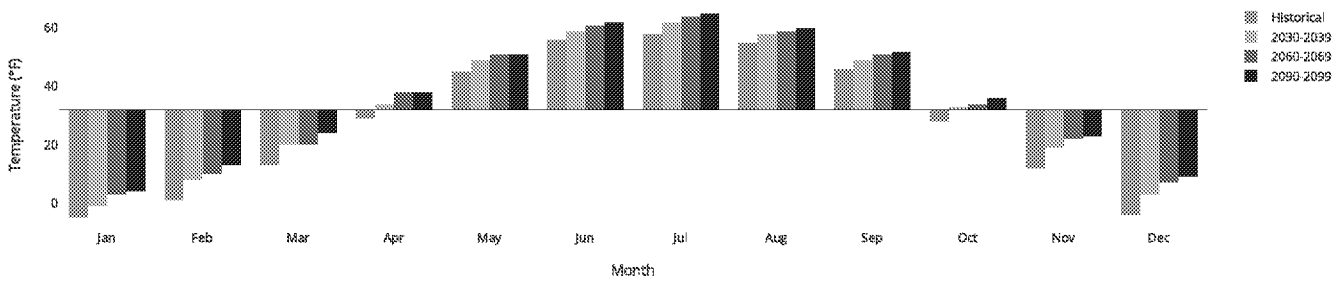
See temperature and precipitation projections through 2099 for over 3,800 communities in Alaska and western Canada.

These projections show only patterns and trends. Look for changes like these:

Higher temperatures in spring and fall could mean a longer growing season and/or a shift from snow to rain.

Warmer, drier spring weather may increase fire risk.

Happy exploring!



These plots are useful for examining possible trends over time, rather than for precisely predicting values.
Credit: Scenarios Network for Alaska + Arctic Planning, University of Alaska Fairbanks.

How to interpret climate outlooks for your community

Climate systems naturally change year to year, as do the models built to simulate them. Because of that, these charts are best for examining trends over time, and not for precise predictions. This tool reports precipitation in terms of rainwater equivalent, even though it could occur as rain or snow.

Look for key changes

For example, higher monthly temperatures in spring and fall may be particularly interesting. Higher temperature could mean any or all of these things:

- A longer growing season.
- A loss of ice and/or frozen ground needed for travel or food storage.
- Precipitation changes. In many locations, winter temperatures are projected to increase dramatically. A shift from snow to rain impacts water storage capacity and surface water availability.
- Increased fire risk. Early snow-melt, warm springs, and hot summers may dry soils and vegetation.
- Changes in species composition. Warmer winters may favor species that are less cold-hardy (including desirable crops and invasive species), or it may mean less snow and/or more rain-on-snow events that impact wildlife.
- Thawing. Higher temperatures will impact permafrost and land-fast ice.

Scenarios (RCPs)

This tool uses Representative Concentration Pathways (RCPs) to display climate scenarios. RCPs describe paths to future climates based on atmospheric greenhouse gas concentrations. They represent climate futures, or scenarios,

extrapolated out to the year 2100, based on a range of possible future human behaviors. RCPs provide a basis for comparison and a "common language" for modelers to share their work.

The RCP values 4.5, 6.0, and 8.5 indicate projected radiative forcing values—the difference between solar energy absorbed by Earth vs. energy radiated back to space—measured in watts per square meter. RCP X projects that in 2100 the concentration of greenhouse gases will be such that each square meter of Earth will absorb X times more solar energy than it did in 1750.

- RCP 4.5 — "low" scenario. Assumes that new technologies and socioeconomic strategies cause emissions to peak in 2040 and radiative forcing to stabilize after 2100.
- RCP 6.0 — "medium" scenario. Assumes that emissions peak in 2080 and radiative forcing stabilizes after 2100.
- RCP 8.5 — "high" scenario. Emissions increase through the 21st century.

Download Data

All data used by this tool can be downloaded as a single CSV file from the SNAP Data Portal.

Government of Northwest Territories Gouvernement des Territoires du Nord-Ouest

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This tool is part of an ongoing collaboration between the Scenarios Network for Alaska + Arctic Planning and the Government of Northwest Territories. We are working to make a wide range of downscaled climate products that are easily accessible, flexibly usable, and fully interpreted and understandable to users in the Northwest Territories, while making these products relevant at a broad geographic scale.

Please contact uaf-snap-data-tools@alaska.edu if you have questions or would like to provide feedback for this tool. Visit the SNAP Climate + Weather Tools page to see our full suite of interactive web tools.

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About the photo: Springtime comes to Ulukhaktok, NWT. Formerly known as Holman, this Inuvialuit community—whose name translates to "where there is ulu material"—is famous for exquisite Inuit prints. Credit: Anne Kokko, used with permission.

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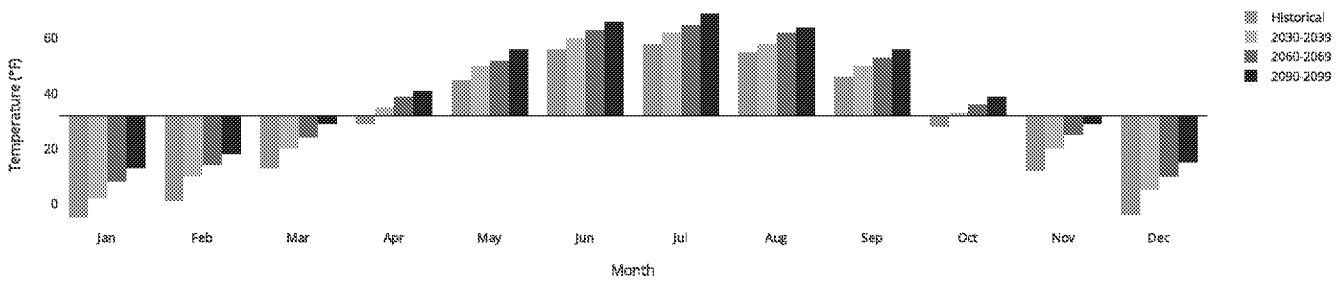

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Climate change is driving a sharp increase in Arctic mercury levels, a new report says

"Global action is necessary to tackle this transboundary issue."

By **Melody Schreiber** - September 7, 2022

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UNITED NATIONS

UNEP

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UNEP/MC/COP.4/INF/24

Distr.: General
20 August 2021

English only

MINAMATA CONVENTION ON MERCURY

Conference of the Parties to the Minamata Convention on Mercury
Fourth meeting
Online, 1–5 November 2021*
Item 4 (d) of the provisional agenda**

Matters for consideration or action by the Conference of the Parties: mercury waste: consideration of the relevant thresholds

Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with mercury or mercury compounds

Note by the secretariat

1. Paragraph 3 of article 11 of the Minamata Convention on Mercury stipulates that each party is to take appropriate measures so that mercury waste is managed in an environmentally sound manner, taking into account the guidelines developed under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and in accordance with requirements that the Conference of the Parties is to adopt in an additional annex in accordance with Article 27.

2. In 2015, at its twelfth meeting, the Conference of the Parties to the Basel Convention, in its decision BC-12/4, adopted technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with mercury or mercury compounds,[1] The Conference of the Parties to the Minamata Convention, in its decision MC-2/2 on mercury waste thresholds, invited the Conference of the Parties to the Basel Convention to consider reviewing, as appropriate, those guidelines, with additional guidance for certain mercury wastes. The Conference of the Parties to the Basel Convention decided, in its decision BC-14/8, that the guidelines should be updated.

3. The Conference of the Parties to the Minamata Convention, in its decision MC-3/5 on mercury waste thresholds, encouraged the parties and other stakeholders to contribute to the process of updating the guidelines by providing comments on the draft updated guidelines when invited to do so, and invited the appropriate bodies of the Basel Convention to take into account decision MC-3/5 in updating the guidelines.

4. The secretariat of the Minamata Convention participated in the meetings of the small intersessional working group established pursuant to decision BC-14/8 of the Conference of the Parties to the Basel Convention and provided an update on the progress made to the group of technical experts on mercury waste thresholds established pursuant to decision MC-2/2.

* The resumed fourth meeting of the Conference of the Parties to the Minamata Convention on Mercury is to convene in person in Bali, Indonesia, and is tentatively scheduled for the first quarter of 2022.

** UNEP/MC/COP.4/1.

[1] UNEP/CHW.12/5/Add.8/Rev.1.

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5. The draft updated technical guidelines,[2] which were prepared by Japan, as the lead country, in consultation with the small intersessional working group, were submitted to the Conference of the Parties to the Basel Convention. The draft updated technical guidelines are reproduced in the annex to the present note. The changes made to the existing guidelines have been tracked so that the revisions can be easily identified. The annex has not been formally edited.

[2] UNEP/CHW.15/6/Add.6.

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Annex

Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with mercury or mercury compounds

(Draft updated version of 1 February 2021)

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Abbreviations and acronyms

AAS	atomic absorption spectrometry
AFS	atomic fluorescence spectrometry
ASGM	artisanal and small-scale gold mining
ASTM	American Society for Testing and Materials
AOX	absorbable organic halides
BAT	best available techniques
CAS	Chemical Abstracts Service
CEN	European Committee for Standardization
CFLs	compact fluorescent lamps
CH_3Hg^+ or $MeHg^+$	monomethylmercury, commonly called methylmercury
Cl	chlorine
EMS	environmental management system
EN	European standard
EPR	extended producer responsibility
ESM	environmentally sound management
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GEMS	Global Environmental Monitoring System
GHS	Globally Harmonized System
HCl	hydrochloric acid
HF	hydrofluoric acid
HFC	hearth furnace coke
Hg	mercury
$HgCl_2$	mercury dichloride
HgO	mercury (II) oxide
HgS	mercury sulphide or cinnabar
$HgSO_4$	mercury sulphate
HNO_3	nitric acid
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICCM	International Conference on Chemicals Management
ICP	inductively coupled plasma
IIED	International Institute for Environment and Development
ILO	International Labour Organization
IMERC	Interstate Mercury Education and Reduction Clearinghouse
IMO	International Maritime Organization
ISO	International Organization for Standardization
JIS	Japanese Industrial Standard
JLT	Japanese standardized leaching test
JSA	Japanese Standards Association
LCD	liquid crystal displays
LED	light emitting diode
LFLs	linear fluorescent lamps
MEE	Ministry of Ecology and Environment (China)
MMSD	Mining, Minerals and Sustainable Development (IIED/WBCSD project)
MSW	municipal solid waste
NEMA	National Electrical Manufacturers Association
NEWMOA	Northeast Waste Management Officials' Association
NIMD	National Institute for Minamata Disease
NOx	nitrogen oxide
OEWG	Open-ended Working Group (of the Basel Convention)
OECD	Organisation for Economic Co-operation and Development
PACE	Partnership for Action on Computing Equipment
PBB	polybrominated biphenyls
PBDE	polybrominated diphenyl ethers
PCB	polychlorinated biphenyl
PCDDs/PCDFs	polychlorinated dibenzodioxins/polychlorinated dibenzo-furans
PRTR	pollutant release and transfer register
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
QSC	Quicksilver Caucus
QSP	Quick Start Programme
RoHS	Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive)
SAICM	Strategic Approach to International Chemicals Management

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SETAC	Society of Environmental Toxicology and Chemistry
SO_2	sulphur dioxide
SOP	standard operational procedure
SPC	sulphur polymer cement
SPSS	sulphur polymer stabilization and solidification
S/S	stabilization and solidification
TCLP	toxicity characteristic leaching procedure
TOC	total organic carbon
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
USEPA	Environmental Protection Agency (United States of America)
VCM	vinyl chloride monomer
WEEE	waste electrical and electronic equipment
WHO	World Health Organization

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WBCSD

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World Business Council for Sustainable Development

Units of measurement

µg	microgram
mg	milligram
g	gram
kg	kilogram
mg/kg	milligram(s) per kilogram. Corresponds to parts per million (ppm) by mass.
L	liter
m^3	cubic meter
cm^3	cubic centimeter
°C	degree Celsius

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I. Introduction

A. Scope

1. The present technical guidelines provide guidance on the environmentally sound management (ESM) of wastes consisting of, containing, or contaminated with mercury[1] or mercury compounds[2], hereinafter referred to as "mercury wastes", pursuant to decisions under the Basel and the Minamata Conventions[3]. This document supersedes the Basel Convention *Technical guidelines for the ESM of wastes consisting of, containing or contaminated with mercury or mercury compounds*, adopted by the Conference of the Parties at its twelfth meeting.

2. In addition, the present technical guidelines address provisions referred to in Article 11, paragraph 3 (a) to (c) and Article 3, paragraphs 4 and 5 (b) of the Minamata Convention. Article 11, paragraph 3 (a), of the Minamata Convention provides for a link between the present guidelines and the obligations of Parties to the Minamata Convention to manage mercury waste in an environmentally sound manner. For further details, see section II.B.1 of the present guidelines.

4. The present guidelines focus on mercury wastes categorized as hazardous wastes or other wastes as defined under the Basel Convention and mercury wastes as defined by the Minamata Convention.

2. The following mercury wastes are covered by the present guidelines (see tables 1 and 4 for additional information[4]):

A: Wastes consisting of mercury or mercury compounds (e.g., excess mercury from the decommissioning of chlor-alkali facilities, mercury recovered[5] from wastes containing mercury or mercury compounds or wastes contaminated with mercury or mercury compounds, or surplus stock of mercury or mercury compounds designated as waste);

B: Wastes containing mercury or mercury compounds, with the following subcategories:

B1: Wastes of products containing mercury or mercury compounds that easily release mercury into the environment, including when they are broken (e.g., mercury thermometers, fluorescent lamps);

B2: Wastes of products containing mercury or mercury compounds other than those listed in B1 (e.g., batteries); and

C: Wastes contaminated with mercury or mercury compounds (e.g., residues generated from mining processes, industrial processes or waste treatment processes).

3. Article 11, paragraph 1, of the Minamata Convention provides for a link between the relevant definitions of the Basel Convention, such as its definition of wastes, and wastes covered by the Minamata Convention. Under Article 11, paragraph 2, of the Minamata Convention, only those wastes (a) consisting of, (b) containing or (c) contaminated with mercury or mercury compounds in a quantity above the relevant thresholds defined by the Conference of the Parties to the Convention are defined as mercury wastes. This definition excludes overburden, waste rock and tailings from mining, except from primary mercury mining, unless they contain mercury or mercury compounds above

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Deleted: <#>The present guidelines focus on mercury wastes categorized as hazardous wastes. ¶
<#> **B. About mercury**[5] ¶

[1] "Mercury" means elemental mercury (Hg(0), CAS No. 7439-97-6) (see Article 2 (d) of the Minamata Convention on Mercury (hereinafter referred to as "Minamata Convention").

[2] "Mercury compound" means any substance consisting of atoms of mercury and one or more atoms of other chemical elements that can be separated into different components only by chemical reactions (see Article 2 (e) of the Minamata Convention).

[3] Decisions VIII/33, IX/15, BC-10/7, BC-11/5, BC-12/4, 14/8 and 15/IX1 of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, decisions VI/20, VII/7 and OEWG-9/4 of the Open-ended Working Group of the Basel Convention, and decisions MC-2/7 and MC-3/5 of the Conference of the Parties to the Minamata Convention.

[4] See paragraph 23 as well.

[5] Taking into account the provisions of the Minamata Convention, the term "recover mercury from wastes" is used in this document both for cases where such recovery falls under an operation included in section B of Annex IV of the Basel Convention or an operation included in section A of Annex IV of the Basel Convention. See also paragraph 179.

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thresholds defined by the Conference of the Parties[8]. Wastes of mercury-added products[9] belong to (b) wastes containing mercury or mercury compounds. According to Article 3, paragraph 5 (b), of the Minamata Convention, excess mercury from the decommissioning of chlor-alkali facilities belongs to (a) wastes consisting of mercury or mercury compounds.

4. The definition of wastes under the Basel Convention is described in paragraph 13 below, and the mercury wastes under the scope of the Basel Convention are described in section II.A.2. It should be noted that the there is no specific definition of "mercury wastes" in the Basel Convention. The mercury thresholds described in the Minamata Convention are independent from the provisions on determination of hazardous wastes and requirements for transboundary movements under the Basel Convention.

B. About mercury[10]

5. Mercury is or has been widely used in products such as measuring devices (barometers, hygrometers, manometers, thermometers, sphygmomanometers), switches and relays, fluorescent lamps, batteries, cosmetics, pesticides, biocides, topical antiseptics and dental amalgam, and in manufacturing processes, such as those involving the production of chlor-alkali, acetaldehydes, vinyl chloride monomers (VCM), sodium or potassium methylates or ethylates, polyurethane, gold plating and products containing mercury or mercury compounds. Mercury may also be a by-product of raw material refining or production processes, such as oil and gas refining and non-ferrous metal production.

6. Mercury emissions and releases can be caused by human activities (i.e., they may be anthropogenic) but may also result from natural sources such as volcanic eruptions. Once mercury is emitted or released into the environment, it persists in the atmosphere (e.g., as mercury vapour, as compounds in particulate form, or on particulates), soil (e.g., as ionic mercury) and water bodies (e.g., methylmercury ($MeHg^+$, or CH_3Hg^+)). Mercury in the air can be carried around the world, eventually being deposited onto soils, waters or plants. From there, it can re-volatilize into the air, or be transported further by water, or be taken into the food web (UNEP, 2019a). The preamble of the Minamata Convention recognizes that mercury is a chemical of global concern owing to its long-range atmospheric transport, its persistence in the environment once released, its ability to bioaccumulate in ecosystems and its significant negative effects on human health and the environment.

7. Handling, collection, transportation or disposal of mercury wastes can lead to emissions or releases of mercury, particularly if carried out improperly.

8. The discharge of wastewater containing mercury into Minamata Bay, Japan, from 1932 to 1968 (Ministry of the Environment of Japan, 2002), the illegal dumping of mercury-contaminated

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[8] The Conference of the Parties has decided that no thresholds need to be established for mercury waste falling under Art. 11(2)(a) and (b) of the Convention, and that, at present, there is no need to develop thresholds for overburden and waste rock from mining other than primary mercury mining, while further work was mandated to establish thresholds for mercury waste falling under Art. 11(2)(c) of the Convention and for tailings from industrial scale non-ferrous metal mining other than primary mercury mining (see decision MC-3/5). See Section II.B.1 for further details.

[9] "Mercury-added product" means a product or product component that contains mercury or a mercury compound that was intentionally added (see Article 2 (f) of the Minamata Convention).

[10] Further information on mercury, including its chemical properties, sources, behaviour in the environment and effects on human health, as well as mercury risks and pollution, is available at the following sources (see bibliography below for full references).

- For chemical properties: Japan Public Health Association, 2001; Steffen et al., 2007; WHO, 2003; Smegel and Veiga, 2006; ILO, 2014 and 2019; Oliveira et al., 1998; and Tajima, 1970.
- For sources of anthropogenic emissions: UNEP, 2008a; and the Zero Mercury Working Group, 2009;
- For behaviour in the environment: Japan Public Health Association, 2001; and Wood, 1974;
- For human health risks: Ozonoff, 2006; Sanborn and Brodberg, 2006; Sakamoto et al., 2005; WHO, 1990; Kanai and Endou, 2003; Kerper, Ballatori, and Clarkson , 1992; Mottet et al., 1985; Sakamoto et al., 2006; Oikawa et al., 1983; Richardson, 2003; Richardson and Allan, 1996; Gay, Cox, and Reinhardt, 1979; Van Boom et al., 2003; Hylander and Meili, 2005; Bull, 2006; WHO, 1972, 1990, 1991, and 2003; Japan Public Health Association, 2001; Canadian Centre for Occupational Health and Safety, undated; Asano et al., 2000; and UNEP and WHO, 2008.
- For mercury pollution, Ministry of the Environment of Japan, 1997 and 2002; Amin-Zaki et al., 1978; Bakir et al., 1973; Demiuji and Tikuti, 1972; UNEP, 2002; Lambrecht, 1989; GroundWork, 2005; The School of Natural Resources and Environment, University of Michigan, 2000; and Butler, 1997.

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waste in Cambodia in 1998 (Honda et al., 2006; NIMD, 1999) and the case involving Thor Chemicals in South Africa (Lambrecht, 1989) are a few examples of cases in which wastes containing or contaminated with mercury or mercury compounds were not managed in an environmentally sound manner.

9. The provisions of the Minamata Convention are intended, inter alia, to reduce mercury supply and demand. The growing global trend towards phasing out mercury-added products and processes using mercury may cause temporary increases in some mercury wastes, particularly wastes consisting of mercury. In some countries, there has been increased use of some products containing mercury or mercury compounds, such as fluorescent lamps, which are being used to replace incandescent lamps, and liquid crystal display (LCD) backlights containing mercury. However, fluorescent lamps are replaced by light emitting diodes (LEDs) in some countries, which are more energy efficient and mercury-free alternatives.

II. Relevant provisions of the Basel Convention and international linkages

A. Basel Convention

1. General provisions

10. The Basel Convention aims to protect human health and the environment against adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes.

11. In Article 2 ("Definitions"), paragraph 1, the Basel Convention defines wastes as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law". Article 2, paragraph 4, of the Convention defines disposal as "any operation specified in Annex IV" to the Convention. Annex IV contains two categories of operations: those leading to the possibility of resource recovery, recycling, reclamation, direct reuse or alternative uses (R operations) and those not leading to this possibility (D operations).

12. Article 4 ("General obligations"), paragraph 1, establishes the procedure by which Parties exercising their right to prohibit the import of hazardous wastes or other wastes for disposal are to inform the other Parties of their decision. Paragraph 1 (a) states: "Parties exercising their right to prohibit the import of hazardous or other wastes for disposal shall inform the other Parties of their decision pursuant to Article 13". Paragraph 1 (b) states: "Parties shall prohibit or shall not permit the export of hazardous or other wastes to the Parties which have prohibited the import of such waste when notified pursuant to subparagraph (a)".

13. Article 4, paragraphs 2 (a) – (e) and 2 (g), and paragraph 8, set out key provisions pertaining to ESM, waste minimization, reduction of transboundary movement, and waste disposal practices aimed at mitigating adverse effects on human health and the environment:

Paragraphs 2 (a) – (e) and 2 (g): "Each Party shall take appropriate measures to:

(a) Ensure that the generation of hazardous wastes and other wastes within it is reduced to a minimum, taking into account social, technological and economic aspects;

(b) Ensure the availability of adequate disposal facilities, for ESM of hazardous wastes and other wastes, that shall be located, to the extent possible, within it, whatever the place of their disposal;

(c) Ensure that persons involved in the management of hazardous wastes or other wastes within it take such steps as are necessary to prevent pollution due to hazardous wastes and other wastes arising from such management and, if such pollution occurs, to minimize the consequences thereof for human health and the environment;

(d) Ensure that the transboundary movement of hazardous wastes and other wastes is reduced to the minimum consistent with the environmentally sound and efficient management of such wastes, and is conducted in a manner which will protect human health and the environment against the adverse effects which may result from such movement;

(e) Not allow the export of hazardous wastes or other wastes to a State or group of States belonging to an economic and/or political integration organization that are Parties, particularly developing countries, which have prohibited by their legislation all

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imports, or if it has reason to believe that the wastes in question will not be managed in an environmentally sound manner, according to criteria to be decided on by the Parties at their first meeting; and

(g) Prevent the import of hazardous wastes and other wastes if it has reason to believe that the wastes in question will not be managed in an environmentally sound manner."

Paragraph 8: "Each Party shall require that hazardous wastes or other wastes, to be exported, are managed in an environmentally sound manner in the State of import or elsewhere".

14. The Ban Amendment entered into force on 5 December 2019, and it provides that Parties listed in Annex VII to the Convention (members of the European Union, OECD and Liechtenstein) shall prohibit transboundary movements to States not listed in Annex VII of hazardous wastes which are destined for operations according to Annex IV.A and hazardous wastes under Article 1, paragraph (a) which are destined for operations according to Annex IV.B[11].

2. Mercury-related provisions

15. Article 1 ("Scope of the Convention") defines the types of waste that are covered by the Basel Convention. Paragraph 1 (a) sets out a two-step process for determining whether a "waste" is a "hazardous waste" covered by the Convention; first, the waste must belong to one of the categories listed in Annex I to the Convention ("Categories of wastes to be controlled"), and second, it must possess at least one of the characteristics listed in Annex III to the Convention ("List of hazardous characteristics").

16. Annex I wastes are presumed to exhibit one or more of the hazardous characteristics listed in Annex III. These may include H6.1 "Poisonous (acute)", H8 "Corrosive", H11 "Toxic (delayed or chronic)", or H12 "Ecotoxic", unless, through "national tests", they can be shown not to exhibit such characteristics. National tests may be useful for identifying a particular hazardous characteristic listed in Annex III until such time as the hazardous characteristic is fully defined. Guidance papers[12] for some Annex III hazardous characteristics have been drafted under the Convention.

17. List A of Annex VIII describes wastes that are "characterized as hazardous under Article 1, paragraph 1 (a) of this Convention" although "their designation on this Annex does not preclude the use of Annex III [hazard characteristics] to demonstrate that a waste is not hazardous". List B of Annex IX includes wastes that "will not be wastes covered by Article 1, paragraph 1 (a), of this Convention unless they contain Annex I material to an extent causing them to exhibit an Annex III characteristic."

18. As stated in Article 1, paragraph 1 (b), "Wastes that are not covered under paragraph (a) but are defined as, or are considered to be, hazardous wastes by the domestic legislation of the Party of export, import or transit" are also subject to the Basel Convention.

19. As stated in Article 1, paragraph 2, "Wastes that belong to any category contained in Annex II that are subject to transboundary movement shall be "other wastes" for the purposes of this Convention".

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[11] For information on the status of individual Parties in relation to the amendment, please see the Status of Ratifications page on the Basel Convention website.

[12] The following papers are available at the Basel Convention website.

"Work on hazard characteristics – Approach to Basel Convention hazard characteristic H11: characterization of chronic or delayed toxicity"

"Interim guidelines on the hazardous characteristic H12 Ecotoxic"

http://basel.int/Implementation/TechnicalMatters/DevelopmentofTechnicalGuidelines/TechnicalGuidelines/tabid/8023/Default.aspx

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20. Mercury wastes listed in annexes I, II and VIII to the Convention are listed in table 1 below.

Table 1: Mercury wastes listed in annexes I, II and VIII to the Basel Convention (emphasis added)

Entries with direct reference to mercury	
Y29	Wastes having as constituents: ***Mercury, mercury compounds***
A1010	Metal wastes and waste consisting of alloys of any of the following: … - ***Mercury*** … but excluding such wastes specifically listed on list B.
A1030	Wastes having as constituents or contaminants any of the following: … - ***Mercury; mercury compounds*** …
A1180	Waste electrical and electronic assemblies or scrap[13] containing components such as accumulators and other batteries included on list A, ***mercury-switches***, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or contaminated with Annex I constituents (e.g. cadmium, ***mercury***, lead, polychlorinated biphenyl) to an extent that they possess any of the characteristics contained in Annex III (note the related entry on list B B1110)[14]
Other entries related to wastes which may contain or be contaminated with mercury	
Y1	Clinical wastes from medical care in hospitals, medical centers and clinics
Y2	Wastes from the production and preparation of pharmaceutical products
Y3	Waste pharmaceuticals, drugs and medicines
Y4	Wastes from the production, formulation and use of biocides and phytopharmaceuticals
Y11	Waste tarry residues arising from refining, distillation and any pyrolytic treatment
Y12	Wastes from production, formulation and use of inks, dyes, pigments, paints, lacquers, varnish
Y46	Wastes collected from households
Y47	Residues arising from the incineration of household wastes
Y48	Plastic waste, including mixtures of such waste, with the exception of the following[15]
A1170	Unsorted waste batteries excluding mixtures of only list B batteries. Waste batteries not specified on list B containing Annex I constituents to an extent to render them hazardous
A2030	Waste catalysts but excluding such wastes specified on list B
A2060	Coal-fired power plant fly-ash containing Annex I substances in concentrations sufficient to exhibit Annex III characteristics (note the related entry on list B B2050)
A3170	Wastes arising from the production of aliphatic halogenated hydrocarbons (such as chloromethane, dichloro-ethane, vinyl chloride, vinylidene chloride, allyl chloride and epichlorhydrin)
A3210	Plastic waste, including mixtures of such waste, containing or contaminated with Annex I constituents, to an extent that it exhibits an Annex III characteristic (note the related entries Y48 in Annex II and on list B B3011)
A4010	Wastes from the production, preparation and use of pharmaceutical products but excluding such wastes specified on list B
A4020	Clinical and related wastes; that is wastes arising from medical, nursing, dental, veterinary, or similar practices, and wastes generated in hospitals or other facilities during the investigation or treatment of patients, or research projects
A4030	Wastes from the production, formulation and use of biocides and phytopharmaceuticals, including waste pesticides and herbicides which are off-specification, outdated, or unfit for their originally intended use
A4070	Wastes from the production, formulation and use of inks, dyes, pigments, paints, lacquers, varnish excluding any such waste specified on list B (note the related entry on list B B4010)
A4080	Wastes of an explosive nature (but excluding such wastes specified on list B)

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[13] This entry does not include scrap assemblies from electric power generation.

[14] PCBs are at a concentration level of 50 mg/kg or more.

[15] See full text of Y48 in the Convention.

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A4100	Wastes from industrial pollution control devices for cleaning of industrial off-gases but excluding such wastes specified on list B
A4130	Waste packages and containers containing Annex I substances in concentrations sufficient to exhibit Annex III hazard characteristics
A4140	Waste consisting of or containing off specification or outdated[9] chemicals corresponding to Annex I categories and exhibiting Annex III hazard characteristics
A4160	Spent activated carbon not included on list B (note the related entry on list B B2060)

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B. International linkages

1. Minamata Convention on Mercury

21. The objective of the Minamata Convention, which entered into force on 16 August 2017, is to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. To achieve this objective, the Minamata Convention aims, *inter alia*:

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(a) To reduce the supply of mercury and control the international trade in mercury;

(b) To reduce the demand for mercury in products, manufacturing processes and artisanal and small-scale gold mining;

(c) To reduce emissions and releases of mercury to air, land and water;

(d) To ensure environmentally sound interim storage of mercury and mercury compounds intended for use;

a. To ensure ESM of mercury wastes; and to address management of sites contaminated with mercury or mercury compounds;

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(e) To promote capacity-building, technical assistance and technology transfer, including through specific financial and other arrangements.

(a) Waste-related provisions

22. Article 11 ("Mercury wastes") of the Minamata Convention sets forth the following waste-related provisions:

"1. The relevant definitions of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal shall apply to wastes covered under this Convention for Parties to the Basel Convention. Parties to this Convention that are not Parties to the Basel Convention shall use those definitions as guidance as applied to wastes covered under this Convention.

2. For the purposes of this Convention, mercury wastes means substances or objects:

(a) Consisting of mercury or mercury compounds;

(b) Containing mercury or mercury compounds; or

(c) Contaminated with mercury or mercury compounds,

in a quantity above the relevant thresholds defined by the Conference of the Parties, in collaboration with the relevant bodies of the Basel Convention in a harmonized manner, that are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law or this Convention. This definition excludes overburden, waste rock and tailings from mining, except from primary mercury mining, unless they contain mercury or mercury compounds above thresholds defined by the Conference of the Parties.

3. Each Party shall take appropriate measures so that mercury waste is:

(a) Managed in an environmentally sound manner, taking into account the guidelines developed under the Basel Convention and in accordance with requirements that the Conference of the Parties shall adopt in an additional annex in accordance with Article 27. In developing requirements, the Conference of the Parties shall take into account Parties' waste management regulations and programmes;

(b) Only recovered, recycled, reclaimed or directly re-used for a use allowed to a Party under this Convention or for environmentally sound disposal pursuant to paragraph 3 (a);

[9] "Outdated" means unused within the period recommended by the manufacturer.

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(c) For Parties to the Basel Convention, not transported across international boundaries except for the purpose of environmentally sound disposal in conformity with this Article and with that Convention. In circumstances where the Basel Convention does not apply to transport across international boundaries, a Party shall allow such transport only after taking into account relevant international rules, standards, and guidelines.

4. The Conference of the Parties shall seek to cooperate closely with the relevant bodies of the Basel Convention in the review and update, as appropriate, of the guidelines referred to in paragraph 3 (a).

5. Parties are encouraged to cooperate with each other and with relevant intergovernmental organizations and other entities, as appropriate, to develop and maintain global, regional and national capacity for the management of mercury wastes in an environmentally sound manner."

23. In relation to Article 11(2) of the Convention, the Conference of the Parties to the Minamata Convention adopted at its third meeting the decision MC-3/5 on thresholds of mercury wastes with the following key elements:

(a) No threshold needs to be established for mercury wastes falling under paragraph 2 (a) of Article 11, and wastes listed in table 2 below are regarded as such waste;

(b) No threshold needs to be established for mercury wastes falling under paragraph 2 (b) of Article 11, and mercury-added products that are disposed of, are intended to be disposed of or are required to be disposed of, including those listed in table 3 below, will be regarded as such mercury waste;

(c) The group of technical experts will further substantiate its present recommendation that a totals concentration threshold may be appropriate for mercury wastes falling under subparagraph 2 (c) of Article 11, including a technical analysis of options and the consideration of possible impacts;

(d) There is no need at present to develop thresholds for overburden and waste rock from mining other than primary mercury mining, and thresholds for tailings from mining other than primary mercury mining should be established in a two-tiered approach using a totals concentration threshold as an initial screen and a leaching threshold as the second tier, and requests the group of technical experts to do further work to establish the thresholds;

(e) The group of technical experts will conduct analysis of whether tailings from artisanal and small-scale gold mining should be subject to a threshold, taking into account the relationship between Articles 11 and 7;

(f) The group of technical experts will develop thresholds for mercury waste falling under 2 (c) of Article 11 and recommend thresholds for tailings from industrial-scale non-ferrous metal mining other than primary mercury mining; Deleted: and

(g) The group of technical experts will, subject to completion of items (e) and (f) above, review, and possibly recommend a revision of, the lists of mercury waste falling under subparagraphs 2 (a) to (c) of Article 11, set out in tables 2, 3 and 4 below, as appropriate.

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Table 2: List of mercury waste consisting of mercury or mercury compounds[6] (subparagraph 2 (a) of article 11) as per Table 1 in the annex to decision MC-3/5

Type of waste	*Waste source*[7]
Recovered elemental mercury[8]	Mining activity: • Tailings from artisanal and small-scale gold mining Mercury captured from: • Non-ferrous metals roasting and smelting processes • Crude oil and natural gas processing Treatment of: • Mercury-added products upon becoming waste • Waste contaminated with mercury or mercury compounds • Contaminated environmental media Treatment of waste from: • Chlor-alkali,[9] alcoholates (e.g., sodium or potassium methylate or ethylate), dithionite and ultrapure potassium hydroxide

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Type of waste	*Waste source*[b]
	solution production with mercury technology, including decommissioning facilities • Polyurethane, vinyl chloride monomer, acetaldehyde production using a mercury-containing catalyst
Elemental mercury	Mercury stockpile (e.g. industries, laboratories, dental offices, educational and research institutions, government institutions, landfills, dumpsites, lighthouses)
Mercury (I) chloride and mercury (II) chloride	Primary zinc, lead, copper and gold roasting and smelting processes Reagent Calomel electrode for electrochemical measurements Medicine/pharmaceuticals Vinyl chloride monomer catalyst – mercury (II) chloride Stockpiles
Mercury (II) oxide (mercuric oxide)	Dry cell batteries, pigment in paints and glass modifiers, fungicide, cosmetics, laboratory reagent, antifouling paints Stockpiles
Mercury (II) sulfate (mercuric sulfate)	Lab reagent, catalyst used for the production of acetaldehyde Stockpiles
Mercury (II) nitrate (mercuric nitrate)	Oxidizing agent, laboratory reagent Stockpiles
Cinnabar concentrate	Primary mercury mining Stockpiles
Mercury sulfide	Pigment Stabilization of waste mercury for storage and/or disposal Stockpiles

[a] The Convention defines a mercury compound as any substance consisting of atoms of mercury and one or more atoms of other chemical elements that can be separated into different components only by chemical reactions.

[b] A facility or activity where waste is likely to be generated or accumulated.

[c] Recovered mercury as described in subparagraph 3 (b) of article 11.

[d] Recovery can sometimes occur without treatment.

Table 3: Non-exhaustive list of waste containing mercury or mercury compounds (subparagraph 2 (b) of article 11)[a] as per Table 2 in the annex to decision MC-3/6

Type of waste	*Waste source*[b]
Non-electronic measuring devices containing mercury (barometers, hygrometers, manometers, thermometers, sphygmomanometers)	Hospitals, clinics, healthcare facilities (human and animal), pharmacies, households, schools, laboratories, universities, industrial facilities, airports, meteorological stations, ship recycling facilities
Electrical and electronic switches, contacts, relays and rotating electrical connectors with mercury	Dismantling facilities of waste electrical and electronic equipment (relays, connectors and switches), industrial facilities (attached to boilers), households, offices
Fluorescent bulbs, high intensity discharge (HID) bulbs (mercury vapour bulbs, metal halide and high-pressure sodium bulbs), neon/argon lamps	Households, industrial and commercial facilities, automobile facilities, collection points
Batteries/accumulators containing mercury	Households, industrial and commercial facilities, collection points
Biocides and pesticides containing mercury and their formulations and products	Agricultural, horticultural, industrial and commercial facilities (including stockpiles), laboratories
Paints and varnishes containing mercury	Industrial and commercial facilities, households
Pharmaceuticals containing mercury for human and veterinary uses, including vaccines	Industrial and healthcare facilities (including stockpiles), livestock industry
Cosmetics and related products containing mercury	Industrial facilities (including stockpiles)

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Type of waste	*Waste source*[b]
Dental amalgam	Dental offices, dental schools, crematoria
Scientific instrument used for the calibration of medical or scientific devices containing mercury	Laboratories, institutions[c] (including stockpiles)

[a] Mercury-added products listed in the "type of waste" column of this table are regarded as waste under subparagraph 2 (b) of article 11 when they are disposed of, are intended to be disposed of or are required to be disposed of by the provisions of national law or the Minamata Convention.

[b] A facility or activity where waste is likely to be generated or accumulated.

[c] Institutions include public and private ones.

Table 4: Indicative list of waste contaminated with mercury or mercury compounds (subparagraph 2 (c) of article 11)[a] as per Table 3 in the annex to decision MC-3/5

Type of waste	*Waste source*[b]
Waste from industrial pollution control devices or cleaning of industrial off-gases[c]	Flue gas from sources such as: Extraction and use of fuels/energy sources Smelting and roasting processes in the production of non-ferrous metals Production processes with mercury impurities Recovery of precious metals from waste electrical and electronic equipment Coal combustion Waste incineration and co-incineration Crematoria
Bottom ash	Coal combustion Biomass fired power and heat generation Waste incineration
Wastewater treatment residues/slurries[d]	Treatment of wastewater from: Extraction and use of fuels/energy Production of mercury-added products Manufacturing processes in which mercury or mercury compounds are used Primary non-ferrous metals production Production processes with mercury impurities Recovery of precious metals from waste electrical and electronic equipment Waste incineration, co-incineration and other thermal treatment Crematoria Healthcare facilities Controlled landfills leachate Uncontrolled dumping of wastes Agricultural facilities
Sludge	Separator tanks and sedimentary sand tanks for refining of crude oil, natural gas production and processing, drilling, ship cleaning, chemical processes, etc. Treatment of wastes contaminated with mercury (e.g., chemical precipitation and chemical oxidation)
Oil and gas refining catalyst	Refining of crude oil Processing of natural gas
Tailings and extraction process residues	Primary mercury mining Artisanal and small-scale gold mining
Rubbles, debris and soil[e]	Construction/demolition Remediation of contaminated sites
Other waste from manufacturing processes using mercury or mercury compounds[f]	Chlor-alkali production with mercury technology Production of alcoholates (e.g., sodium or potassium methylate or ethylate) Dithionite and ultrapure potassium hydroxide solution Vinyl chloride monomer (VCM) production with mercuric chloride ($HgCl_2$) catalyst Acetaldehyde production with mercury sulphate ($HgSO_4$) catalyst, etc.
Other waste from the manufacturing of mercury-added products[g]	Manufacturing of mercury-added products

Type of waste	*Waste source*[a]
Other waste from natural gas cleaning[j]	Natural gas cleaning
Wastes from waste treatment facilities[k]	Waste treatment facilities

[a] Wastes listed in this table are regarded as mercury waste when they exceed thresholds. Waste exceeding the established threshold but not listed here would also be considered mercury waste.
[b] A facility or activity where waste is likely to be generated or accumulated.
[c] Includes filters and activated carbon.
[d] Include filters and resins.
[e] Contaminated soil transported off-site is regarded as waste.
[f] Mercury cells, mercury recovery units, (retort), waste catalysts, decommissioning or demolition waste, personal protective equipment, chemicals used to contain mercury spills, etc.
[g] Process residues, demolition waste, etc.
[h] Scale removed from pipework and pipe cleaning equipment, etc.
[i] Waste treated to stabilize/solidify mercury in the waste, fluorescent coatings, metal and glass.

(b) **Other provisions relevant to mercury wastes**

24. Paragraphs 25 to 32 below describe other provisions of the Minamata Convention that are relevant to mercury wastes.

25. Article 3 of the Minamata Convention addresses sources of mercury supply and trade. Paragraph 4 provides that "each Party shall only allow primary mercury mining that was being conducted within its territory at the date of entry into force of the Convention for it for a period of up to fifteen years after that date. During this period, mercury from such mining shall only be used in manufacturing of mercury-added products in accordance with Article 4, in manufacturing processes in accordance with Article 5, or be disposed in accordance with Article 11, using operations which do not lead to recovery, recycling, reclamation, direct re-use or alternative uses". Paragraph 5 (b) provides that "each Party shall take measures to ensure that, where the Party determines that excess mercury from the decommissioning of chlor-alkali facilities is available, such mercury is disposed of in accordance with the guidelines for environmentally sound management referred to in paragraph 3 (a) of Article 11, using operations that do not lead to recovery, recycling, reclamation, direct re-use or alternative uses".

26. Article 4 of the Convention addresses mercury-added products. Paragraph 1 provides that "each Party shall not allow, by taking appropriate measures, the manufacture, import or export of mercury-added products listed in Part I of Annex A after the phase-out date specified for those products, except where an exclusion is specified in Annex A or the Party has a registered exemption pursuant to Article 6". Part I of Annex A provides that by 2020 the manufacture, import or export of the mercury-added products subject to paragraph 1 of Article 4 shall not be allowed (i.e., phase-out date). Part I of Annex A lists batteries; switches and relays; compact fluorescent lamps; linear fluorescent lamps; high-pressure mercury vapour lamps; cold cathode fluorescent lamps and external electrode fluorescent lamps; cosmetics; pesticides, biocides and topical antiseptics; non-electronic measuring devices with some conditions and exceptions. It should be noted that not only those wastes listed in Annex A but also all other mercury-added products are, upon becoming waste, categorized as mercury waste (wastes containing mercury or mercury compounds) under Article 11.

27. Article 4 of the Minamata Convention also addresses measures to phase-down the use of mercury dental amalgam. Paragraph 3 provides that "each Party shall take measures for the mercury-added products listed in Part II of Annex A in accordance with the provisions set out therein". Part II of Annex A provides that "measures to be taken by a Party to phase down the use of dental amalgam shall take into account the Party's domestic circumstances and relevant international guidance and shall include two or more" of the measures listed therein. Wastes of dental amalgam and its packaging are categorized as waste containing mercury under Article 11. In addition, in decision MC-3/2, Parties are encouraged to take an additional measure listed in Part II of Annex A.

28. Article 5 of the Minamata Convention addresses the use of mercury and mercury compounds in product manufacturing. Paragraph 2 provides that "each Party shall not allow the use of mercury or mercury compounds in the manufacturing processes listed in Part I of Annex B after the phase-out date specified in that Annex for the individual processes, except where the Party has a registered exemption pursuant to Article 6". Part I of Annex B lists chlor-alkali production and acetaldehyde production in which mercury or mercury compounds are used as a cathode and a catalyst respectively. In addition, Paragraph 3 provides that "each Party shall take measures to restrict the use of mercury or mercury compounds in the processes listed in Part II of Annex B in accordance with the provisions set out therein". Part II of Annex B lists vinyl chloride monomer production, sodium or potassium

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(b) . Products for research, calibration of instrumentation, for use as reference standard;¶
(c) Where no feasible mercury-free alternative for replacement is available, switches and relays, cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for electronic displays, and measuring devices; ¶
(d) Products used in traditional or religious practices; and¶
(e) Vaccines containing thiomersal as preservatives."

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Batteries, except for button zinc silver oxide batteries with a mercury content < 2 per cent and button zinc air batteries with a mercury content < 2 per cent. ... [9]

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methylate or ethylate, and production of polyurethane using mercury containing catalysts. Measures to reduce or control mercury emissions and releases from manufacturing or production processes in which mercury or mercury compounds are used may result in the capture and generation of residues and substances contaminated with mercury or mercury compounds that should be managed appropriately as waste.

29. Article 7 of the Minamata Convention provides for the reduction, and where feasible elimination, of the use of mercury and mercury compounds in, and the emissions and releases to the environment of mercury from artisanal and small-scale gold mining (ASGM) and processing. Article 7 applies to ASGM and processing in which mercury amalgamation is used to extract gold from ore. Such activities may generate wastes consisting of or contaminated with mercury or mercury compounds such as tailings and extraction process residues.

30. Article 8 of the Minamata Convention addresses emissions of mercury or mercury compounds to the ambient air. Paragraph 3 provides that "[a] Party with relevant sources shall take measures to control emissions". "Relevant source" means a source falling within one of the categories listed in Annex D to the Convention. Relevant sources listed in Annex D include waste incineration facilities, coal-fired power plants, coal-fired industrial boilers, smelting and roasting processes used in the production of non-ferrous metals, and cement clinker production facilities. Mercury emission control measures and practices may generate solid wastes contaminated with mercury or mercury compounds.

31. Article 9 of the Minamata Convention addresses mercury releases to land and water. Paragraph 3 requires that "Each Party shall, no later than three years after the date of entry into force of the Convention for it and on a regular basis thereafter, identify the relevant point source categories". Relevant point source categories are those anthropogenic sources of mercury release considered significant by Parties, and which are not addressed in other provisions of the Convention. In decision MC-3/4, the Conference of the Parties of the Minamata Convention provided guidance for implementation of Article 9, noting that: "The obligation to ensure the environmentally sound management of waste set out under the Convention addresses significant releases to land and water; ..." and that "While wastewater is addressed under article 9, Parties may additionally control wastewater under article 11 of the Convention; ..."

32. Lastly, Article 12 of the Minamata Convention provides that "each Party shall endeavour to develop appropriate strategies for identifying and assessing sites contaminated by mercury or mercury compounds" and that "the Conference of the Parties shall adopt guidance on managing contaminated sites". Remediation activities for mercury-contaminated sites may generate mercury waste. This guidance[17] was adopted in decision MC-3/6 and may be updated periodically.

2. UNEP Global Mercury Partnership

33. In decision 25/5, Part III, the UNEP Governing Council requested the Executive Director of UNEP, coordinating as appropriate with governments, intergovernmental organizations, stakeholders and the Global Mercury Partnership, to continue and enhance, as part of the international action on mercury, existing work in a number of areas. The Global Mercury Partnership currently has eight identified priorities for action or "partnership areas"[18]. One such partnership area is the mercury waste management partnership area, launched in 2008 with the Ministry of the Environment of Japan as lead. Among other things, the partnership area has identified and grouped country-level projects by waste stream and created a list of experts on mercury waste. Several relevant reports have been developed and are also available on the website including the 2015 *Practical sourcebook on mercury waste storage and disposal*[19], and the 2019 *Catalogue of technologies and services on mercury waste management*[20].

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(a) . A quantified goal for controlling and, where feasible, reducing emissions from relevant sources;¶
(b) . Emission limit values for controlling and, where feasible, reducing emissions from relevant sources;¶
(c) . The use of best available techniques and best environmental practices to control emissions from relevant sources;¶
(d) . A multi-pollutant control strategy that would deliver co-benefits for control of mercury emissions; and¶
(e) . Alternative measures to reduce emissions from relevant sources." ¶
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[17] "Guidance on the management of contaminated sites" http://www.mercuryconvention.org/Portals/11/documents/forms-guidance/English/Guidance_Contaminated_Sites_EN.pdf.[18] For further information, http://web.unep.org/globalmercurypartnership/

[18] For further information, http://web.unep.org/globalmercurypartnership/

[19] https://wedocs.unep.org/bitstream/handle/20.500.11822/9839/-Practical_Sourcebook_on_Mercury_Waste_Storage_and_Disposal-2015Sourcebook_Mercury_FINAL_web.pdf.pdf?sequence=3&isAllowed=y

[20] http://web.unep.org/globalmercurypartnership/catalogue-technologies-and-services-mercury-waste-management

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[10] For further information, http://www.unep.org/chemicalsandwaste/Mercury/GlobalMercuryPartnership/tabid/1253/language/en-US/Default.aspx….

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3. Heavy Metals Protocol

34. The objective of the 1998 Protocol on Heavy Metals to the 1979 Convention on Long-Range Transboundary Air Pollution, which was amended in 2012, is to control anthropogenic emissions of heavy metals, including mercury, that are subject to long-range transboundary atmospheric transport and are likely to have significant adverse human health or environmental effects. Parties to the Protocol are required to reduce emissions of target heavy metals below 1990 levels (or an alternative year between 1985 and 1995) by applying best available techniques for stationary sources and imposing emissions limit values for certain stationary sources. Parties are also required to develop and maintain emission inventories for heavy metals covered under the Protocol. Annex VII to the Protocol lists mercury-containing electrical components, measuring devices, fluorescent lamps, dental amalgam, pesticides, paint and batteries for recommended product management measures, including substitution, minimization, labelling, economic incentives, voluntary agreements, and programmes for collection, recycling or disposal.

Deleted: 3. Rotterdam Convention ¶
Annex III to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade lists "mercury compounds, including inorganic mercury compounds, alkyl mercury compounds and alkyloxyalkyl and aryl mercury compounds." Annex III lists chemicals that have been banned or severely restricted for health or environmental reasons in at least two regions and that are subject to the prior informed consent procedure.¶
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4. SAICM (to be changed after ICCM5)

35. The Strategic Approach to International Chemicals Management (SAICM) is made up of a ministerial declaration (the "Dubai Declaration on International Chemicals Management"), an overarching policy strategy, and a global plan of action. Mercury is specifically addressed in the SAICM global plan of action, under work area 14, as follows: "Mercury and other chemicals of global concern; chemicals produced or used in high volumes; chemicals subject to wide dispersive uses; and other chemicals of concern at the national level"; specific activities under the work area pertain to risk reduction, the need for further action and the review of scientific information. A quick start programme (QSP) was established under SAICM in 2006 to support initial enabling capacity-building and implementation activities in developing countries, least developed countries, small island developing states and countries with economies in transition (UNEP, 2006a). As of February 2014, seven projects including mercury components such as campaign on minimization of mercury use and inventory development of mercury products, mercury releases, and mining sites have been implemented under the quick start programme (UNEP, 2014).

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III. Guidance on environmentally sound management (ESM)

A. General considerations

36. ESM is a broad policy concept that is understood and implemented in various ways by different countries, organizations and other stakeholders. International guidance documents and core performance elements pertaining to ESM of hazardous wastes and other wastes have been developed by the Basel Convention and by the Organisation for Economic Co-operation and Development (OECD) and should help stakeholders to implement the ESM of hazardous wastes, and other wastes as well as of mercury wastes as defined by the Minamata Convention.

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Deleted: <#>In Article 2, paragraph 8, the Basel Convention defines ESM of hazardous wastes or other wastes as taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner that will protect human health and the environment against the adverse effects which may result from such wastes. ¶
<#>In Article 4, paragraph 2 (b), the Convention requires each party to take the appropriate measures to "ensure the availability of adequate disposal facilities for the environmentally sound management of hazardous or other wastes, that shall be located, to the extent possible, within it, whatever the place of their disposal", while in paragraph 2 (c) it requires each party to "ensure that persons involved in the management of hazardous wastes or other wastes within it take such steps as are necessary to prevent pollution due to hazardous wastes and other wastes arising from such management and, if such pollution occurs, to minimize the consequences thereof for human health and the environment."¶
<#>In Article 4, paragraph 8, the Convention requires that "hazardous wastes or other wastes, to be exported, be managed in an environmentally sound manner in the State of import or elsewhere. Technical guidelines for the environmentally sound management of wastes subject to this Convention shall be decided by the Parties at their first meeting." The

1. Basel Convention

37. While provisions relevant to ESM of hazardous wastes or other wastes under the Basel Convention are listed in paragraph 13, the present guidelines are intended to provide a more precise definition of ESM when applied to mercury wastes, including by defining appropriate treatment and disposal methods for mercury waste streams that constitute ESM.

38. At its eleventh meeting in 2013, the Conference of the Parties to the Basel Convention adopted a *Framework for the environmentally sound management of hazardous wastes and other wastes*[21]. The framework establishes a common understanding of what ESM encompasses and identifies tools and strategies to support and promote the implementation of ESM. It is intended as a practical guide for governments and other stakeholders participating in the management of hazardous wastes and other wastes and constitutes the most comprehensive ESM guidance produced thus far, complementing the various technical guidelines adopted under the Basel Convention.

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39. Under the Basel Convention, ESM is the subject of multiple provisions (refer to section II A.1 above) and the following two declarations:

[21] www.basel.int/Implementation/CountryLedInitiative/EnvironmentallySoundManagement/ESMFramework/tabid/3016/Default.aspx

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(a) The 1999 Basel Declaration on Environmentally Sound Management, which was adopted by the Conference of the Parties to the Basel Convention at its fifth meeting and calls on Parties to enhance and strengthen their efforts and cooperation to achieve ESM, including through prevention, minimization, recycling, recovery and disposal of hazardous and other wastes subject to the Basel Convention, taking into account social, technological and economic concerns, and through further reduction of transboundary movements of hazardous and other wastes subject to the Convention;

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(b) The 2011 Cartagena Declaration on the Prevention, Minimization and Recovery of Hazardous Wastes and Other Wastes, which was adopted by the Conference of the Parties to the Basel Convention at its tenth meeting and reaffirms that the Basel Convention is the primary global legal instrument for guiding the ESM of hazardous wastes and other wastes and their disposal.

40. ESM criteria recommendations for computing equipment have been developed under the Basel Convention Partnership for Action on Computing Equipment (PACE).

2. Organisation for Economic Co-operation and Development

41. OECD has adopted a recommendation on ESM of waste that covers such items as the core performance elements of ESM guidelines applying to waste recovery facilities, including: elements of performance that precede collection, transport, treatment and storage; and elements subsequent to storage, transport, treatment and disposal of pertinent residues (OECD 2004).

42. Further information may be found in the guidance manual for the implementation of the OECD recommendation on ESM of waste (OECD 2007).

3. Life cycle management of mercury

43. The concept of life cycle management can serve as a useful approach to promote the ESM of mercury wastes. Life cycle management provides a framework for analysing and managing the sustainability performance of goods and services. Global businesses are using it, for instance, to reduce the carbon, raw material and water footprints of their products, improve their social and economic performance, and make value chains more sustainable (UNEP and SETAC, 2009). When a life cycle management approach is applied to mercury, performance should be assessed during the following stages: production of products containing mercury or mercury compounds or of other products using mercury; use of such products; collection and transportation of wastes; and disposal of wastes.

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44. In life cycle management of mercury, it is important to give priority to reducing the use of mercury in products and industrial processes, thereby reducing the mercury content of wastes resulting from such products and processes. When using products containing mercury or mercury compounds, special care should be taken not to emit or release mercury into the environment. Mercury wastes should be treated to either recover the mercury in them or to immobilize it in an environmentally sound manner. In those cases where mercury is recovered, the recovered mercury should be disposed of, after stabilization and solidification (S/S), at a permanent storage site or at a specially engineered landfill site. Alternatively, for non-Parties to the Minamata Convention, the recovered mercury may, for example, be used as an input in products for which mercury-free alternatives do not exist or are unavailable, or in cases in which it would take a long time to replace products containing mercury or mercury compounds; such reuse could help to reduce the production of new mercury from primary mining. For Parties to the Minamata Convention, the recovered mercury may be used as an input for products or processes that are still allowed under, and respecting the relevant conditions, of the Minamata Convention. Mercury wastes may be stored pending further treatment or disposal or until export to other countries for disposal is possible (see figure 1 below).

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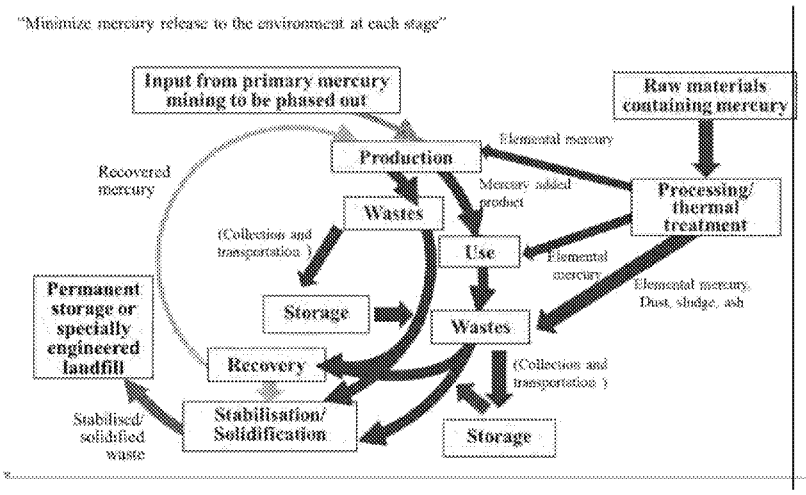
Figure 1: Basic concept of mercury management



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45. Waste management covers source separation, collection, transportation, storage and disposal (e.g., recovery, solidification, stabilization, permanent storage and disposal in a specially engineered landfill). When a government plans to collect mercury wastes, it also needs to plan for the subsequent waste management steps, such as storage and disposal.

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B. Legislative and regulatory framework

46. Parties to the Basel Convention should examine their national controls, standards and procedures to ensure that they are in agreement with their obligations under the Convention, including those pertaining to the transboundary movement and ESM of mercury wastes; Parties to the Minamata Convention should also examine such controls, standards and procedures to ensure that they are in agreement with their waste-related obligations under that Convention.

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47. Implementing legislation should give governments the power to enact and enforce specific rules and regulations, conduct inspections and establish penalties for violations. Legislation on hazardous wastes should define hazardous wastes in accordance with the Basel Convention, and legislation on mercury wastes should define mercury wastes in accordance with the Minamata Convention. The legislation could define ESM and require adherence to ESM principles, thus ensuring that countries comply with the provisions on ESM of mercury wastes. The specific components and features of a regulatory framework that would meet the requirements of the Basel Convention and other international agreements are discussed below.[22]

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1. Registration of waste generators

48. One approach to facilitate ESM of mercury waste involves the establishment, through regulation, of registers of generators of this type of waste. Such registers should include large-scale mercury waste generators such as power plants, industrial establishments (e.g., chlor-alkali plants using mercury cell technology, VCM production facilities using a mercury catalyst or smelting operations), as well as hospitals, medical and dental clinics, research institutes, mercury waste collectors, etc. A register of mercury waste generators would make it possible to determine the origins, types and volumes of various kinds of mercury waste, as well as the quantities of products containing mercury or mercury compounds being used by various waste generators.

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[22] Further guidance on Basel Convention regulatory frameworks can be found in the following documents: Model National Legislation on the Management of Hazardous Wastes and Other Wastes as well as on the Control of Transboundary Movements of Hazardous Wastes and Other Wastes and their Disposal (UNEP, 1995a), Manual for Implementation of the Basel Convention (UNEP, 2015b) and Basel Convention: Guide to the Control System (UNEP, 2015c).

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49. Regulations on registries of generators of mercury wastes could require waste generators to provide their name, address, the name of the responsible person, their type of business, the amounts and kinds of mercury waste generated, and information on collection schemes applicable to such wastes and how the wastes are to be handed over to collectors and disposed of. Waste generators could be required to transmit and provide regular updates on this information to the authorities (central or local governments). Based on the amounts and kinds of waste obtained through registries, Parties could also develop waste inventory programmes.

50. Mercury waste generators should have a duty to prevent mercury emissions and releases to the environment until the wastes are handed over to collectors or sent to a disposal facility. They should strictly comply with national and local legal requirements regarding the management of mercury wastes and be held liable for remediating or compensating any environmental or health damages that they might cause when handling such wastes, to the degree required by applicable legislation.

2. Reduction and phase-out of mercury use in ASGM, products and industrial processes

51. The reduction and phase-out of mercury use in ASGM, products and industrial processes is one of the most effective ways of reducing emissions and releases of mercury to the environment.

52. According to Article 7 of the Minamata Convention, Parties to that convention that have ASGM and processing within their territories are required to take steps to reduce, and where feasible eliminate, the use of mercury and mercury compounds in, and the emissions and releases to the environment of mercury from, such mining and processing. In addition, a party to the Minamata Convention which determines that ASGM and processing in its territory is more than insignificant is required to develop and implement a national action plan and review its progress every three years.

53. Articles 4 and 5 of the Minamata Convention require Parties to phase-down or phase-out specific mercury-added products and use of mercury in specific industrial processes (see paragraphs 26-28 above).

54. Examples of regional/national provisions on reduction and phase-out of mercury use are shown in boxes 1 to 3.

Box 1 Regional Example: European Union

Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, known as the "RoHS Directive", is an example of a regulation phasing out the use of mercury in certain products. The RoHS Directive restricts the use of mercury and other substances in electrical and electronic equipment and, while exemptions may be granted in cases where no satisfactory alternatives are available (e.g., some types of lamps containing mercury), most mercury-containing electrical and electronic equipment has been phased out in the European Union market since the Directive entered into force on 1 July 2006. A revised version of the RoHS Directive entered into force on 21 July 2011 (European Union, 2011a).

Another example from the European Union is Directive 2006/66/EC of the European Parliament and of the Council on batteries and accumulators and waste batteries and accumulators, which prohibits the placing on the market of all batteries, whether or not incorporated into appliances, that contain more than 0.0005 per cent of mercury by weight. Batteries and accumulators lawfully placed on the market prior to the date of application of the prohibitions set out in Article 4 of the Directive may continue to be marketed until stocks run out (European Union, 2006; European Commission, 2014a).

Box 2 Country Example: Canada

Canada's *Products Containing Mercury Regulations* prohibit the manufacture and import of products containing mercury or any of its compounds, with some exemptions for essential products for which there are no technically or economically viable alternatives (Government of Canada, 2014).

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Deleted: <#>Minamata Convention parties should develop and enforce a legislative or regulatory framework for a reduction and phase-out programme and measures according to the provisions of the Minamata Convention (see paragraphs 22-24 above). One approach for a phase-out programme involves the establishment, through legislation or regulations, of a cut-off date by which the manufacture, export and import of products containing mercury or mercury compounds and the use of mercury or mercury compounds in processes, except for those for which there are no technically or practically viable alternatives or for which exemptions apply, would no longer be allowed. This approach would require that producers, importers and exporters of mercury and mercury-added products to comply with the requirement to embark on a mercury phase-out programme. ¶
<#>Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, known as the "RoHS Directive", is an example of a regulation phasing out the use of mercury in certain products. The RoHS Directive restricts the use of mercury and other substances in electrical and electronic equipment and, while exemptions may be granted in cases where no satisfactory alternatives are available (e.g., some types of mercury-added lamps), most mercury-containing electrical and electronic equipment has been phased out in the European Union market since the Directive entered into force on 1 July 2006. A revised version of the RoHS Directive, known as the "RoHS 2 Directive", was adopted in May 2011 and entered into force on 21 July 2011.¶
<#> Another example from the European Union is Directive 2006/66/EC of the European Parliament and of the Council on batteries and accumulators and waste batteries and accumulators, which prohibits the placing on the market of all batteries, whether or not incorporated into appliances, that contain more than 0.0005 per cent of mercury by weight. Button cells with a mercury content of no more than 2 per cent by weight were exempt from this prohibition until 1 October 2015, while batteries and accumulators lawfully placed on the market prior to the date of application of the prohibitions set out in Article 4 of the Directive may continue to be marketed until stocks run out (European Union, 2006).¶
<#>Norway's imposes a general ban on the use of mercury in products to ensure that mercury is not used in products where alternatives exist.[12] The regulation prohibits the manufacture, import, export, sale and use of substances or preparations that contain mercury or mercury compounds, and the manufacture, import, export and sale of solid processed mercury-added products or mercury compounds. The regulation therefore is expected to reduce the number of mercury-added products on the market, in addition to discharges from products that have inadvertently failed to be disposed of as hazardous waste.¶
<#>Canada's *Products Containing Mercury Regulations* prohibit the manufacture and import of products containing mercury or any of its compounds, with some exemptions for essential uses for which there are no technically or economically viable alternatives (e.g., certain medical and research applications and dental amalgam)....

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Box 3 Country Example: Norway

Norway imposes a general ban on the use of mercury in products to ensure that mercury is not used in products where alternatives exist[7]. The regulation prohibits the manufacture, import, export, sale and use of substances or preparations that contain mercury or mercury compounds, and the manufacture, import, export and sale of solid processed products containing mercury or mercury compounds. The regulation therefore is expected to reduce the number of products containing mercury or mercury compounds on the market, in addition to discharges from products that have inadvertently failed to be disposed of as hazardous waste (Government of Norway, 2011).

3. Transboundary movement requirements

55. Under the Basel Convention, mercury wastes subject to transboundary movement that belong to any category contained in Annex I (see Table 1) are considered hazardous waste unless, through national tests, they can be shown not to exhibit any of the characteristics listed in Annex III (list of hazardous characteristics).

56. If a party to the Convention has national legislation of banning the import of mercury wastes, and has reported the information in accordance with Article 4, paragraph 1 (a), other Parties shall prohibit or shall not permit the export of such wastes to that party. In addition, in cases where the State of import has not prohibited the import of mercury wastes, Parties to the Convention shall prohibit or shall not permit the export of such wastes if the State of import does not consent in writing to the specific import.

57. Parties listed in Annex VII to the Convention (members of the European Union, OECD and Liechtenstein), that are bound by the Ban Amendment, shall prohibit transboundary movements to States not listed in Annex VII of hazardous wastes which are destined for operations according to Annex IV A and hazardous wastes under Article 1.1(a) which are destined to operations according to Annex IV B[8].

58. The Minamata Convention also includes a provision on transboundary movements of mercury waste in Article 11, paragraph 3 (c) (see paragraph 22 above).

59. Transboundary movements of hazardous wastes and other wastes must be kept to a minimum consistent with their environmentally sound and efficient management and conducted in a manner that protects human health and the environment from any adverse effects that may result from such movements. Transboundary movements of these wastes are permitted only under the following conditions:

(a) If the country of export does not have the technical capacity and the necessary facilities, capacity or suitable disposal sites in order to dispose of the wastes in question in an environmentally sound and efficient manner;

(b) If the wastes in question are required as a raw material for recycling or recovery industries in the country of import; or

(c) If the transboundary movements in question are in accordance with other criteria decided by the Parties.

60. Any transboundary movements of hazardous and other wastes are to be notified in writing to the competent authorities of all countries concerned by the movement (country of export, country of import and, if applicable, country of transit). This notification is to contain the declarations and

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[7] Norwegian Product Regulations (Section 2.3 on mercury and mercury compounds in Chapter 2 on regulated substances, preparations and products in Norwegian, available at: https://lovdata.no/dokument/SF/forskrift/2004-06-01-922/KAPITTEL_2#KAPITTEL_2/
Special exemptions apply:

- Limited use (concentration limits specified) in packaging, batteries, some components in vehicles and in some electrical and electronic equipment according to the European Union Regulations implemented in Norway.
- Substances/preparations and solid processed products where the content of mercury or mercury compounds is lower than 0.001 per cent by weight.

[8] For information on the status of individual Parties in relation to the amendment, please see the Status of Ratifications page on the Basel Convention website.

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information requested in the Convention and shall be written in a language acceptable by the State of import. Prior written consent from the importing and the exporting country and, if appropriate, from transit countries, in addition to a confirmation of the existence of a contract specifying ESM of the wastes between the exporter and the owner of the disposal facility are required before any transboundary movements of hazardous and other wastes can take place. Parties are to prohibit the export of hazardous wastes and other wastes if the country of import prohibits the import of such wastes. The Convention also requires that information regarding any consignment be accompanied by a movement document from the point where the transboundary movement commences to the point of disposal.

61. Hazardous wastes and other wastes subject to transboundary movements should be packaged, labelled and transported in conformity with international rules and standards.[12]

62. When a transboundary movement of hazardous or other wastes to which the consent of the countries concerned has been given cannot be completed in accordance with the terms of the contract, the country of export must ensure that the wastes in question are taken back into the country of export by the exporter if alternative arrangements cannot be made for their disposal in an environmentally sound manner. This is to be done within 90 days of the importing country's notification to the country of export and the secretariat, or within another period of time on which the countries involved agree (Article 8). In the case of illegal traffic (as defined in Article 9, paragraph 1), the country of export shall ensure that the wastes in question are returned to the country of export for disposal or are disposed of in accordance with the provisions of the Convention.

63. When required by the country of import or any transit country that is a party to the Convention, transboundary movements of hazardous or other wastes are to be covered by insurance, bonds or other guarantees.

64. No transboundary movements of hazardous wastes or other wastes are permitted between a party and a non-party to the Convention unless a bilateral, multilateral or regional arrangement exists, as required under Article 11 of the Convention. Existing bilateral and multilateral agreements that have been notified to the Secretariat are listed on the Basel Convention webpage.[13]

4. Authorization and inspection of disposal facilities

65. Mercury wastes should be disposed of in facilities that practise ESM.

66. Most countries have legislation or sector-specific regulations that require waste disposal facilities to obtain approvals or operating permits to commence their operations. Approvals or operating permits may include specific conditions (e.g., facility design and operating conditions) that must be maintained in order for the approval or permit to remain valid. It may be necessary to add requirements specific to mercury waste to meet the requirements of ESM, to comply with specific requirements of the Basel Convention and to take into account recommendations and guidelines on best available techniques (BAT), such as guidelines on BAT and provisional guidance on best environmental practices produced under the Stockholm Convention, reference documents on BAT produced by the European Union (known as "BREFs"), and guidelines for the chlor-alkali sector (Euro Chlor, 2004). Approvals or operating permits should be reviewed periodically and, if necessary, should be updated in order to improve occupational and environmental safety through the use of improved or new technologies.

67. Disposal facilities should be periodically inspected by independent authorities or technical inspection associations in order to verify their compliance with the requirements set out in their permits. Legislation should enable authorities to conduct extraordinary inspections if there is evidence of non-compliance with permit requirements by disposal facilities.

Deleted: Some countries have implemented national prohibitions following decision III/1 of the Conference of the Parties, which contains an amendment to the Convention that has not yet entered into force and bans the export of hazardous wastes from the countries listed in Annex VII (OECD and EU countries and Liechtenstein) to non-Annex VII countries.

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It is worth noting that the export from the European Union of metallic mercury and certain mercury compounds and mixtures has been banned since 15 March 2011, through Regulation (EC) No 1102/2008 (European Commission, 2010b). Similarly, through the Mercury Export Ban Act of 2008, the United States of America severely restricts the export of mercury since January 2013.

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[12] See, e.g., *United Nations Recommendations on the Transport of Dangerous Goods – Model Regulations* (21st revised edition) (United Nations, 2011a).

[13] For bilateral agreements, see:
http://www.basel.int/Countries/Agreements/BilateralAgreements/tabid/1517/Default.aspx;
for multilateral agreements, see:
http://www.basel.int/Countries/Agreements/MultilateralAgreements/tabid/1518/Default.aspx

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C. Identification and inventory

68. To enable effective action to prevent, minimize and manage mercury wastes, it is important that Parties identify the sources of mercury waste generation and quantify the amount of mercury wastes generated and the mercury concentrations in such wastes.

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1. Identification of sources of mercury wastes

69. While the sources of mercury waste generation vary across countries, globally the major sources of mercury waste include industrial processes using mercury or mercury compounds and mercury devices that have become waste. Other major sources of mercury waste are the production, processing and use of natural resources (e.g., non-ferrous metals ore processing, oil and gas processing and coal combustion). Figure 2 shows trends of estimated global mercury use by application from 2005 to 2015. The largest use sector was artisanal and small-scale gold mining (ASGM), followed by vinyl chloride monomer VCM/polyvinyl chloride (PVC) production and chlor-alkali production up to 2010. Mercury is also used in products such as batteries, dental amalgams, measuring devices, lamps, and electrical and electronic devices, although the amounts of mercury used in these categories varies among countries. The total amount of mercury used globally in 2015 was 4,715 tonnes, which was increased from 2005 due to the increase of mercury use in ASGM, VCM production, measuring devices, lamps and other uses. Meanwhile mercury use decreased in chlor-alkali production, batteries and electrical and electronic devices (UNEP, 2017).

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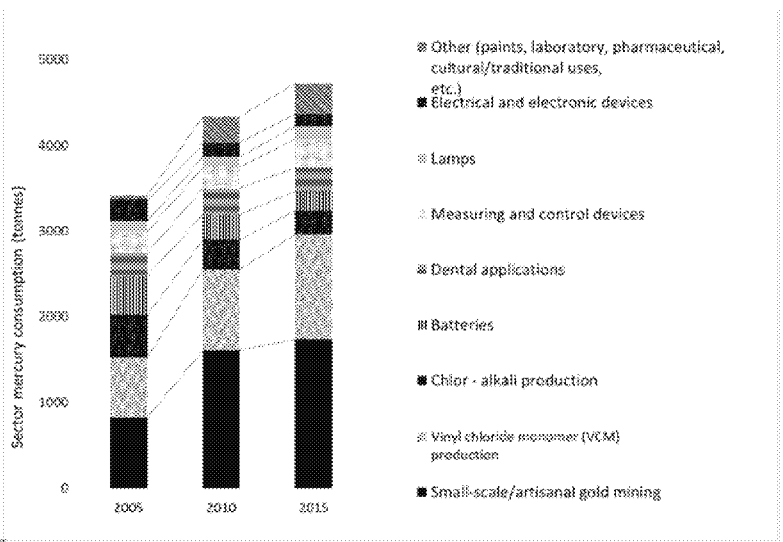
Figure 2: Trends of estimated global mercury uses (UNEP, 2017)



70. The sources, categories and examples of mercury wastes are summarized in table 5 below.

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71. It should be noted that in some countries some of the industrial sources presented in table 5 (sources 1, 2, 3, 4 and 7, except for production processes using mercury) neither use mercury nor generate mercury wastes. Industrial processes depend on a country's technological and social conditions, and these will determine whether mercury-free processes are used. It should be noted that when disposal operations (e.g., "8. Waste treatment other than incineration" or "9. Waste deposition/landfilling and wastewater treatment") are included in an inventory of mercury waste, this may result in an overestimation, as mercury waste generated in or mercury releases from such facilities may result from mercury contained in waste being treated.

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Table 3: Sources, categories and examples of mercury wastes (UNEP 2002; 2005; 2006b; 2006c, decision MC-3/5).

Source	Categories*	Examples of waste types generated	Remarks
1. Extraction and use of fuels/energy sources			
1.1. Coal combustion in power plants	C	C: Flue gas cleaning residues (fly ash, particulate matter, wastewater / sludge, etc.), bottom ash, sludge, catalyst, process water, contaminated personal protective equipment, equipment wash down waste	• Accumulation in bottom ashes and flue gas cleaning residues
1.2. Other coal combustion	C		
1.3. Extraction and use of other fossil fuels	C		
1.4. Biomass fired power and heat generation	C		
1.5. Extraction, refining and use of mineral oil	A/C	A: Mercury captured from crude oil and natural gas processing C: Flue gas cleaning residues (fly ash, particulate matter, wastewater / sludge, etc.), bottom ash, sludge, catalyst, process water, contaminated personal protective equipment, equipment wash down waste	• Accumulation in bottom ashes and flue gas cleaning residues; • Sludge from separator tanks and sedimentary sand tanks for refining of crude oil; • Sludge from natural gas production and processing; • Catalyst for refining of crude oil and processing of natural gas.
1.6. Extraction, refining and use of natural gas	A/C		
2. Primary (virgin) metal production			
2.1. Primary extraction and processing of mercury	A C	Cinnabar concentrate Smelting residue, tailings	• Pyrometallurgy of mercury concentrate
2.2. Metal (aluminium, copper, gold, lead, manganese, zinc, primary ferrous metal, other non-ferrous metals) metal processing of ores	C	Tailings	• Crushing, grinding, flotation and dewatering of ore to produce concentrate
2.3. Metal (aluminium, copper, gold, lead, manganese, zinc, primary ferrous metal, other non-ferrous metals) smelting/roasting processes	A	Mercury chloride (I) and mercury chloride (II) recovered from roasting and smelting processes	• Thermal treatment of concentrate
	C	Smelting/roasting process residues, flue gas cleaning residues, wastewater treatment residues	• Thermal treatment of concentrate
3. Production processes with mercury impurities			
3.1. Cement production	C	Process residues, flue gas cleaning residues, sludge	• Pyroprocessing of raw materials and fuels with naturally occurring mercury impurities
3.2. Pulp and paper production			• Combustion of raw materials with naturally occurring mercury impurities
3.3. Lime production and lightweight aggregate kilns			• Calcination of raw materials and fuels with naturally occurring mercury impurities

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Source	Categories*	Examples of waste types generated	Remarks
4. Intentional use of mercury in industrial production			
4.1. Chlor-alkali production with mercury-technology	A C	Waste electrodes, stockpiles of mercury Solid waste contaminated with mercury, process residues, soil	• Mercury cell; • Mercury recovery units (retort).
4.2. Production of alcoholates (e.g. sodium or potassium methylate or ethylate), dithionite and ultrapure potassium hydroxide solution	A C	Waste electrodes, stockpiles of mercury Solid waste contaminated with mercury, process residues, soil	• Mercury cell; • Mercury recovery units (retort).
4.3. VCM production with mercuric chloride ($HgCl_2$) catalyst	A C	Waste catalyst, stockpiles of mercury catalyst Process residues	• Mercury catalyst process
4.4. Acetaldehyde production with mercury sulphate ($HgSO_4$) catalyst	A C	Waste catalysts, stockpiles of mercury catalyst Wastewater	• Mercury catalyst process
4.5. Polyurethane production with mercury catalyst	A C	Waste catalysts, stockpiles of mercury catalyst Waste catalysed materials	• Mercury catalyst process
4.6. Other production of chemicals and pharmaceuticals with mercury compounds and/or catalysts	A C	Waste catalysts, stockpiles of mercury catalyst Process residues, wastewater	• Mercury catalyst process
4.7. Production of products referred to in 5. below	A C	Stockpiles of mercury and mercury compounds not used for production Process residues, wastewater	
5. Products and applications with intentional use of mercury			
5.1. Thermometers and other measuring devices with mercury	B1	Used, obsolete or broken products	• Mercury
5.2. Electrical and electronic switches, contacts and relays with mercury			
5.3. Light sources with mercury	B1		• Vapour-phase mercury; • Divalent mercury adsorbed on phosphor powder.
5.4. Batteries containing mercury	B2		• Mercury, mercury oxide
5.5. Biocides and pesticides	B1	Stockpiles of obsolete pesticides, soil and solid waste contaminated with mercury	• Mercury compounds (mainly ethylmercury chloride)
5.6. Paints	B1 C	Stockpiles of obsolete paints Solid waste contaminated with mercury, wastewater treatment residues	• Phenylmercuric acetate and similar mercury compounds

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Source	Categories*	Examples of waste types generated	Remarks
5.7. Pharmaceuticals for human and veterinary uses	B1 C	Stockpiles of obsolete pharmaceuticals Medical waste, wastewater treatment residues from agricultural facilities	• Thimerosal; • Mercuric chloride; • Phenyl mercuric nitrate; • Mercurochrome, etc.
5.8. Cosmetics and related products	B2	Stockpiles of cosmetics and related products	• Mercury iodide; • Ammoniated mercury, etc.
5.9. Dental amalgam fillings	B2 C	Stockpiles of dental amalgam Amalgam separator residues and wastewater treatment residues from dental clinics	• Alloys of mercury, silver, copper and tin
5.10. Scientific instrument used for the calibration of medical or scientific devices	B1	Used, obsolete or broken products	• Mercury
5.11. Laboratory chemicals and equipment	A B1/B2 C	Stockpiles of laboratory chemicals Stockpiles of laboratory equipment Wastewater treatment residues, laboratory wastes	• Mercury; • Mercury chloride, etc.
5.12. Polyurethane elastomers	B2 C	Used or end-of-life products Defective and excess product waste	• Elastomer waste containing mercury compounds
5.13. Sponge gold/gold production from ASGM sources	C	Tailings	• Thermal treatment of gold; • Industrial processing.
5.14. Mercury metal use in religious rituals and folklore medicine	A C	Mercury used for religious rituals Solid waste	• Mercury
5.15. Mercury bearings in lighthouses	A	Waste mercury bearings, stockpiles	• Mercury
5.16. Calomel electrode	B1	Used or obsolete products	• Mercury; • Mercury chloride.
5.17. Miscellaneous product uses, mercury metal uses and other sources	B1/B2 C	Stockpiles Wastewater treatment residues, solid wastes, demolition waste	• Infra-red detection semiconductors with mercury; • Bougie and Cantor tubes; • Educational uses, etc.
6. Secondary metal production			
6.1. Recovery of mercury	A B1/B2 C	Spillage during recycling processes, stockpiles of recovered mercury Wastes of products containing mercury or mercury compounds	• Treatment of waste from chlor-alkali, alcoholates, dithionite and ultrapure potassium hydroxide solution production with mercury technology including decommissioning facilities;

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Source	Categories*	Examples of waste types generated	Remarks
		Extraction process residues , flue gas cleaning residues, wastewater treatment residues, contaminated environmental media	• Treatment of waste from polyurethane, vinyl chloride monomer, acetaldehyde production using a mercury containing catalyst • Recovery from mercury meters used in natural gas pipelines; • Recovery from manometers, thermometers, and other equipment.
6.2. Recovery of ferrous metals	C		• Shredding of vehicles containing mercury switches; • Smelting of materials containing mercury.
6.3. Recovery of gold from e-waste (printed circuit boards)	A/C		• Mercury used for amalgamation of gold in small-scale, informal recovery process. • Thermal process.
6.4. Recovery of other metals, such as copper and aluminium	C		• Other materials or products /components containing mercury or mercury compounds
7. Waste incineration			
7.1. Incineration of municipal solid waste	C	Flue gas cleaning residues, wastewater treatment residues, bottom ash, fly ash	• Wastes of products containing mercury or mercury compounds and process waste; • Natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals.
7.2. Incineration of hazardous waste			
7.3. Incineration of medical waste			
7.4. Sewage sludge incineration			
8. Waste treatment other than incineration			
8.1. Physico-chemical treatment of mercury wastes	C	Sludge, wastewater treatment residues	• Chemical precipitation and chemical oxidation of wastes contaminated with mercury or mercury compounds
8.2. Thermal treatment of mercury wastes	C	Flue gas cleaning residues	
8.3. Other treatment of mercury wastes	C	Wastewater treatment residues, materials contaminated with mercury or mercury compounds	• Crushing and separation of products containing mercury or mercury compounds
9. Waste deposition/landfilling and wastewater treatment			
9.1. Controlled landfills/deposits	C	Wastewater, wastewater treatment residues, solid waste contaminated with mercury	• Results from disposal of products containing mercury or mercury compounds and process waste; Natural mercury impurities in bulk materials (plastics, tin cans, etc.) and minerals.
9.2. Diffuse deposition under some control			
9.3. Uncontrolled local disposal of industrial production waste			
9.4. Uncontrolled dumping of general waste			

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Source	Categories*	Examples of waste types generated	Remarks
9.5. Wastewater system/treatment		Wastewater treatment residues, slurries	• Intentionally used mercury in spent products and process waste; • Mercury as an anthropogenic trace pollutant in bulk materials.
10. Crematoria and cemeteries			
10.1. Crematoria	C	Flue gas cleaning residues, wastewater treatment residues	• Dental amalgam fillings
10.2. Cemeteries		Soil contaminated with mercury	
11. Remediation of contaminated sites			
11.1. Remediation of contaminated sites	C	Rubble, debris and soil contaminated with mercury or mercury compounds that has been excavated or removed as part of remediation activities.	

*A: Waste consisting of mercury or mercury compounds; B: Wastes containing mercury or mercury compounds; C: Wastes contaminated with mercury or mercury compounds.

72. More detailed information on products containing mercury or mercury compounds (e.g., names and manufacturers of specific products) is available from the following sources:

(a) UNEP, 2008b. *Report on the major mercury-containing products and processes, their substitutes and experience in switching to mercury-free products and processes*;

(b) European Commission, 2008. *Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society*;

(c) UNEP Global Mercury Partnership – Mercury-Containing Products Partnership Area[27];

(d) UNEP, 2016. *Lessons from Countries Phasing Down Dental Amalgam Use*;

(e) Lowell Center for Sustainable Production, 2003. *An Investigation of Alternatives to Mercury-Containing Products*; and

(f) The Interstate Mercury Education and Reduction Clearinghouse (IMERC). Mercury-Added Products Database[28].

2. Inventories

73. Inventories are an important tool for identifying, quantifying and characterizing wastes. National inventories may be used:

(a) To establish a baseline for quantities of products containing mercury or mercury compounds produced, circulated, traded or in use, commodity mercury, mercury-containing by-products and mercury wastes;

(b) To establish an information registry to assist with safety and regulatory inspections;

(c) To obtain the accurate information needed to draw up plans for lifecycle management of mercury;

(d) To assist in estimating the quantities of mercury and mercury compounds that require storage;

(e) To assist with the preparation of emergency response plans;

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[27] Reports and publications available at: http://web.unep.org/globalmercurypartnership/publication_resource?title=&field_gmp_partnership_area_value=product&field_resource_type_value=All

[28] See http://www.newmoa.org/prevention/mercury/imerc/notification

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(f) To track progress towards reducing and phasing out mercury in products and processes.

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74. After identifying the sources and types of mercury wastes, process-specific information and quantities should be used to estimate the amounts of waste from the identified sources for different types of waste in a given country (or area, community, etc.) (UNEP, 2005).

75. It is in some cases very difficult to collect the necessary data to estimate the quantities of mercury waste generated, particularly in developing countries and countries with economies in transition, due to a lack of data, particularly where small-scale facilities are concerned. In cases where actual measurements are not feasible, data collection could be carried out using questionnaire-based surveys.

76. The *Methodological guide for the undertaking of national inventories of hazardous wastes under the Basel Convention* (UNEP, 2015a) could be used when producing inventories of mercury wastes.

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77. The *Toolkit for Identification and Quantification of Mercury Releases* (UNEP, 2013b) can also be applied. There are two versions of the toolkit, which correspond to two levels of inventory development (i.e., simplified and comprehensive). The toolkit is intended to help countries to develop national inventories of mercury releases and provides a standardized methodology and accompanying database enabling the development of consistent national and regional mercury inventories. It should be noted that the default factors suggested in this Toolkit are based on a limited data base and as such they should be considered subject to revisions as the data base grows. Therefore, it may be appropriate to review, and confirm to the extent feasible, main source specific data for local/national conditions, before major decisions are taken on implementation of mitigation initiatives (UNEP, 2013b). The toolkit has been applied in a number of countries (UNEP, 2008c) and GEF-funded projects. Online training is available from the platform MercuryLearn[8], developed by UNEP and UNITAR. The publication by UNIDO (2018), *Waste mercury perspective*[9], could also be considered.

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78. In keeping with a lifecycle management approach, channels or pathways through which mercury in wastes may be released into the environment should also be identified. In view of the potential risks of mercury releases into the environment, the various types of mercury waste should be ranked in order of priority for action. Information about possible measures to mitigate releases should then be collected, especially with regard to sources and types of mercury waste involving large quantities of mercury and presenting higher risk of mercury release into the environment. Measures must then be evaluated in terms of the magnitude of environmental mercury releases that they could help to prevent, their administrative and social costs, the availability of techniques and facilities associated with them, their social acceptability, etc.

79. In some countries, a Pollutant Release and Transfer Registry (PRTR) is used to collect data about specific mercury content in wastes and its transfer by each facility (Kuncova et al., 2007). PRTR data are publicly available but often not available for recent years[10].

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D. Sampling, analysis and monitoring

80. Sampling, analysis and monitoring are critical components of mercury waste management. Waste sampling, analysis and monitoring should be conducted by trained professionals in accordance with well-designed programmes using internationally accepted or nationally approved methods and should be carried out using the same methods throughout the lives of such programmes. They should also be subjected to rigorous quality assurance and quality control measures. Mistakes in sampling, analysis or monitoring or deviation from standard operational procedures can result in meaningless data or even programme-damaging data. Each party, as appropriate, should therefore develop standards to ensure that training, protocols and laboratory capabilities are in place for sampling, monitoring and analytical methods and that those standards are enforced.

81. Because there are numerous reasons for sampling, analysing and monitoring and because waste comes in so many different physical forms, many different sampling, analysis and monitoring methods are available. Although it is beyond the scope of this document to discuss them specifically,

[8] https://mercurylearn.unitar.org/

[9] https://www.unido.org/sites/default/files/files/2019-07/UNIDO%20Mercury%20Waste%20Forecast%202025.pdf

[10] For example, the Czech Republic PRTR (available at http://www.irz.cz, in Czech only) collects specific data on mercury and mercury compounds transferred to environmental media from wastes, as well as data on how mercury wastes are handled.

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the next three sections consider key elements that should be included in sampling, analysis and monitoring activities. Waste testing priorities should be set based on existing knowledge (or lack thereof) of the mercury content of different types of waste (e.g., testing waste mercury lamps is unlikely to be a high priority, as significant information about their mercury content is readily available).

82. For information on good laboratory practices, the OECD series on good laboratory practice (OECD, various years) may be consulted; on general methodological considerations, the *Guidance for identifying populations at risk from mercury exposure* (UNEP and WHO, 2008) contains helpful information and may be used.

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Deleted: [18] Further guidance on global monitoring of mercury is being developed through a UNEP GEF-funded project that is also expected to establish an online databank of operational mercury laboratories.[19]

1. Sampling

83. The overall objective of any sampling activity is to obtain a sample that can be used for a targeted purpose, e.g., site characterization, compliance with regulatory standards or determination of the suitability of proposed treatment or disposal methods. This objective should be identified before sampling is started. It is indispensable that quality requirements for equipment, transportation and traceability be met.

84. Standardized sampling procedures should be established and agreed upon before the start of the sampling campaign (both matrix- and mercury-specific). Elements of these procedures include the following:

(a) The number of samples to be taken, the sampling frequency, the duration of the sampling project and a description of the sampling method to be used (including quality assurance procedures put in place, e.g., use of appropriate sampling containers[35] and field blanks and of chain-of-custody procedures);

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(b) Selection of locations or sites at which mercury wastes are generated and time and date of sample-taking (including description and geographic localization);

(c) Identity of person who took the sample and conditions during sampling;

(d) Full description of sample characteristics – labelling;

(e) Preservation of the integrity of samples during transport and storage (before analysis);

(f) Close cooperation between the sampler and the analytical laboratory;

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(g) Appropriately trained sampling personnel.

85. Sampling should comply with specific national legislation, where it exists, or with international regulations and standards. In countries where regulations do not exist, qualified staff should be appointed. Sampling procedures include the following:

(a) Development of a standard operational procedure (SOP) for sampling each of the matrices for subsequent mercury analysis;

(b) Application of well-established sampling procedures such as those developed by the International Organization for Standardization (ISO), the European Committee for Standardization (CEN), the United States Environmental Protection Agency (USEPA), the Global Environment Monitoring System (GEMS) and the American Society for Testing and Materials (ASTM);

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(c) Establishment of quality assurance and quality control (QA/QC) procedures.

86. All these steps should be followed if sampling programmes are to be successful. Similarly, documentation should be thorough and rigorous.

87. Mercury can occur and be sampled in liquids, solids, gases and biota:

(a) Liquids:

(i) Leachate from dumpsites and landfills;

(ii) Liquid collected from spills;

(iii) Water (surface water, drinking water and industrial effluents);

(b) Solids:

[35] Polyethylene bottles are permeable to mercury and should not be used. For details, see Parker and Bloom, 2005.

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(i) Stockpiles of products and formulations consisting of, containing or contaminated with mercury or mercury compounds;

(ii) Solids from industrial sources and treatment or disposal processes (fly ash, bottom ash, sludge, still bottoms, other residues, clothing, etc.);

(iii) Containers, equipment or other packaging materials (rinse or wipe samples), including the tissues or fabric used in the collection of wipe samples;

(iv) Soil, sediment, rubble, sewage sludge and compost;

(c) Gases:

(i) Air (indoor) of facilities handling mercury wastes;

(ii) Mercury releases to the air from treatment of mercury wastes;

(iii) Flue gas from waste incinerators;

(d) Biota:

(i) Biological materials (blood, urine and hair, especially those obtained through worker health monitoring);

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(ii) Plants and animals.

88. In environmental and human monitoring programmes, both biotic and abiotic matrices may be included:

(a) Plant materials and food;

(b) Human hair, urine, nails, breast milk or blood;

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(c) Air (ambient, wet or dry deposition or, possibly, snow).

2. Analysis

89. Analysis refers to the extraction, purification, separation, identification, quantification and reporting of mercury concentrations in the matrix of interest. In order to obtain meaningful and acceptable results, the analytical laboratory should have the necessary infrastructure (housing) and proven experience with the matrix and the mercury species (e.g., successful participation in inter-laboratory comparison studies and in external proficiency testing schemes).

90. Accreditation of the laboratory in accordance with ISO 17025 or other standards by an independent body is important. Essential criteria for obtaining high-quality results include:

(a) Specification of the analytical technique used;

(b) Maintenance of analytical equipment;

(c) Validation of all methods used (including in-house methods);

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(d) Training of laboratory staff.

91. Mercury analysis is typically performed in a dedicated laboratory. For screening purposes, test kits are available and can be used in the field.

92. For the analysis of mercury, there is no single analytical method available. Methods of analysing the various matrices for mercury, either for total mercury content or speciation of mercury, have been developed by the International Organization for Standardization (ISO), the European Committee for Standardization (CEN) at the international level, and by the Ministry of Ecology and Environment (MEE) of China, the Japan Standards Association and USEPA at the national level. Table 5 lists some examples of methods for analysing mercury in wastes, flue gas, wastewater and soil. Most in-house methods are variations of these. As with all chemical analysis, laboratories should use only validated methods, and performance should be evaluated through QA/QC programmes.

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Table 6: Chemical analysis of mercury in waste, flue gas, wastewater and soil

Matrix or waste medium	Purpose	Method
Waste	To determine the mobility of mercury in waste	EN 12457-1 to 4: Characterization of waste - Leaching - Compliance test for leaching of granular waste materials and sludges (CEN, 2002a)
		EN 12920: Characterization of waste - Methodology for the determination of the leaching behaviour of waste under specified conditions (CEN, 2006)
		EN 13656: Soil, treated biowaste, sludge and waste - Digestion with a hydrochloric (HCl), nitric (HNO_3) and tetrafluoroboric (HBF4) or hydrofluoric (HF) acid mixture for subsequent determination of elements (CEN, 2020)
		EN 14405: Characterization of waste - Leaching behaviour test - Up-flow percolation test (under certain conditions) (CEN, 2017)
		HJ 702-2014, Solid Waste - Determination of Mercury, Arsenic, Selenium, Bismuth, Antimony - Microwave Dissolution / Atomic Fluorescence Spectrometry (MEE China, 2014)
		HJ/T 299-2007, Solid waste - Extraction Procedure for Leaching Toxicity - Sulphuric Acid & Nitric Acid Method (MEE China, 2007a)
		HJ/T 300-2007, Solid waste - Extraction Procedure for Leaching Toxicity - Acetic Acid Buffer Solution Method (MEE China, 2007b)
		HJ 557-2010, Solid waste - Extraction Procedure for Leaching Toxicity - Horizontal Vibration Method (MEE China, 2010)
		GB/T 15555.1-1995, Solid Waste - Determination of Total Mercury - Cold Atomic Absorption Spectrometry (MEE China, 1995)
		Leaching Environmental Assessment Framework (LEAF) How-To Guide (USEPA, 2019)
		EPA Method 1313 - Liquid-Solid Partitioning as a Function of Extract pH Using a Parallel Batch Extraction Procedure[33] (USEPA, 2017a)
		EPA Method 1314 - Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials Using an Up-Flow Percolation Column Procedure[33] (USEPA, 2017b)
		EPA Method 1315 - Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Procedure[33] (USEPA, 2017c)
		EPA Method 1316 - Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Parallel Batch Extraction Procedure[33] (USEPA, 2017d)
	To determine concentrations of mercury in waste	EN 13657: Characterization of waste - Digestion for subsequent determination of aqua regia soluble portion of elements in waste (CEN, 2002c)
		EN 15309: Characterization of waste and soil - Determination of elemental composition by X-ray fluorescence (CEN, 2007)
		HJ 702-2014, Solid Waste - Determination of Mercury, Arsenic, Selenium, Bismuth, Antimony - Microwave Dissolution / Atomic Fluorescence Spectrometry (MEE China, 2014)
		EPA Method 7471B: Mercury in Solid or Semisolid Waste (Manual Cold-Vapor Technique) (USEPA, 2007d)
		EPA Method 7473: Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry (USEPA, 2007e)

[33] Technical guidance for implementing US EPA leach test methods 1313-1316 (*Leaching Environmental Assessment Framework (LEAF) How-To Guide* (USEPA, 2019) is available at: https://www.epa.gov/sites/production/files/2019-05/documents/final_leaching_environmental_assessment_framework_leaf_how-to_guide.pdf.

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Matrix or waste medium	Purpose	Method
		EPA Method 7470A: Mercury in Liquid Waste (Manual Cold-Vapor Technique) (USEPA, 1994)
Flue Gas		ISO 21741:2020 Stationary source emissions — Sampling and determination of mercury compounds in flue gas using gold amalgamation trap (ISO, 2020)
		EN 13211: Air quality - Stationary source emissions - Manual method of determination of the concentration of total mercury (CEN, 2001) *This method determines the total mercury content (i.e., metallic/elemental Hg + ionic Hg).
		EN 14884: Air quality - Stationary source emissions - Determination of total mercury: Automated measuring systems (CEN, 2005)
		HJ 543-2009, Stationary Source Emission - Determination of Mercury - Cold Atomic Absorption Spectrophotometry (Provisional) (MEE China, 2009)
		HJ 917-2017, Stationary Source Emission - Determination of Total Gaseous Mercury - Carbon Sorbent Traps / Thermal Cracking Atomic Absorption Spectrophotometric Method (MEE China, 2017)
		JIS K 0222:1997 Methods for determination of mercury in stack gas (JSA, 1997)
		EPA Method 0060: Determination of Metals in Stack Emissions (USEPA, 1996)
	For the chemical speciation of mercury	ASTM D6784 - 16 Standard Test Method for Elemental, Oxidized, Particle-Bound and Total Mercury in Flue Gas Generated from Coal-Fired Stationary Sources (Ontario Hydro Method) (ASTM International, 2016)
Wastewater		ISO 12846:2012, Water quality -- Determination of mercury - Method using atomic absorption spectrometry (AAS) with and without enrichment (ISO, 2012)
		ISO 17852: 2006, Water quality -- Determination of mercury - Method using atomic fluorescence spectrometry (ISO, 2006)
Soil		ISO 18400-104:2018 Soil quality - Sampling - Part 104: Strategies (ISO, 2018a)
		ISO 18400-202:2018 Soil quality - Sampling - Part 202: Preliminary investigations (ISO, 2018b)
		ISO 18400-203:2018 Soil quality - Sampling - Part 203: Investigation of potentially contaminated sites (ISO, 2018c)

93. In addition, procedures and acceptance criteria for storage, handling and preparation of the sample in the laboratory, e.g., homogenization, should be established.

94. The individual steps in the analytical determination include:

(a) Extraction;

(b) Purification;

(c) Identification by suitable detectors such as inductively coupled plasma (ICP), atomic fluorescence spectroscopy (AFS), amino acid analysers and compact instruments;

(d) Quantification and reporting as required;

(e) Reporting in accordance with regulation(s).

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3. Monitoring

95. In Article 10 ("International Cooperation"), paragraph 2 (b), the Basel Convention requires Parties to "cooperate in monitoring the effects of the management of hazardous wastes on human health and the environment". In Article 12, paragraph 1 (b), the Minamata Convention requires Parties to endeavour to cooperate to develop and improve, taking into account their respective circumstances

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and capabilities, modelling and geographically representative monitoring of levels of mercury and mercury compounds.

96. Monitoring programmes should be implemented for facilities managing mercury wastes, as they provide an indication of whether a facility is functioning in accordance with its design and environmental regulations. The information obtained through monitoring programmes should be used to ensure that different types of mercury wastes are properly managed, to identify potential issues relating to possible mercury releases or exposure to mercury and to determine whether amendments to the management approach might be appropriate.

97. It should be noted that a number of continuous mercury measurement systems are commercially available for some types of mercury monitoring. Such monitoring may be required under national or local legislation.

E. Waste prevention and minimization

98. The prevention and minimization of mercury wastes are the first and most important steps in the ESM of such wastes. In Article 4, paragraph 2, the Basel Convention calls on Parties to "ensure that the generation of hazardous wastes and other wastes … is reduced to a minimum". Waste prevention should be the preferred option in any waste management policy so that the need for waste management is reduced, enabling resources for ESM to be used more efficiently. Paragraphs 100 to 131 below provide information on ways to prevent and minimize mercury wastes from important sources of mercury wastes.

99. Article 5 of the Minamata Convention requires Parties to phase out mercury use in chlor-alkali and acetaldehyde production processes and to restrict mercury use in vinyl chloride monomer production, sodium or potassium methylate or ethylate, and production of polyurethane using mercury-containing catalysts (for details, see paragraph 28 of the present guidelines). Article 4 of the Minamata Convention requires Parties to not allow the manufacture of certain mercury-added products and to phase down the use of dental amalgam (for details, see paragraphs 26 and 1 of the present guidelines).

1. Waste prevention and minimization for processes

100. There are many processes where mercury wastes are generated. Artisanal and small-scale gold mining, vinyl-chloride monomer production and chlorine and caustic soda (chlor-alkali) production are major sources of mercury wastes since those processes intentionally use large volume of mercury. Industrial processes where mercury is not intentionally used could also generate mercury wastes when mercury exists in their inputs as an impurity. Such processes include, but are not limited to, coal-fired power plants/industrial boilers, smelting and roasting processes used in the production of non-ferrous metals and crude oil and natural gas production processes. Therefore, this subsection discusses waste prevention and minimization measures with respect to those processes.

(a) Artisanal and small-scale gold mining

101. According to Article 7 of the Minamata Convention, Parties that have ASGM and processing activities within their territories in which mercury amalgamation is used to extract gold from ore shall take steps to reduce, and where feasible eliminate, the use of mercury and mercury compounds in, and the emission and releases of mercury to the environment from, such mining and processing. In decision MC-1/13, the Conference of the Parties to the Minamata Convention adopted a guidance document[21] on the development of national action plans to assist Parties in meeting their obligations under Article 7. In decision MC-3/5, the Conference of the Parties to the Minamata Convention requested the secretariat, in cooperation with the ASGM partnership area, to seek comments from Parties and other stakeholders to improve the guidance on the preparation of national action plans for ASGM regarding management of tailings from such mining.

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Deleted: Table 4: Chemical analysis of mercury in waste, flue gas and wastewater ¶

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[21] *Guidance on developing a national action plan to reduce and, where feasible, eliminate mercury use in artisanal and small-scale gold mining*. http://www.mercuryconvention.org/Portals/11/documents/forms-guidance/English/ASGM_guidance_e_2017.pdf

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102. Mercury-free techniques such as gravimetric methods and in combination with non-mercury methods are available. Specific guides such as the following are available at the website of the Global Mercury Partnership, ASGM area[35]:

b. UNEP, 2018. Illustrated Guide to Mercury Free Artisanal and Small Scale Gold Mining; and

c. UNEP, 2017. A path to mercury-free artisanal and small scale gold mining.

103. In cases where feasible alternatives are unavailable, interim solutions that lead towards mercury-free techniques should be used. Such solutions could include mercury capture and recycling technologies such as retorts and fume hoods, mercury re-activation, and avoidance of mercury-intensive processing such as whole-ore amalgamation. Details on these interim solutions can be found in the following reference materials:

(a) Artisanal Gold Council. 2014. Using Retorts to Reduce Mercury Use, Emissions, and Exposures in Artisanal and Small-Scale Gold Mining: A Practical Guide;

(b) USEPA. 2008. Manual for the Construction of a Mercury Collection System for Use in Gold Shops.

104. Artisanal miners, their families and communities in the vicinity of mining operations should be educated about the risks of exposure to mercury and related health hazards and the environmental impacts of mercury use in ASGM.

105. Once awareness of the environmental and health risks of mercury use in ASGM has increased, training in techniques and systems to prevent waste generation should be provided.

(b) Vinyl chloride monomer (VCM) production

106. VCM production using the acetylene process involves the use of mercuric chloride as a catalyst. According to Article 5, paragraph 3 in connection with Annex B of the Minamata Convention, Parties to that Convention are required to take measures to reduce the use of mercury in VCM production in terms of per unit production by 50 per cent by the year 2020 against 2010 use. Also, such Parties are required to promote measures to reduce the reliance on mercury from primary mining and to take measures to reduce emissions and releases of mercury to the environment. Methods to prevent and minimize mercury waste in VCM production fall into two primary categories: (a) alternative, mercury-free manufacturing methods; and (b) methods to better manage mercury during the production process and to capture mercury environmental releases.

107. In mercury-free VCM manufacturing, VCM is manufactured using a variety of mercury-free methods, most commonly based on the oxychlorination of ethylene (Office of Technology Assessment, 1983). While mercury-free methods are common worldwide, in several countries the acetylene process continues to be used because it is significantly less expensive in locations where coal is cheaper than ethylene (Maxson, 2011). Efforts to develop a mercury-free catalyst for the acetylene process have resulted in the development (by Johnson Matthey) of a mercury-free catalyst for the manufacture of VCM and has been commercialized. It is economically viable and can be used as a direct replacement for catalysts in existing VCM reactors[36].

108. Suggested measures to reduce the generation of wastes contaminated with mercury include better management of mercury; development and application of low-mercury catalysts; implementation of technological reforms to prevent mercuric chloride evaporation; prevention of catalyst poisoning; and delaying carbon deposition to reduce the use of mercury. For further information, see the *Project Report on the Reduction of Mercury Use and Emission in Carbide PVC Production* (Ministry of Environmental Protection of China, 2010) and information in the publication *Global mercury supply, trade and demand* (UNEP, 2017).

(c) Chlor-alkali production

109. Chlor-alkali production using the mercury cell involves the use of elemental mercury as an electrode. According to Article 5, paragraph 2 in connection with Annex B of the Minamata Convention, Parties to that Convention are required to phase out the use of mercury in chlor-alkali

[35] https://web.unep.org/globalmercurypartnership/publication_resources?title=&field_gmp_partnership_area_value=asgm&field_resource_type_value=All

[36] See https://matthey.com/en/products-and-services/chemical-processes/licensed-processes/vinyl-chloride-monomer-process.

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production by the year 2025 except where the Party has a registered exemption. As the mercury cell process is replaced by mercury-free processes in chlor-alkali facilities, mercury emissions and waste generation are eliminated at these facilities. Mercury-free chlor-alkali production employs either diaphragm or membrane processes. Membrane processes are more cost effective than diaphragm processes because they require less electricity (Maxson, 2011). Although the mercury cell process is being phased out, as of 2019 there were still 12 plants using the process in six countries. Solid waste from these chlor-alkali plants amounted to 10 113 kg in 2019 (World Chlorine Council, 2020).

110. Waste contaminated with mercury generated from chlor-alkali plants may include semi-solid sludges from water, brine and caustic treatment, graphite and activated carbon from gas treatment, residues from retorting, and mercury collected in tanks or sumps. In addition to monitoring of possible leakages and good housekeeping, mercury waste generation can be reduced through reduction of mercury evaporation, better control of mercury emissions, recovery of mercury from wastewater and from flue gas and caustic treatment. For further information, the following documents or website should be consulted:

(a) European Commission, 2013a. *Commission implementing decision of 9 December 2013 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the production of chlor-alkali* (2013/732/EU);

(b) European Commission, 2014b. *Integrated Pollution Prevention and Control (IPPC)-Best Available Techniques (BAT) Reference Document for the Production of Chlor-alkali*;

(c) Global Mercury Partnership, Chlor-alkali sector resources[37].

111. When decommissioning mercury cell plants, it is recommended to develop a decommissioning plan in consultation with external contractors as appropriate. The implementation phase of the decommission plan may include setting up a working area, emptying of the cells and handling of metallic mercury, as well as dismantling, demolition and decontamination of equipment and buildings. It is also recommended to use one or a combination of the oxidation and ion exchange, oxidation and precipitation and reduction and adsorption on activated carbon in order to reduce mercury releases during the decommission or conversion of mercury cell plants[38].

(d) Coal-fired power plants and coal-fired industrial boilers

112. Coal washing is a process primarily to reduce ash, particulate matters and sulfur content of coal in order to improve its heating value. It is considered as an economical and effective technique to minimize related environmental problems (Zhao and Luo, 2017). The removal of mineral impurities also reduces operation and maintenance costs and slows the deterioration of the boiler system (UNEP, 2019c). This process can also decrease the mercury content of coal, which leads to the reduction of mercury wastes. Generally, such decrease is greater ~~reduction in~~ for bituminous coals ~~higher~~ than for lower rank coals/lignite since in lower rank coals a greater fraction of mercury is likely to be bound to the organic carbon structure (European Commission, 2017a). Removal of mercury from coal is feasible when conventional coal washing methods are used. The effectiveness of mercury removal during conventional coal washing, however, varies widely depending on the source of the coal and on the nature of the mercury within it (UNEP, 2019c). It should be noted that coal washing may generate slurry waste contaminated with mercury.

113. Coal blending is a cost-effective option to reduce the relative amount of mercury since some coal ranks have more oxidized forms of mercury. Coal blending can increase halide concentrations, thereby increasing the proportion of oxidized mercury which becomes easier to capture mercury by a flue-gas desulphurisation (FGD) scrubber (European Commission, 2017a) since oxidized mercury is soluble to water.

(e) Smelting and roasting processes used in the production of non-ferrous metals

114. Mercury content of non-ferrous metal concentrates significantly varies across ore mining areas. The mercury content of non-ferrous metal concentrates is contributes directly ~~linked~~ to the input

[37] See http://web.unep.org/globalmercurypartnership/publication_resources?title=&field_gmp_partnership_area_value=chlor&field_resource_type_value=Guidance (this link contains guidance for the chlor-alkali industry)

[38] According to European Commission (2014b), the measures described in this sentence allow reducing mercury releases to water to 3-15 µg/l expressed as Hg, at the outlet of the mercury treatment unit during decommissioning or conversion.

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of mercury to the smelting and roasting processes and also the resulting emissions and releases. Where possible, priority should be given to use low-mercury concentrates while meeting production specifications in order to minimize the generation of mercury wastes. Blending low-mercury concentrates from different sources is an alternative option to control the mercury input in the processes and to reduce the mercury output to the environment (Zhang et al., 2019).

(f) Crude oil and natural gas processing

115. Mercury is naturally present in natural gas, crude oil and bitumen but the mercury concentration significantly varies depending on reservoirs and geographic areas. Crude oil and natural gas processing facilities generate several types of mercury wastes such as waste elemental mercury, spent catalyst and adsorbent and sludge. One way to reduce mercury wastes is to return spent catalysts and adsorbents to the manufacturers for recycling.

2. Waste prevention and minimization for products containing mercury or mercury compounds

116. Introducing mercury-free alternatives and banning products containing mercury or mercury compounds are important ways to prevent the generation of mercury wastes. Under the Minamata Convention, the manufacture, export and import of specific mercury-added products are prohibited after 2020 (see paragraph 26 above). Article 4 in conjunction with Annex A of the Minamata Convention provides for the phase-out of some mercury-added products (e.g., certain mercury batteries and switches, certain lamps, pesticides, biocides and antiseptics), and phase down of mercury use in dental amalgam.

117. As a transitional measure, setting maximum limits of mercury content in products where mercury-free alternatives are not available in the foreseeable future would help to reduce the generation of mercury wastes from the products containing mercury or mercury compounds sector. Replacement of such products with mercury-free or low-mercury alternatives can be facilitated through green purchasing.

118. Where products containing mercury or mercury compounds are still in use, the establishment of a safe closed system for utilization of mercury is desirable. Mercury contamination of waste streams should be prevented through:

(a) The use of mercury-free products;

(b) Setting maximum limits of mercury content in products;

(c) Setting procurement standards to purchase mercury-free and low-mercury products.

119. Extended producer responsibility (EPR) schemes can be effective instruments to encourage the production of mercury-free or low-mercury products.

(a) Mercury-free products

120. The substitution of mercury in products depends on factors such as efficacy or performance of substitutes, substitute and overall product costs, the environmental and human health impacts of substitutes, technology, government policies and economies of scale. Many kinds of mercury-free alternatives are now available. Detailed information about mercury-free alternatives is available in the following websites and publications:

(a) Information on the uses of mercury and on non-mercury alternatives under "Review of annexes A and B" of the Minamata Convention[39];

(b) "Many products still contain mercury. These alternatives could replace them" on the UNEP website[40];

(c) *Replacement of mercury thermometers and sphygmomanometers in health care: Technical guidance* (WHO, 2011);

(d) "Listings of Alternatives for Mercury Added and Mercury Contaminated Products" on the National Institute of Health, U.S. Department of Health & Human Services website[41].

[39] See http://www.mercuryconvention.org/Meetings/Intersessionalwork/tabid/8279/language/en-US/Default.aspx

[40] See https://www.unenvironment.org/news-and-stories/story/many-products-still-contain-mercury-these-alternatives-could-replace-them

[41] See https://www.orf.od.nih.gov/EnvironmentalProtection/MercuryFree/Pages/Alternatives.aspx

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Figure 3: Closed System for Utilization of Mercury¶

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<#>*Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society* (European Commission, 2008).¶

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(b) Setting maximum limits of mercury content in products

121. Article 4 in conjunction with Annex A of the Minamata Convention sets mercury content limits for certain mercury-added products as follows:

(a) Button zinc silver oxide batteries, button zinc air batteries: 2 per cent;

(b) Very high accuracy capacitance and loss measurement bridges and high frequency radio frequency switches and relays in monitoring and control instruments: 20 mg per bridge;

(c) Compact fluorescent lamps (CFLs) for general lighting purposes that are ≤ 30 watts: 5mg per lamp burner;

(d) Linear fluorescent lamps (LFLs) for general lighting purposes: 5 mg per lamp for triband phosphor ≤ 60 watts, 10 mg per lamp for halophosphate phosphor ≤ 40 watts;

(e) Cold cathode fluorescent lamps and external electrode fluorescent lamps for electronic displays: 3.5 mg per lam for short length (≤ 500 mm), 5 mg per lamp for medium length (> 500 mm and ≤ 1,500 mm), 13 mg per lamp for long length (> 1,500 mm);

(f) Cosmetics: 1ppm

122. Mercury content limits should be established for products containing mercury or mercury compounds until such time as those products can be phased out. Such limits can result in less mercury being used per product in the production stage, which in turn could result in less mercury being emitted throughout the entire product lifecycle, including from accidental release or breakage, and reduce the total amount of mercury in wastes requiring mercury-specific management.

123. Mercury content limits for products can be set through legislation (see examples in section III, B, 2 below) or through voluntary industry actions under public environmental/mercury management plans. As stated previously, legal requirements for mercury content limits for batteries and fluorescent lamps have been established in the European Union, and several states of the United States have adopted mercury content limits for batteries. In Japan, mercury content limits for fluorescent lamps have been set by an industry association, and the national government has used those limits as a criterion to select fluorescent lamps under green purchasing policies. In Canada, the Products Containing Mercury Regulations set limits on the amount of mercury that fluorescent and other types of lamps can contain.

124. In order to reduce the amount of mercury in fluorescent lamps, manufacturers have developed various technologies for injecting specific amounts of mercury into individual lamps that correspond to the minimum amounts of mercury required for adequate lamp performance. Examples of methods for injecting precise amounts of mercury in lamps include using mercury amalgam, a mercury alloy pellet, a mercury alloy ring, and a mercury capsule instead of injecting mercury (Ministry of the Environment of Japan, 2010).

125. The use of mercury amalgam dosing may have environmental and performance advantages over the use of mercury throughout the life cycle of compact fluorescent lamps (CFLs) and other types of lamps containing mercury. The strength of accurate mercury dosing methods is that they minimize worker and consumer exposure to, as well as environmental releases of, mercury vapour during manufacturing, transportation, installation, storage and recycling and disposal, particularly when lamps break. In addition, accurate mercury dosing methods enable manufacturers to produce CFLs that contain very low mercury levels (two milligrams or less) while meeting important performance requirements such as high efficiency and long lamp life.

(c) Procurement

126. Procurement programmes for mercury-free products should be encouraged in order to pursue waste prevention and promote the use of mercury-free and low-mercury products. Purchasing practices should, where possible, be aimed at the purchase mercury-free products, except in the few cases where alternatives to products containing mercury or mercury compounds are practically or technologically unavailable, or at the purchase of products whose mercury content is minimized.

127. Larger users of products containing mercury or mercury compounds, such as government institutions and healthcare facilities, can play an important role in stimulating demand for mercury-free products by implementing green procurement programmes. In some cases, financial incentives could be used to encourage green procurement programmes. Some states in the United States, for instance, have subsidized the purchase of mercury-free thermometers.

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3. Extended producer responsibility

128. Extended producer responsibility (EPR) is defined as "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle". "Producer"[22] is considered to be the brand owner or importer except in cases such as packaging, and in situations where the brand owner is not clearly identified, as in the case of electronics, in which the manufacturer (and importer) would be considered as the producer (OECD, 2001a). EPR programmes shift the responsibility for the end-of-life management of products from local government authorities and taxpayers to producers, and can create incentives for producers to incorporate environmental considerations into the design of their products and ensure that the cost of environmentally sound treatment and disposal of those products once they have become waste are reflected in product prices. EPR can be implemented through mandatory or voluntary approaches, or a combination of the two (e.g., via negotiated agreements). Take-back collection programmes can be incorporated into EPR programmes (see paragraph 157 below).

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129. EPR programmes, depending on how they are designed, can achieve a number of objectives, including: (1) to relieve local governments of the financial and in some cases operational burden of disposing of waste/products/materials; (2) to encourage companies to design products for reuse and recyclability and to reduce both the quantity and hazardousness of materials used; (3) to incorporate waste management costs into product prices; and (4) to promote innovation in recycling technology. EPR therefore promotes a market in which prices reflect the environmental costs of products (OECD 2001a). Detailed descriptions of EPR schemes are available in several OECD publications on the issue[23].

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130. When EPR programmes are used, the environmental authorities may develop regulatory frameworks setting out the responsibilities of relevant stakeholders, standards for the management of products and the components that all EPR programmes should have, and encourage participation by relevant parties and the public. The environmental authorities should also monitor the performance of EPR programmes (e.g., amount of wastes collected, amount of mercury recovered and costs accrued for collection, recycling and storage) and make recommendations for improvement as necessary. The responsibility to implement EPR programmes should be shared by all producers of a given product and there should be no "free riders" (i.e., producers who do not have to implement EPR) in such programmes so as to avoid a situation in which certain producers are forced to bear a disproportionate share of the costs of EPR that goes beyond their product market share.

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131. Boxes 4 to 6 provide information on regional/national EPR programmes.

Box 4 Regional Example: European Union

In the European Union, fluorescent lamps, including CFLs, are one of the products subject to the requirements of the *Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment (WEEE)* (European Union, 2012). The directive requires extended producer responsibility for management of waste electrical and electronic equipment that contain, *inter alia*, mercury.

In addition, batteries are subject to the requirements of the *Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC* (European Union, 2006). Producers of batteries and accumulators and producers of other products incorporating a battery or accumulator are given responsibility for the waste management of batteries and accumulators that they place on the market.

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[22] European Union Directive 2008/98/EC provides that any natural or legal person who professionally develops, manufactures, processes, treats, sells or imports products has extended producer responsibility.

[23] Available at: http://www.oecd.org/environment/evaluation/extendedproducerresponsibility.htm.

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Box 5 Country example: Canada

In Canada, EPR programmes across Canada on mercury containing products, such as lamps and batteries[44] are in operation. For example, in the province of Québec, The RecycFluo is a non-profit program that accepts mercury-containing light bulbs and fluorescent tubes from Québec consumers and businesses, and responsibly recycles them free of charge. It is operated by Product Care Recycling, a non-profit industry association, specializing in product stewardship, on behalf of the manufacturers, distributors and retailers of these products and funded by recycling fees paid by the consumer at the point of sale on new mercury-containing light lamps in Québec[45].

Box 6 Country Example: Korea

In the Republic of Korea, fluorescent lamps and batteries are targets of the EPR that mandates producers and importers of products to recycle a certain amount of wastes from products. Ones who fail to follow this obligation are subject to recycling charges. Producers fulfill the responsibility for recycling individually or by joining a PRO (Producer Responsibility Organization)[46].

F. Handling, separation, collection, packaging, labelling, transportation and storage

132. The procedures for the handling, separation, collection, packaging, labelling, transportation and storage of mercury wastes pending their disposal are similar to those applicable to other kinds of hazardous waste. However, because the physical and chemical properties of mercury make it very mobile in the environment, the ESM of mercury waste requires the use of additional precautions and handling techniques.

133. Specific technical guidance on the most appropriate handling of mercury wastes is provided in this section, but it is imperative that generators also consult and adhere to applicable national and local requirements. For transport and the transboundary movement of hazardous wastes, the following documents should be consulted to determine specific requirements:

(a) UNEP, 2015b. *Manual for the Implementation of the Basel Convention*;

(b) International Maritime Organization (IMO), 2018. *International Maritime Dangerous Goods Code*;

(c) International Civil Aviation Organization (ICAO), 2017. *Technical Instructions for the Safe Transport of Dangerous Goods by Air*;

(d) International Air Transport Association (IATA), 2020. *Dangerous Goods Regulations Manual*; and

(e) United Nations, 2019a. *United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations*.

134. Product-specific guidance for handling, separation, collection, packaging, labelling, transportation and storage of mercury wastes is available in the following reference materials:

(a) UNDP, 2010. *Medical devices: Guidance on the Clean-up, Temporary or Intermediate Storage, and Transport of Mercury Waste from Health Care Facilities*;

(b) WHO, 2010. *Future Use of Materials for Dental Restoration* (Chapter 6, Best management practices (BMP) for amalgam waste); and

(c) Lamp Recycling Outreach Project, undated. *Training Module (1-hour version) for Generators and Handlers of Fluorescent and Mercury-Containing Lamps (and Ballasts)*.

135. Relevant information regarding the hazardous characteristics and risks of mercury wastes should be collected and analysed in order to plan the proper handling of such wastes, for example by consulting and following the instructions given on the chemicals they contain and related safety data

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[44] https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/overview-extended-producer-responsibility/mercury-recycling-programs.html

[45] https://www.recycfluo.ca/en/about-recycfluo

[46] Information is available at https://www.keco.or.kr/en/eng/operation_extended/contentid/1950/index.do

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sheets. For labelling and packaging, the United Nations Globally Harmonized System of the Classification and Labelling of Chemicals (GHS) should be taken into account, as appropriate.

136. To ensure that releases of mercury or mercury compounds are kept to a minimum, it is important to first raise awareness of those involved in handling, separation, collection, packaging, labelling, transportation and storage (i.e. transporters, recyclers, and treatment operators) about the risks of mercury. Such awareness raising can be achieved through training activities such as seminars providing information on new systems and regulations and opportunities of information exchange, preparation and distribution of leaflets and dissemination of information via the Internet.

1. Handling

137. Those who handle mercury waste should pay particular attention to the prevention of evaporation and spillage of mercury into the environment. Mercury waste should be placed in a gas- and liquid-tight containers that bear a distinctive mark indicating that they contain "toxic" mercury.

138. End users should safely handle and prevent any breakage of or damage to wastes of products containing mercury or mercury compounds such as fluorescent lamps, thermometers and electrical and electronic devices. Wastes of products containing mercury or mercury compounds such as paints and pesticides should be handled safely and should not be discharged into sinks, toilets, storm sewers or other rainfall runoff collection systems. Wastes of products containing mercury or mercury compounds should not be mixed with any other wastes. If such products are accidentally broken or spilled, clean-up procedures should be followed (see subsection III.K.2 below).

139. Those who handle wastes contaminated with mercury should not mix them with other wastes. Wastes contaminated with mercury should be placed in sealed containers to prevent the release of mercury to the environment.

2. Separation

140. Separation of mercury wastes is important because if such wastes are simply disposed of, e.g. as part of municipal solid waste (MSW), without any separation, the mercury content in them could be released into the environment.

141. Industrial mercury wastes should be separated from other wastes generated at industrial facilities in accordance with applicable national laws. Keeping such wastes separate allows for appropriate treatment to either extract the mercury from them or to stabilize the wastes for proper disposal without diluting their mercury content. Dilution of the mercury in the waste by mixing it with other wastes could make treatment less effective, or could inappropriately reduce the mercury concentration to be below the threshold(s) to be established under paragraph 2 of Article 11 of the Minamata Convention, thereby hindering the proper management of such wastes.

142. Depending on national and local legislation, separation can be facilitated through labelling of products that contain mercury. Labelling systems for products containing mercury or mercury compounds should be implemented by producers during the manufacturing stage of such products to facilitate the identification of products that contain mercury and need special handling under collection and recycling programmes.[25] Labels may need to comply with national right-to-know regulations, which may require the disclosure of the identity and properties of toxic chemical ingredients in products. Labelling systems for products containing mercury or mercury compounds could also require that labels include instructions on proper use of those products, as well as waste management instructions that encourage recycling and proper disposal.

143. Labelling systems for products containing mercury or mercury compounds could help achieve the following objectives:

(a) Informing consumers at the point of purchase that such products contain mercury and may require special handling upon becoming waste;

(b) Identifying products containing mercury or mercury compounds at the point of collection so that they can be kept separate from other wastes;

144. Manufacturers can indicate the presence of mercury in products containing mercury or mercury compounds by using the international chemical symbol for mercury, "Hg", on product labels. For example, products containing mercury or mercury compounds sold in certain states of the

[25] By way of example, guidelines are available at http://www.newmoa.org/prevention/mercury/merclabelinginfo.cfm

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<#>Include, to the extent practical, the collection of all mercury wastes in collection programmes; ¶
<#>Make acceptable containers and safe-transport materials available to mercury waste owners for those wastes that need to be repackaged or made safe for transport;¶
<#>Establish simple, low-cost mechanisms for collection;¶
<#>Ensure the safety both of those delivering mercury wastes to depots and of workers at such depots;¶
<#>Ensure that the operators of depots are using an accepted disposal method;¶
<#>Ensure that programmes and facilities meet all applicable legislative requirements; and¶ ... [10]

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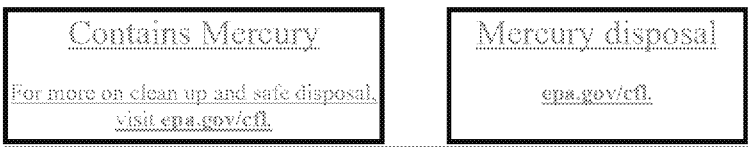
United States are required to carry this symbol[25] (Hg). In the European Union, the chemical symbol "Hg" must be printed on batteries containing mercury under Directive 2006/66/EC (European Union, 2006). The use of a similar symbol on the packaging labels for lamps containing mercury traded internationally could promote global recognition that such lamps contain mercury. Additional information provided in local languages could further serve to explain the meaning of the symbol.

145. Box 7 provides a national example of labelling on products containing mercury or mercury compounds.

Box 7 Country Example: USA

In the United States, the Lamp Section of the National Electrical Manufacturers Association (NEMA) maintains that a harmonized national or international approach to labelling lamps containing mercury is an essential component of the efficient and economic distribution of energy-efficient lighting[26]. On 19 July 2010, the United States Federal Trade Commission promulgated a rule[27] requiring that, starting in 19 July 2011, packaging for CFLs, light emitting diode (LED) lamps and traditional incandescent lamps include new labels to help consumers choose the most efficient lamps for their lighting needs. For lamps containing mercury, both their packaging and the lamps themselves must be labelled as follows[28]:

Figure: Example of product labelling (fluorescent lamp: left for packaging, right for product)



146. When products containing mercury or mercury compounds are exported and become waste in importing countries, consumers, users and other stakeholders in those countries may be unable to read or understand product labels written in a foreign language. In such cases, importers, exporters, manufacturers or national agencies in charge of product labelling should make sure that product labels are locally appropriate and/or are written in the relevant local language(s).

3. Collection

147. The following issues should be considered when establishing and implementing collection programmes for mercury wastes, in particular waste of products containing mercury and mercury compounds from households and commercial and institutional entities:

(a) Advertise the programmes, depot locations and collection time periods to all potential holders of mercury wastes;

(b) Allow enough time for the operation of collection programmes for the complete collection of all mercury wastes included in the programmes;

(c) Include, to the extent practical, the collection of all mercury wastes in collection programmes.

(a) Collection of waste consisting of mercury or mercury compounds

148. Wastes consisting of mercury or mercury compounds, such as those generated during the closure of mercury cell chlor-alkali facilities, are different from other mercury wastes in terms of the hazards that they may pose if mishandled. Wastes consisting of mercury or mercury compounds may also be generated in higher volumes than other mercury wastes, making their safe collection more

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<#>**Figure 4:** Example of product labelling (fluorescent lamp: left for packaging, right for product)¶
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<#>When mercury-added products

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[25] Available at http://www.nemo.org/prevention/mercury/more/labelinginfo.cfm

[26] Available at https://www.nema.org/Standards/Pages/The-Labeling-of-Mercury-Containing-Lamps.aspx .

[27] Appliance Labeling Rule, 75 Fed. Reg. 41696 (July 19, 2010).

[28] Available at http://www.ftc.gov/os/2010/06/100618lightbulbs.pdf (last visited on 20 May 2011). For information about recycling etc., see http://www.epa.gov/cfl/cflrecycling.html.

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difficult. Mercury in bulk form must be carefully packaged in appropriate containers before shipping to designated storage or disposal facilities[52].

(b) Collection of wastes of products containing mercury or mercury compounds

149. Products containing mercury or mercury compounds, after becoming wastes, should be collected separately from other wastes and efforts should be made to prevent as much breakage and contamination as possible. The quantity of waste generated by households on the one hand and by other waste generators such as companies, governments, schools and other organizations on the other hand differs. It is therefore recommended that the waste from the two groups be collected separately.

150. There are six options, discussed below, for collecting wastes of products containing mercury or mercury compounds from households such as those referred to in table 5 above. Batteries containing mercury may be collected together with other types of batteries if they are treated through the same process.

(i) Waste collection stations or drop-off depots

151. Wastes of products containing mercury or mercury compounds should be discarded in a specially designed container at waste collection stations or depots in order to avoid the mixing of such wastes with other wastes. Wastes of products containing mercury or mercury compounds should be collected exclusively by collectors authorised by local governments or other appropriate authorities.

152. Containers or boxes for wastes of products containing mercury or mercury compounds should be made available for public use at waste collection stations. Indoor waste collection stations should be ventilated separately whenever possible. Waste of products containing mercury or mercury compounds such as fluorescent lamps, thermometers and batteries should only be placed in coloured, marked waste containers. Designated containers should all be the same colour and/or bear the same logo so as to facilitate public awareness. Breakage of fluorescent lamps and thermometers should be avoided, inter alia through appropriate design and the provision of written information on collection procedures. Different containers should be used for tube bulbs and CFLs. For CFLs, it is important to minimize the "free fall" of lamps by installing soft, cascading baffles or flaps. ~~could a small open~~ Another option to minimize lamp breakage would be to ask consumers to hand fluorescent lamps over to qualified collection station staff members. In the event of lamp breakage, staff should be informed and apply clean up procedures[53]. Waste drop-off stations for lamps could be established outdoors to minimize worker exposure should lamp breakage occur.

(ii) Collection at public places or shops

153. Waste of products containing mercury or mercury compounds, particularly used fluorescent lamps, thermostats, batteries and thermometers may be collected by specially designed collection vehicles or at public places such as near or in municipal buildings, electronics stores, shopping malls and other retail outlets, provided that appropriate collection containers are used and that necessary measures to prevent mercury exposures from broken products are taken. Indoor waste collection places should be ventilated separately whenever possible. Separate collection containers or boxes for wastes of products containing mercury or mercury compounds should be designed to accommodate the characteristics of such wastes and to minimize waste breakage. Only containers specifically designed to carry wastes containing mercury or mercury compounds and shown to be capable of containing mercury vapours from broken lamps should be used in any outdoor public collection locations[54]. Consumers should be able to take used fluorescent lamps, batteries, thermostats and thermometers to such locations free of charge. Authorized collectors, such as municipal collectors or private sector collectors (e.g., collectors trusted by producers), should collect the wastes in the designated waste collection boxes or containers.

154. Containers or boxes for wastes of products containing mercury or mercury compounds should be monitored to ensure that no other type of waste is deposited in them. They should be labelled and placed in areas where they can be monitored, either inside buildings, in well-ventilated areas, or outside, in covered and protected areas. In any indoor retail settings, they should be placed away from

[52] The United States Department of Energy provides detailed guidance on the safe handling and storage of mercury, which is available at: http://energy.gov/em/services/waste-management/waste-and-materials-disposition-information.

[53] See USEPA, "Cleaning up a broken CFL," available at: http://www.epa.gov/cfl/cflcleanup.html; Mercury Policy Project, 2008, *Shedding Light on Mercury Risks from CFL Breakage*, available at: http://ledgebeyondgreen.com/images/mercury-risks.pdf; and German Environment Protection Agency, available at: http://umweltbundesamt.de/energie/licht/bgf.htm (in German).

[54] See Glenz, Brosseau, and Hoffbeck, 2009.

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areas of high foot traffic and positioned in a way to prevent them from being hit or bumped. This could involve placing the containers in a corner or surrounding them with a barrier to direct the flow of people and minimize any accidental contact.

(iii) Collection at households by collectors

155. The collection of wastes of products containing mercury or mercury compounds from households by authorized collectors can be carried out to deal with certain wastes such as mercury-containing e-waste. In order to ensure the efficient collection of such wastes by local collectors, special arrangements or legal mechanisms will often be required; for example, government or other agencies and producers of products containing mercury or mercury compounds may need to provide arrangements for the collection of wastes of such products by local collectors.

(iv) Collection coordinated by business associations

156. The collection of wastes of products containing mercury or mercury compounds from business and commercial entities could be carried out by business or commercial associations in an efficient manner. In Japan, for example, the Tokyo Medical Association established an ad hoc collection system for unnecessary mercury thermometers and sphygmomanometers that collected several thousands of these devices during a collection period of one month. During the collection period, each member medical institution was encouraged to bring the devices to a designated local association branch office and requested to pay specific fees for transportation and disposal. The Tokyo Medical Association coordinated with local association branches and waste transporters and managers to ensure the efficient collection and disposal of devices collected. Each member medical institution benefited from lower transportation fees because the system created economies of scale and efficient transport arrangements.

(v) Take-back collection programmes

157. Take-back programmes can refer to a variety of programmes established to divert spent products from the waste stream for the purpose of recycling, reuse, refurbishing, and in some cases recovery. Take-back programmes are often voluntary initiatives developed by the private sector (e.g., manufacturers and retailers) that offer consumers the opportunity to return used products at their points of purchase or at some other specified facilities. Some take-back programmes offer financial incentives to consumers, others are mandated or operated by governments (e.g., bottle deposits schemes), and some serve to partly finance disposal or recycling activities. Take-back collection programmes generally focus on consumer products that are widely used, such as batteries, switches, thermostats, fluorescent lamps and other products containing mercury or mercury compounds (Honda, 2005).

(vi) Pre-paid shipping services

158. Some mercury-containing product recyclers offer a recycle-by-mail concept where consumers or waste generators purchase boxes or containers from the recycler, which includes the cost of delivery. Waste mercury-containing products are placed in the box, and once it is full, is shipped back to the recycler. This pre-paid shipping service is convenient for small quantity generators, and for those in remote locations that otherwise may not have access to other types of collection programs or have limited transportation options. The type of waste accepted via this program may vary by recycler.

(c) Collection of wastes contaminated with mercury or mercury compounds

159. Sewage treatment plants and waste incinerators are generally designed to include equipment for collecting sewage sludge, ash and residues that might contain trace amounts of mercury and other heavy metals. Mercury air pollution control devices in incinerators may increase mercury concentrations in collected fly ash. If mercury concentrations in these wastes exceed the criteria for hazardous waste or mercury wastes, the wastes should be collected separately.

4. Packaging and labelling

160. Mercury wastes being transported from the premises of generators or from public collection points to waste treatment facilities should be properly packaged and labelled. Packaging and labelling for transport are often controlled by national hazardous waste or dangerous goods transportation legislation, which should be consulted first. If such legislation is lacking or does not provide sufficient guidance, care should be taken to use labels that are in line with the United Nations *Globally Harmonized System of Classification and Labelling of Chemicals*. IATA, IMO and UNECE should be consulted. International standards for the proper packaging, labelling and identification of wastes have been developed, including the following reference materials:

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(a) United Nations, 2019b. *Globally Harmonized System of Classification and Labelling of Chemicals* (revised and improved every two years); and

(b) OECD, 2001b. *Harmonised Integrated Classification System for Human Health and Environmental Hazards of Chemical Substances and Mixtures*.

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5. Transportation

161. Mercury wastes should be transported in a way to avoid accidental spills; they should also be tracked during transport until they have reached their final destination. Prior to transportation, contingency plans should be prepared in order to minimize environmental impacts associated with spills, fires and other potential emergencies. The shipping paper should include an emergency response telephone number and a certificate that the shipment is in compliance with the regulations. In addition, the shipper should mark the containers with appropriate signs, including the specified label, the proper shipping name and the UN number. For mercury, the proper shipping name is "Mercury," and the UN number is "UN 2809" (QSC, 2003). During transportation, mercury wastes should be identified, packaged and transported in accordance with the following: (a) *United Nations Recommendations on the Transport of Dangerous Goods: Model Regulations* (Orange Book); (United Nations, 2019a); (b) *International Maritime Dangerous Goods Code* (IMO, 2018); (c) *Technical Instructions for the Safe Transport of Dangerous Goods by Air* (ICAO, 2017); and (d) *Dangerous Goods Regulations Manual* (IATA, 2020).

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162. Companies transporting mercury wastes within their own countries should, if appropriate, be certified as carriers of hazardous materials and wastes, and their personnel should, if appropriate, be qualified and certified as handlers of hazardous materials and wastes in accordance with applicable national and local requirements. Transporters of mercury wastes should have an insurance that covers the expenses caused by personal, material and environmental damages from any accidents that may occur during the transportation of mercury wastes. Transporters should manage mercury wastes in a way that prevents breakage, environmental releases and exposure to moisture.

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163. Transport of waste containing of mercury should be accompanied by information that demonstrates the mercury's level of purity and identifies any contaminants. Upon arrival, the transport vehicle should be visually inspected for any obvious leaks, spills, droplets or other pools of free elemental mercury and all suspected mercury sources should be documented and reported to management. The shipment should be accepted as compliant or rejected as non-compliant on the basis of the inspection; a written report including all the relevant information should be kept by the facility (QSC, 2003). When rejecting the transport, the facility operator should ensure that the required actions under the contingency plan have been taken without causing further spread of leakage outside of the facility. Guidance on the safe transportation of hazardous materials can be obtained from IATA, IMO, UNECE and ICAO (see paragraph 133 above).

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6. Storage

(a) Storage of wastes containing mercury by waste generators pending collection

164. Wastes of products containing mercury or mercury compounds should be stored temporarily at the premises of waste generators before they are collected for disposal. Wastes of products containing mercury or mercury compounds should be stored safely and kept apart from other wastes until they are brought to waste collection stations or facilities or picked up by collection programmes or contractors. Bulk waste should be stored in such a manner as to minimize mercury releases to the environment, including, if feasible, through the use of closed containers, impermeable concrete pads with runoff controls, or waterproof tarp covers. Waste should be stored by generators for a limited period of time, as allowed by national standards or regulations, and should in any case be sent off-site for appropriate disposal as soon as is practical.

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165. Household wastes containing mercury or mercury compounds, mainly fluorescent and other lamps, batteries and thermometers, should be appropriately packaged (e.g., using product packaging or boxes that fit the shape of the wastes) and temporarily stored. Any mercury devices that are broken during handling should be cleaned up and all clean-up materials should be stored outdoors until they are collected for further management[33]. Liquid wastes containing mercury or mercury compounds such as paints and pesticides should be kept in their original containers, whose lids should be tightly closed. Containers and packages holding wastes of products containing mercury or mercury compounds should not be placed together with other wastes; containers and packages should be

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[33] Materials should be stored outdoors because many commonly available containers such as plastic bags are permeable to mercury vapour. See, Maine Department of Environmental Protection, 2008.

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marked and stored in a dry and secure place, such as a warehouse or other space that is not usually frequented by people.

166. In addition to following the guidance contained in paragraphs 164 and 165 above, large-scale users of products containing mercury or mercury compounds such as governments, businesses and schools will also need plans for storing large amounts of such wastes. When original boxes or packages are not available, containers that are specially designed to store wastes of products containing mercury or mercury compounds (e.g., fluorescent lamp containers) should be purchased. Containers or boxes for storing such wastes should be marked and dated and stored in a dry place. The use of an area or room separated from work areas or areas not open to the public for storing such wastes is recommended. Such areas should not share building ventilation systems with work or public areas and should have their own ventilation systems or be vented directly to the outdoors. Guidance developed by UNDP for mercury wastes generated by healthcare facilities[35] provides detailed advice in this regard and may be applicable to many commercial facilities that generate waste mercury devices as well as local governments and other entities that need to store collected wastes of products containing mercury or mercury compounds for a longer period.

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(b) Storage of mercury wastes pending disposal operations

167. During the storage of mercury wastes at disposal facilities, the potential for mercury releases to the environment should be minimized.

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(i) Technical and operational considerations for storage facilities

168. In terms of siting and design, in principle storage facilities should not be built in sensitive locations whenever possible. Sensitive locations may include floodplains, wetlands, groundwater, earthquake zones, Karst terrain, unstable terrain and areas with unfavourable weather conditions and incompatible land uses in order to avoid any risk of mercury releases and possible human and environmental exposure to mercury. However, such location limitations may not apply in cases where technical design and legal requirements govern the ESM of storage facilities. Storage areas should be designed to ensure the security of the facilities and to prevent unnecessary chemical and physical reactions to mercury. The floors of storage facilities should be covered with mercury-resistant materials to prevent seepage or penetration of mercury from accidental leaks and spills. Storage facilities should have fire alarm and fire suppression systems. To reduce the risks of fire, facilities should be constructed of non-combustible materials, which should be used as well for pallets, storage racks and other interior furnishings. To further minimize the risks of fire, it is suggested that battery-powered electric forklifts be used to transport the mercury or mercury compounds inside the storage facility. The temperature in storage areas should be maintained as low as feasibly possible, preferably at a constant temperature of 21 degrees Celsius. Storage areas for mercury wastes should be clearly marked with warning signs (FAO, 1985; USEPA, 1997b; UNEP, 2022a; U.S. Department of Energy, 2009).

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169. In terms of operation, storage facilities should be kept locked to avoid theft or unauthorized access. Access to mercury wastes should be restricted to those with adequate training in, among other things, the identification of types of mercury wastes, mercury-specific hazards and the handling of such wastes. It is recommended that storage buildings for suitable types of mercury wastes not be used to store other liquid wastes or materials. A full inventory of the wastes kept at the storage site should be created and updated as waste is added or removed. Regular inspections of storage areas should be undertaken, focusing particularly on damage, leaks, spills and deterioration. Clean-up and decontamination should be carried out speedily, but not without alerting the authorities concerned, and in compliance with national laws and regulations. (FAO, 1985; USEPA, 1997b).

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170. In terms of the safety of facilities, site-specific procedures should be developed to implement safety requirements identified for the storage of mercury wastes. A workable emergency plan, preferably with multiple procedures, should be in place and implemented immediately in the event of accidental spillage and other emergencies. The protection of human life and the environment is of paramount importance. In the event of an emergency, there should be a responsible person who can authorize modifications to safety procedures when necessary in order to allow emergency response personnel to act. Adequate security siting and access to the area should be ensured (Environmental Management Bureau, Republic of the Philippines, 1997; UNEP, 2022a; U.S. Department of Energy, 2009).

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[35] UNDP (GEF Global Healthcare Waste Project), *Guidance on the Clean Up, Temporary or Intermediate Storage, and Transport of Mercury Waste from Healthcare Facilities*. Available at: http://www.gefmedwaste.org/guidance-documents.

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(ii) Special considerations for storage of wastes consisting of mercury or mercury compounds

171. Containers of wastes consisting of mercury or mercury compounds should be structurally sound and make possible the environmentally sound storing of such wastes. Containers should meet the following requirements: (1) they should not be damaged from any materials previously stored in them or have contained materials that could adversely react with mercury; (2) their structural integrity should be intact; (3) they should not be corroded; and (4) they should have a protective coating (paint) to prevent against corrosion (if not made from stainless steel). Appropriate materials for mercury containers include carbon (minimum ASTM A36) and stainless steel (AISI 304 or 316L) (European Union, 2010), which do not react with mercury at ambient temperatures. There are two main types of internationally approved mercury storage and transport containers: 34.5 kg flasks and one-metric-ton containers (QSC, 2003). The design type of the container should pass the drop test and the leak proof test as described in chapters 6.1.5.3 and 6.1.5.4 of the United Nations Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria (European Union, 2011b). For transporting smaller quantities of mercury, other sizes (e.g., 1-8 kg) and types (e.g., polyethylene, glass) of containers are often used (QSC, 2003); however, the level of protection such containers provide should be taken into account. When storing mercury in containers, it is important to leave some "head space" to allow for thermal expansion of the mercury. In European Union guidance, the maximum filling ratio of a container is 80 per cent by volume, and the head space is therefore at least 20 per cent (European Union, 2011b). Other jurisdictions specify a maximum filling ratio of 85 per cent, for a 15 per cent head space. No protective coating is required for the inner surface of such containers as long as the mercury to be stored in them meets purity requirements and no water is present inside the container. Protective coatings (e.g., epoxy paint and electroplating) should be applied to all exterior carbon steel surfaces in a manner that does not leave any steel exposed. Coatings should be applied in a manner that minimizes paint blistering, peeling and cracking. Labels should include information on the content (description) and risks, the names of the supplier/generator of the mercury waste, the origin of the waste, the container number, net weight and gross weight, the date when the mercury was injected and a "corrosives" label indicating that the container contains corrosive materials, should be affixed to each container (U.S. Department of Energy, 2009). In addition, the label should show that the container meets specific technical requirements regarding tightness, pressure stability, shock resistance, behaviour when exposed to heat, etc.

172. In the storage facilities, containers for wastes consisting of mercury or mercury compounds should be stored upright on pallets off the ground. Aisles in storage areas should be wide enough to allow the passage of inspection teams, loading machinery and emergency equipment. The floors of storage facilities should be coated with an epoxy coating and be light in colour to allow the detection of mercury droplets. The floor and floor coating should be inspected frequently to ensure that the floor has no cracks, and the coating is intact. The floor should not be penetrated by any drains or plumbing and sloped floors and open flow gutters with rounded-down edges (to avoid mercury trapping under gutter covers) could be used to facilitate the collection of spills. The liquid containment volume should have enough margin from the maximum liquid volume, taking into account the space taken up by items stored in the containment area. If two or more containers are stored at a containment area, the volume of the largest container should be used as the maximum liquid volume. When choosing the materials from which to construct the walls of storage facilities, materials that do not readily absorb mercury vapour should be selected. It is important to include redundant systems to prevent mercury releases in the event of an unexpected occurrence. Areas used to store mercury or mercury compounds should have their own ventilation systems or be vented directly to the outdoors. Ideally, ventilation systems for handling areas should be filtered or include pollution control devices to capture any mercury vapor or dust. When mercury is transferred between containers, negative pressure environments are recommended in order to avoid mercury emissions escaping from buildings (U.S. Department of Energy, 2009; Euro Chlor, 2004; UNEP, 2018).

173. When storing wastes consisting of mercury or mercury compounds, the mercury content of such wastes should be as pure as possible in order to avoid chemical reactions and the degradation of containers. A mercury content greater than 99.9 weight per cent is recommended. For purification techniques, see subsection III.G.1 (b) (v) below.

(iii) Special considerations for storage of wastes contaminated with mercury or mercury compounds

174. Liquid wastes in containers should be placed in containment trays or curved, leak-proof areas. The liquid containment volume should be at least 125 per cent of the maximum liquid waste volume, taking into account the space taken up by stored items in the containment area.

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175. Solid wastes should be stored in sealed containers such as barrels or pails, steel waste containers or in specially constructed containers that do not release mercury vapour.

G. Environmentally sound disposal

176. The following disposal operations, as provided for in Annex IV, parts A and B, of the Basel Convention, should be permitted for the purpose of ESM of mercury wastes[37]:

D5 Specially engineered landfill;

D9 Physico-chemical treatment;

D12 Permanent storage;

D13 Blending or mixing[38] prior to submission to operations D5, D9, D12, D14 or D15;

D14 Repackaging prior to submission to operations D5, D9, D12, D13 or D15;

D15 Storage pending operations D5, D9, D12, D13 or D14;

R4 Recycling/reclamation of metals and metal compounds;

R5 Recycling/reclamation of other inorganic materials;

R7 Recovery of components used for pollution abatement;

R8 Recovery of components from catalysts;

R12 Exchange of wastes[38] for submission to operations R4, R5, R8 or R13;

R13 Accumulation of material intended for operations R4, R5, R8 or R12.

177. In addition, the stowage of suitable mercury waste in underground facilities may also be permitted whereby waste is utilized in underground facilities for mining safety purposes taking advantage of the respective structural properties of the waste, except for waste consisting of mercury (metallic mercury) that underwent stabilization and solidification (S/S)[39]. Box 8 provides information on national legislation related to this issue.

> Box 8 Country Example: Germany
>
> In Germany, for example, stowing of suitable waste in underground facilities for mining safety purposes is regulated by the *Ordinance on Underground Waste Stowage* (see: http://www.bmu.de/fileadmin/bmu-import/files/pdfs/allgemein/application/pdf/underground_waste_stowage.pdf), whose requirements are equivalent to those found in the European Union's *Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste* and include special licensing procedures and supervision.

178. Wastes of products containing mercury or mercury compounds should be treated to remove or recover mercury in accordance with the guidance provided in section I below. This treatment will produce wastes consisting of mercury or mercury compounds and wastes contaminated with mercury or mercury compounds.

179. Should one of the mercury recovery processes described in subsection III.G.1 below be carried out and the mercury subsequently sent to a specially engineered landfill or permanent storage (i.e., operations D5 or D12), such mercury recovery would fall under operations D13 and D9 (i.e., blending or mixing, and physico-chemical treatment, respectively). On the other hand, acid washing and acid extraction described under subsection III.G.2:(i) below can lead, under specific conditions, to subsequent "R" operations listed in paragraph 176 above. In this case, the operation would also constitute an "R" operation. These two conclusions may not apply to all countries.

[37] For information on storage pending disposal operations (operations R13 and D15), see section III. F. 6.

[38] Examples include pre-processing such as sorting, crushing, drying, shredding, conditioning or separating.

[39] Exchange of wastes is interpreted to cover pre-treatment operations unless another R code is appropriate.

[39] Such stowage of mercury waste is currently possible only in Germany.

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1. Mercury recovery processes

180. Mercury recovery from solid waste generally comprises: (1) pre-treatment; (2) thermal treatment; and (3) purification, as shown in figure 3 below. In order to minimize mercury emissions from the mercury recovery process, facilities should employ closed systems. The entire process should take place under reduced pressure in order to prevent leakage of mercury vapour into processing areas (Tanel, Reyes-Osorno, and Tansel, 1998). The small amount of exhausted air that is emitted in the recovery process should pass through a series of particulate filters and a carbon bed that absorbs the mercury before the air is exhausted into the environment. For example, with certain measures for mechanical treatment of waste electrical and electronic equipment, it is possible to reduce emission levels for channelled mercury emissions to air to 2-7 µg/Nm³ (European Commission, 2018a).

181. Examples for mercury wastes whose recovery can generate mercury emissions are wastes of products containing mercury or mercury compounds that easily release mercury into the environment when broken and wastes contaminated with high concentrations of mercury. The former includes measuring devices containing mercury (thermometers, sphygmomanometers and manometers) and mercury switches and relays, and could also include lamps containing mercury. Mercury waste can also include wastewater treatment sludges from wet scrubbers in non-ferrous metal smelters, depending on their mercury content. Box 9 provides information on national legislation for the treatment of mercury-bearing hazardous wastes.

> **Box 9 Country Example: USA**
>
> In the United States, standards require mercury recovery for reuse, for mercury-bearing hazardous wastes with a mercury content greater than or equal to 260 mg/kg. Waste containing less than 260 mg/kg can be land disposed following treatment to control mercury leaching (see U.S. Code of Federal Regulations (CFR), Title 40 (Protection of the Environment), Section 268.40: Applicability of treatment standards).

182. The Basel Convention *Technical guidelines on the environmentally sound recycling/reclamation of metals and metal compounds (R4)* focus mainly on the environmentally sound recycling and reclamation of metals and metal compounds, including mercury, that are listed in Annex I to the Convention ("Categories of wastes to be controlled"). It is possible to recycle mercury wastes, particularly wastes consisting of mercury or mercury compounds, in special facilities that have advanced mercury-specific recycling technologies. It should be noted that appropriate procedures should be employed in such recycling to prevent any releases of mercury into the environment. In addition, recycled mercury may be sold on the international commodities market, where it can be re-used. The recycling of mercury[6] will usually be determined by the degree of allowable use, demand, and a commercial evaluation as to whether the mercury can be profitably reused.

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[6] See Article 11(3 alt) of the Minamata Convention. Furthermore, note that Article 3(5)(b) of that Convention prevents recycling of excess mercury (but not mercury wastes) from the decommissioning of chlor-alkali facilities.

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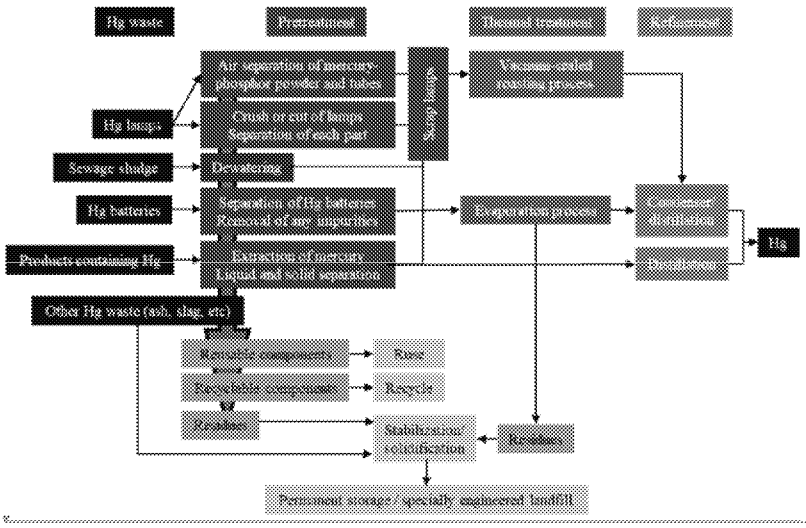
Figure 3: Flow of mercury recovery from solid waste (Nomura Kohsan Co. Ltd., 2007)



183. Mercury in wastewater should generally be captured through chemical oxidation, chemical precipitation, or adsorption, followed by various treatment processes. Mercury exists in wastewater due to accidental or intentional discharging of mercury from dental amalgams, or industrial processes using mercury or mercury compounds. Mercury may be found in wastewater from wet-type air pollution control devices and leachate from landfills and dumping sites where wastes containing mercury such as mercury thermometers were disposed of or dumped. To the extent possible, mercury in wastewater should not be released into the aquatic environment, where mercury is methylated and converted into methylmercury, which then bioaccumulates and biomagnifies in the food chain. With appropriate pre-treatment in certain processes such as adsorption, it is possible to reduce discharges of mercury to a receiving water body for certain solid wastes to 0.5-5 µg/l expressed as Hg (for metals and metalloids) as daily average or average over the waste discharge duration, and for water-based liquid wastes to 1-10 µg/l (European Commission, 2018a). Mercury content from the influent should be considered when establishing wastewater treatment processes.

184. Pre-treatment prior to recycling/reclamation of mercury (operation R4) falls under operation R12 (see paragraph 176 above), while roasting in a furnace (hereinafter referred to as "roasting") purification, chemical oxidation/precipitation and adsorption fall under operation R4.

(a) Pre-treatment (exchange of wastes for submission to operations R4 or R13)

185. Before undergoing thermal treatment, wastes that contain or are contaminated with mercury are treated in order to increase the efficiency of the thermal treatment; pre-treatment processes include, *inter alia*, removal of materials other than those containing mercury by crushing and air separation, dewatering of sludge, and removal of impurities. Examples of mercury waste-specific pre-treatment operations are summarized in table 7 below.

186. For the reduction of mercury emissions from waste pre-treatment, the following document provides additional technical information: European Commission, 2018b. *Best Available Techniques (BAT) Reference Document Waste Treatment.*

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Table 7: Examples of pre-treatment operations by type of waste

Waste Type	Pre-treatment
Fluorescent lamps	***Mechanical crushing*** Waste lamps containing mercury should be processed in a machine that crushes and separates the lamps into three categories: glass, end-caps and mercury-phosphor powder mixtures. This is accomplished by injecting the lamps into a sealed crushing and sieving chamber. Upon completion, the chamber automatically removes the end products to prevent cross-contamination. End-caps and glass should be removed and sent for reuse in manufacturing. However, the metal pins of the end caps should be removed and treated separately as their mercury content may be considerable. Mercury-phosphor powder may be disposed of or further processed to separate the mercury from the phosphor (Nomura Kohsan Co. Ltd., 2007). Lamp glass from the crushed lamps can contain significant amounts of mercury and should be treated thermally or in other ways to remove the mercury before sending the glass for recovery (Jang, Hong, and Park, 2005) or disposal. If the glass is sent to a melting unit for re-melting as part of the recovery process, the unit should have air pollution controls specifically directed at capturing released mercury (e.g., activated carbon injection). A high-performance exhaust air system should prevent the emission of any mercury vapours or dust during the entire process.
	Air separation The aluminium end caps of fluorescent lamps (straight, circular and compact tubes) are cut by hydrogen burners. Air is then blown into the cut lamps from the bottom of the lamps to remove mercury-phosphor powder adsorbed on lamp glass (Jang, Hong, and Park, 2005). Mercury-phosphor powder is collected in a precipitator, and glass parts are crushed and washed with acid, mercury-phosphor powder adsorbed on the glass is completely removed. In addition, the end-caps are crushed, and aluminium, iron and plastics are magnetically separated for recycling (Kobelco Eco-Solutions Co. Ltd., 2001; Ogaki, 2004).
Batteries containing mercury	***Removal of impurities*** In order to recycle mercury from batteries containing mercury, the batteries should be collected separately and stored in suitable containers before treatment and recycling. If batteries containing mercury are collected together with other types of batteries or with waste electrical and electronic equipment (WEEE), the batteries containing mercury should be separated from other types of batteries. However, when a facility can treat batteries containing mercury, other types of batteries, and WEEE together without emitting mercury to outside of the facility, such separation may not be necessary. Before roasting treatment, impurities mixed with and adsorbed onto batteries containing mercury should be removed, preferably through a mechanical process. In addition, mechanical screening of the size of the batteries is necessary for an effective roasting process. (Nomura Kohsan Co. Ltd., 2007).
Sewage sludge	***Dewatering*** Sewage sludge has a high water content of over 95 per cent. As a result, sludge contaminated with mercury needs to be dewatered to about 20 to 35 per cent solids before any thermal treatment. After dewatering, sewage sludge with high mercury content should be treated through a roasting process (Nomura Kohsan Co. Ltd., 2007; USEPA, 1997a). Extracted water may need to be managed as mercury waste, depending on the mercury content.
Wastes of products containing mercury	***Extraction*** Wastes of products containing mercury such as thermometers and barometers should be collected without any product breakage, to the degree feasible. After collection of such wastes, mercury in the products should be extracted, and so the extracted mercury distilled for purification under reduced pressure.

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Waste Type	Pre-treatment
Wastes containing mercury attached to devices	***Dismantling*** Wastes containing mercury, such as electric switches and relays, are usually attached to electric devices. Therefore, such wastes should be removed from such devices without breaking the devices' outer glass. Computer monitors and televisions with flat screen liquid crystal displays (LCD) contain one or more small lamps for illumination, usually located along the outside edge of screens. While current technologies use light emitting diodes (LED) in these small lamps, old LCD screens contain fluorescent lamps. These lamps will often break during handling and mechanized processing and release mercury vapour, so they should be carefully removed by hand[62] and should not be treated through mechanized processing such as shredding, unless shredding machines have the necessary pollution control equipment to manage such operations and are licensed and permitted for the processing of fluorescent lamps, such as at mercury treatment facilities. For further information, see section 7.3 of the Basel Convention Partnership for Action on Computing Equipment (PACE) *Guideline on environmentally sound material recovery and recycling of end-of-life computing equipment* (UNEP, 2013). Further information on the presence of mercury in LCD backlights is available in *Demonstration of flat panel display recycling technologies* (Waste and Resources Action Programme, 2010).

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(b) Recycling/reclamation of mercury or mercury compounds (R4)

(i) Thermal treatment

187. Thermal treatment facilities for wastes containing or contaminated with mercury or mercury compounds such as sewage sludge, contaminated soils and other wastes from contaminated sites should be equipped with mercury vapour collection technology for the recovery of mercury (ITRC, 1998; Chang and Yen, 2006).

188. Thermal desorption is a process that uses either indirect or direct heat exchange to just primarily organic contaminants to a high enough temperature to volatilize and separate them from a contaminated solid matrix and then either collect or destroy them. Thermal desorption using indirect heat exchange is the recommended option for mercury and its compounds. Air, combustion gas or an inert gas is used as a transfer medium for vaporized components. Thermal desorption systems involve physical separation processes that transfer contaminants from one phase to another. The systems have two major components, a desorber and an off-gas treatment/collection system[63].

189. There are several evaporation processes for the treatment of mercury wastes, including rotary kiln distillation and vacuum thermal processing.

190. Rotary kiln distillation serves to remove and recover mercury in wastes such as mineral industrial slurries, slurries from the movement of natural gas, activated carbon, catalysts, button cells and contaminated soil by means of evaporation and recycling of the resulting mercury-free products (e.g., glass, iron and non-ferrous metals, zeolites).

191. In the rotary kiln distillation process, input wastes, such as activated carbon, catalysts, soils, batteries and conditioned sludge, are transported by a scraper chain conveyor directly into the feeding screw of the rotary kiln. The wastes are continuously treated at temperature of up to 800 °C. As a result, mercury is transformed into a gas phase and can be removed as exhaust vapor from the rotary kiln. The treatment is carried out at under pressure in order to prevent dust emissions. The exhaust gas from the rotary kiln is transported by a cyclone, which separates dust particles, into the post-combustion chamber. After combustion, the remaining exhaust gas reaches a three-stage treatment, in which the exhaust gas is cooled down to achieve a condensation of mercury and water, passed through

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[62] See section III.I for details on worker safety precautions.

[63] The first large-scale thermal desorption unit for the treatment of mercury-containing wastes was constructed for the remediation of the Marktredwitz Chemical Factory (CFM) in Wittum, Germany. The operation commenced in October 1993, including the first optimizing phase. Some 50,000 tons of mercury-contaminated solid wastes were treated successfully between August 1993 and June 1996. Thermal desorption units were also used to decontaminate the old chlor-alkali plant in Usti nad Labem in the Czech Republic and to decontaminate the soil in Taipei (Chang and Yen, 2006).

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an electro filter to achieve the deposition of aerosols, and then fed to an active carbon filter system for final cleaning[64].

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192. Pre-treated waste, such as mercury-phosphor powder in fluorescent lamps, crushed lamp glass, cleaned batteries containing mercury, dewatered sewage sludge and screened soil, may be treated in roasting/retorting facilities equipped with mercury vapour collection technology through which mercury can be recovered. However, it should be noted that volatile metals, including mercury, and organic substances (including persistent organic pollutants), are emitted during roasting and other thermal treatments and are transferred from the input waste to both the resulting flue gas and fly ash. Therefore, flue gas treatment devices should be used to capture volatilized pollutants and to prevent the pollutants from being emitted to the environment (see subsection III.H.1 below).

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193. Waste contaminated with mercury or mercury compounds can be treated in a continuous roasting and reactivation kiln. In the furnace the material is cleaned at temperatures of up to 850 °C. At this temperature volatile compounds that are absorbed, adsorbed or chemisorbed on the material are thermally destroyed and/or vaporized; this includes mercury and sulphur. It is important to note that at 850 °C the very stable mercury sulphide (HgS or cinnabar) is broken down into mercury and sulphur. The system is therefore especially qualified for the treatment of adsorbents (e.g., S-impregnated activated carbon, mercury guards) that fix the mercury in the form of HgS on the adsorbent. Activated carbon is reactivated by means of temperature and steam releasing contaminants trapped in the pores and opening those pores up to increase the surface area of the carbon. This process maximises the efficiency of the activated carbon as a filter material for re-use. Activated carbon can be re-charged in this manner multiple times before disposal. Spent catalysts such as Hg guards are decontaminated so that a subsequent Cu or Zn recovery in a smelter is possible. Pollutants, such as mercury, remaining after the furnace travel with the exhaust gas into the waste gas treatment system. Here they first pass a post combustion chamber operating at temperatures between 1,000 and 1,200 °C, where organic compounds are incinerated. After the post combustion chamber, the waste gas is quenched to 40 °C and finally cleaned in a system consisting of 4 scrubbers (acid, basic, lime milk, peroxide), a bag filter and a final activated carbon filter. Mercury is transferred into the slurry of the first 2 scrubbers. This slurry is removed in batches and transferred to the mercury distillation plant for recovery of the mercury in a separate process for further treatment[65].

194. Vacuum thermal processing enables the treatment of thermometers, batteries, especially button cells, dental amalgam, electrical switches and rectifiers, fluorescent powder, exhaust tubes, crushed glass, soil, sludge, primary mercury mining residues and catalyst materials, among others. The vacuum thermal process generally includes the following stages:

(a) Heating the input waste in a special kiln or in a charging operation at temperatures of between 340 °C and 650 °C and pressures of a few millibars so that the mercury contained in the waste evaporates;

(b) Applying thermal post-treatment to mercury-containing vapour at temperatures ranging from 800 °C to 1,000 °C, where, for example, organic components can be destroyed;

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(c) Collecting and cooling of mercury-containing vapour;

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(d) Using distillation to generate pure liquid mercury.

195. The residue that remains at the end of the vacuum thermal processing is essentially mercury-free and is recycled or otherwise disposed of depending on its composition[66].

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(ii) Chemical oxidation

196. Chemical oxidation of mercury and organomercury compounds in waste is carried out to convert the mercury into mercury salts and to destroy the organomercury compounds. Chemical oxidation is an effective method for treating liquid and aqueous waste, such as slurry and primary mercury or ASGM tailings, containing or contaminated with mercury. Oxidizing reagents used in the chemical oxidation process include sodium hypochlorite, ozone, hydrogen peroxide, chlorine dioxide and free chlorine (gas). Chemical oxidation can be conducted as a continuous or batch process in mixing tanks or plug flow reactors. Mercury halide compounds formed in the oxidation process are separated from the waste matrix, treated and sent for subsequent treatment such as acid leaching and precipitation (USEPA, 2007a).

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[64] See https://www.remondis-gmbh.de/fileadmin/user_upload/pdf/downloads/Anlagenbeschreibung_Dorbrohr_Rf%20QR_engl_16f406.pdf.
[65] https://bauer.cl/recycling-services/#active-carbon
[66] See www.gmr-leipzig.de/gbvertahren.htm.

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(iii) Chemical precipitation

197. Precipitation uses chemicals to transform dissolved contaminants into insoluble solids that may precipitate or be removed by flocculation or filtration. In co-precipitation, the target contaminant may be in a dissolved, colloidal or suspended form. Dissolved contaminants do not precipitate but are adsorbed onto other species that are then precipitated. Colloidal or suspended contaminants become enmeshed with other precipitated species or are removed through processes such as coagulation and flocculation. Processes to remove mercury from wastewater can include a combination of precipitation and co-precipitation. The precipitated/co-precipitated solid is then removed from the liquid phase through clarification or filtration. More detailed information can be found in the report entitled *Treatment technologies for mercury in soil, waste, and water* (USEPA, 2007b).

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(iv) Adsorption treatment

198. Adsorption materials hold mercury on their surfaces through various types of chemical forces such as hydrogen bonds, dipole-dipole interactions and van der Waals forces. Adsorption capacity is affected by surface area, pore size distribution and surface chemistry. Liquid wastes are passed through adsorption materials that are usually packed into a column, through which mercury or mercury compounds are adsorbed. The column should be regenerated or replaced with new media when adsorption sites become filled (USEPA, 2007b). The resulting spent adsorbent is mercury waste.

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199. Examples of adsorption materials include activated carbon and zeolite. Activated carbon is a carbonic material that has many fine interconnected openings and typically has a wooden (coconut shells and sawdust), oil or coal base. It can be classified, based on its shape, into powdery activated carbon and granular activated carbon. Many activated carbon products are commercially available, offering the specific advantages of their individual materials. Mercury and other heavy metals, as well as organic substances, adsorb on activated carbon (Bansal, 2005). Zeolites are naturally occurring silicate minerals that can also be produced synthetically. Zeolites, in particular clinoptilolite, have a strong affinity for heavy metal ions where the adsorption mechanism is an ion exchange (Chojnacki et al., 2004). Ion exchange resins have proven to be useful in removing mercury from aqueous streams, particularly at mercury concentrations in the order of 1 µg/L to 10 µg/L. Ion exchange applications usually serve to treat mercuric salts, such as mercuric chlorides, that are found in wastewaters. The ion exchange process involves suspending a medium, which can be either a synthetic resin or mineral, into a solution where suspended metal ions are exchanged onto the medium. The anion exchange resin can be regenerated with strong acid solutions, but this is difficult since the mercury salts are not highly ionized and are not readily cleaned from the resin. The resin would therefore have to be disposed of. In addition, organic mercury compounds do not ionize, so they are not easily removed by using conventional ion exchange. If a selective resin is used, the adsorption process is usually irreversible and the resin should be disposed of as hazardous waste in a disposal facility not leading to recovery (Amuda, 2010).

200. Chelating resin is an ion exchange resin that has been developed as a functional polymer that selectively catches and removes ions, including various metal ions, from solutions. It is made of a polymer-based three-dimensional mesh construction, with a functional group that chelate-combines metal ions. The most commonly used chelating resin is polystyrene, followed by phenolic plastic and epoxy resin. Chelating resins are used to treat plating wastewater to remove mercury and other heavy metals remaining after neutralization and coagulating sedimentation, or to collect metal ions by adsorption from wastewater whose metal-ion concentration is relatively low. Chelating resin of the mercury adsorption type can effectively remove mercury in wastewater (Chiarle and Raito, 2000).

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(v) Distillation of mercury – purification

201. Following waste treatment, collected mercury is purified by successive distillation (USEPA, 2000). High purity mercury is produced by distillation through many steps, with each step enabling a higher purity grade to be achieved. High purity mercury is required for many uses of mercury, or if the mercury is to be stored for a number of years, since high purity will help to prevent chemical reactions between the container and impurities.

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2. Operations not leading to recovery of mercury or mercury compounds

202. Before mercury wastes undergo final disposal in accordance with operations D5 and D12, they should be treated so that they meet the acceptance criteria of disposal facilities (see subsection III.G.2 (b) and (c) below). Wastes consisting of mercury or mercury compounds should be stabilized and solidified before final disposal and final disposal should be carried out in accordance with national and local laws and regulations. It is noted that a number of methods for final disposal are

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now available, e.g., the methods referred to in paragraphs 212 and 217. Treatment operations prior to D5 and D12 operations fall under operation D9 (see subsection III.G.2 (a) below).

(a) Physico-chemical treatment (D9)

(i) Stabilisation and solidification (S/S)

203. Stabilisation processes include chemical reactions that may change the hazardous characteristics of waste by reducing the mobility and sometimes the toxicity of the waste constituents. Solidification processes only change the physical state of waste (e.g., converting a liquid into a solid) through the use of additives without changing the chemical properties of the waste (European Commission, 2003). The combination of these processes is referred to as S/S, or sometimes referred to as "conversion" that, which means the chemical transformation of the physical state of mercury from a liquid state to mercury sulphide or a comparable chemical compound that is equally or more stable and equally or less soluble in water and that presents no greater environmental or health hazard than mercury sulphide (European Union, 2017).

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204. S/S is applied, for example, to waste consisting of mercury or mercury compounds and mercury-contaminated waste such as soil, sludge, ash and liquid. S/S reduces the mobility of contaminants in the waste media by physically binding them within a stabilized mass or by inducing chemical reactions that may reduce their solubility or volatility, or both, thereby reducing their mobility (USEPA, 2007b). In the United States, only low-concentration mercury wastes (i.e., those with a mercury content lower than 260 mg/kg) can be stabilized, after which they may be landfilled.

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205. Stabilization induces chemical reactions between a stabilizing agent and waste contaminants to reduce the mobility of the contaminants, and solidification involves physically binding or enclosing contaminants within a stabilized mass. Solidification is used to encapsulate or absorb waste, and forms a solid material when free liquids other than mercury are present in the waste. Waste can be encapsulated in two ways: microencapsulation and macroencapsulation. Microencapsulation is the process of mixing the waste with an encasing material before solidification occurs. Macroencapsulation refers to the process of pouring an encasing material over and around a waste mass, thus enclosing it in a solid block (USEPA, 2007b).

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206. Generally speaking, the solidification process involves mixing soil or waste with binders such as Portland cement, sulphur polymer cement (SPC), sulphide or phosphate binders, cement kiln dust, polyester resins or polysiloxane compounds to create a slurry, a paste, or another kind of semi-liquid substance, which is then cured into a solid form over a period of time (USEPA, 2007b).

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207. There are two main chemical approaches to the S/S process that can be applied to mercury wastes (Hagemann, 2009):

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(a) Chemical conversion to mercury sulphide;

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(b) Amalgamation (formation of a solid alloy with suitable metals).

208. In both approaches, the risk of mercury volatility and leachability can be reduced to an acceptable level if the conversion rate to mercury sulphide (percentage of reacted mercury) reaches near 100 per cent. If a sufficiently high rate is not achieved, the probability of mercury volatility and leachability remains high, as is the case with amalgams (Mattus, 1999).

209. While appropriate technologies for S/S of wastes consisting of mercury can reduce releases of mercury to the environment, the long-term effectiveness of these technologies has not been sufficiently studied. Therefore, the collection and analysis of information and data on such effectiveness are necessary.

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210. When wastes consisting of mercury or mercury compounds that have gone through the S/S process are disposed of, special consideration should be given to the combination of S/S and methods for the final disposal of such wastes. Mercury sulphide is thermally decomposed at fire temperatures and can be oxidised by atmospheric oxygen at approximately 250-300 °C to gaseous mercury and sulphur dioxide. Therefore, measures to prevent fire incidents and release of gaseous mercury should be considered at the stage of planning disposal facilities.

Stabilization and solidification as mercury sulphide

211. One of the most important and well investigated mercury S/S approaches is to produce mercury sulphide (HgS), which is much less soluble and has lower volatility than most mercury compounds and is therefore less mobile in the environment. Mercury is mixed with elemental sulphur or other sulphur-containing substances to form HgS. The production of HgS can result in two different types of HgS, alpha-HgS (cinnabar) and beta-HgS (meta-cinnabar). Pure alpha-HgS is intensively red

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and has a slightly lower water solubility compared to pure beta-HgS, which is black in colour. HgS is a powder with a density of 2.5-3 g/cm³.

212. HgS can be produced by blending mercury and sulphur under ambient conditions for a certain period of time, until HgS is produced. To start the reaction process, a certain activation energy is required and may be provided by forcefully mixing the blend. Among other factors, high shear rates and temperatures during the process support the production of alpha-HgS, while a longer process time favours the creation of beta-HgS. Excessively long milling in the presence of oxygen can lead to the production of mercury (II) oxide (HgO). Because HgO has higher water solubility than HgS, its creation should be avoided through milling under inert atmospheric conditions or through the addition of an antioxidant (e.g., sodium sulphide). Since the reaction between mercury and sulphur is exothermic, an inert atmosphere also contributes to making the operation safe. The conversion process is robust and relatively simple to carry out, but strict controls are needed to prevent volatile losses of mercury during conversion. In addition, treatment residue should be tested to ensure the completeness of the conversion to mercury sulphide.

213. Mercury sulphide can also be formed by creating a reaction between mercury and sulphur in the vapour phase. Reaction of mercury with sulphur in a sealed vessel at elevated temperature and pressure can also form the alpha cinnabar form of mercury sulphide (United States Patent: US 7691361 B1, April 10, 2010). This process is commercially available in the U.S.[67], although U.S. waste disposal regulations currently prohibit landfilling of most high concentration mercury waste.

214. HgS is very insoluble in water and has very low volatility. Although HgS is chemically very stable and non-reactive, exposure to ambient environmental conditions will result in its conversion to other mercury compounds over time. The isolation of HgS from the environment through encapsulation and disposal in a specially engineered landfill or permanent underground storage may therefore be necessary to ensure that it does not convert into other mercury compounds. In addition, the fact that dissolved organic matter and high chloride concentrations in leachate increase mercury releases from HgS (Waples et al., 2005; Science Applications International Corporation, 2002) suggest that mercury converted into HgS should be disposed of in ways that ensure the waste has no contact with water or other types of waste, especially those containing organic matter and chloride. Moreover, since micro-organisms inhabiting acid mine drainage systems, which are dominated by Fe-oxidizing and S-oxidizing bacteria, in the microcosm with metacinnabar (beta-HgS) increase dissolved Hg concentrations (Jew et al., 2014), exclusion or at least inhibition of the influence of such microorganisms in specially engineered landfills and permanent underground storage may be required for disposal of mercury treated as HgS.

215. As a fine powdery material, the handling of HgS is subject to specific requirements, including solidification, in order to avoid, for example, the risk of dust releases. The solidification process leads to an increase in volume by approximately 300 per cent and in weight by approximately 16 per cent, based on molecular weight compared to mercury. For solidification of mercury sulphide, materials with low alkali content should be used as a recent study indicates that mercury release from mercury sulphide increases when pH value of eluate exceeds 10 (Mizutani, Kadotani, and Kanio, 2010).

216. Large-scale S/S processes for waste consisting of mercury that use sulphur compounds to form HgS are also available[68]:

(a) One process takes place in a vacuum mixer operated in inert vacuum atmosphere which ensures good process control and safe operation. The mixer is operated batch-wise. A dust filter and an activated carbon filter prevent releases from the facility. The reaction between mercury and sulphur takes place at a stoichiometric ratio. The end product consists of red mercury sulphide. The end product is thermodynamically stable up to 350 °C[69]; and

(b) Another process consists in a wet chemical reaction. The active sulphur of a polysulfide solution reacts with the metallic mercury to become HgS. The benefits of using a wet chemical process over a dry powder process are that it mitigates the chances of HgO (mercuric oxide) forming without the need for an inert gas environment and without the explosion risks associated with processing dry powders. The wet chemistry reaction is conducted at a low temperature (60-70 °C). The chemistry should be carefully controlled to stop unwanted toxic compounds forming. The

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[67] http://www.bethlehemapparatus.com/mercury-retirement

[68] See https://www.remondis-qr.de/fileadmin/user_upload/nqr/downloads/Anlagenbeschreibung_engl_HgS_RE%20QR_160406.pdf

[69] https://www.remondis-qr.de/uploads/tx_3sdownloadlibrary/Anlagenbeschreibung_engl_HgS_RE_QR_160406_02.pdf

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conversion rate of Hg to HgS is greater than 99.999 per cent with a remaining metallic mercury concentration in the output of less than 100 mg/kg[70].

Sulphur polymer stabilization and solidification (SPSS)[71,72]

217. The sulphur polymer stabilization and solidification (SPSS)[73] process involves sulphur stabilization followed by solidification, with the advantage of a lower chance of mercury vaporization and leaching because the final product is monolithic with a low surface area. The process involves two steps: in the first step, mercury is stabilized with sulphur to form beta-HgS (meta-cinnabar dust) (López et al., 2010; López-Delgado et al., 2012); in the second step, the beta-HgS is incorporated and microencapsulated in a polymeric sulphur matrix at 135°C to obtain a fluid that is cooled to room temperature, in moulds, to obtain solid blocks (monoliths). The second step is the creation of a barrier to prevent mercury releases to the environment, thereby minimizing the possibility of HgS converting into other forms of mercury by reducing its contact with the environment. The SPSS process has low energy consumption, entails low mercury emissions, requires no water, has no effluents and generates no wastes other than HgS. Controls should be in place to prevent and emissions of mercury and to ensure safe conditions for workers and for the environment, including engineering controls to prevent possible fires and explosions.

218. A relatively high Hg load of the monolith (about 70 per cent) can be achieved with this process. The process is robust and relatively simple to implement and its final product is very insoluble in water, has a high resistance to corrosive environment, is resistant to freeze-thaw cycles and has a high mechanical strength. The SPSS technology can be directly applied to waste consisting of mercury with different degrees of purity, without the need for previous distillation, and to a wide range of mercury-containing wastes without previous treatment of such wastes (López et al., 2010, López-Delgado et al., 2012, López et al., 2015). All the final stabilized-microencapsulated products (from metallic mercury, zinc waste, aluminum waste and fluorescent lamp dust) are compact solids that have a stability and resistance similar to that of concrete. The SPSS process therefore ensures the complete immobilization of mercury, rendering it impermeable and giving it extremely low porosity, thereby minimizing the risk of mercury releases to the environment. The final products are hard monolithic blocks, the shape of which can be adapted to facilitate transport.

219. Monolith samples (of 40 x 40 x 160 mm) have been tested for leaching in accordance with European standards TS 14405 (CEN, 2017) and EN-12457-4 (CEN, 2002a), with tests involving a dynamic flow percolation assay on encapsulate monoliths and a leaching by agitation assay on granular material obtained through monolith crushing. All mercury concentrations found in the leachates, for a liquid/solid ratio of 10 l/kg, were <0.01 mg/kg, so the monoliths met the European Union criterion for the acceptance of waste into landfills for inert waste (<0.01 mg/kg, as per Council Decision 2003/33/EC, establishing criteria and procedures for the acceptance of waste at landfills (European Union, 2003).

220. Another example of a similar technology is solidification of beta-HgS with modified sulphur. The first step is to form beta-HgS by mixing mercury with a purity of 99.9 per cent or higher with sulphur powder, and the second step involves solidifying the beta-HgS with modified sulphur by mixing the two substances for one hour and subsequently heating the mix to 130°C for one hour. Results of a Japanese leaching test (JLT-13) of solidified mercury sulphide show that the product's leaching rate ranges from 0.0009 to 0.0018 mg/L, which is below the elution test standard (0.005 mg/L) (Committee on consideration of environmentally sound management of mercury waste, 2014).

Stabilization and solidification with sulphur microcements[74]

221. The treatment of mercury wastes with sulphur microcements is another S/S technology. Application of the technology results in a solid matrix that ensures the confinement of mercury because of its precipitation in the form of very insoluble oxides, hydroxides and sulfides. The

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[70] http://bauer.de/recycling-services?ro-uploaded=1#stabilisation-of-mercury

[71] This section contains information provided by the National Technological Centre for Mercury Decontamination (CINDM) (Spain). For further information, please contact: info@cindm.es or visit: http://www.cindm.es.

[72] There is a standard definition for sulphur polymer cement in ASTM C1159-98.

[73] The project of an industrial plant in Spain to develop this process is already made and the budget for its construction is approved; the commercial availability of this plant is expected at the end of 2015.

[74] This section contains information provided by Cement International Technologies S.L. For further information please contact: info@cementinternationaltechnologies.com, or consult their website at: http://www.cemintech.com/en.

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technology is commercially available and has been tested in wastes with low levels of mercury contamination (Hg ≤ 2 per cent by weight).

222. Once the contaminated material to be treated has been characterized, the amount and type of microcement suitable for the application is determined. Microcements must have the following characteristics so that an adequate level of stabilization and microencapsulation of the mercury contained in contaminated materials can be achieved:

(a) They must be inorganic and all particles are less than a certain size (a few microns);

(b) They must contain mercury stabilising components, such as alkali sulphides;

(c) They must have very high mechanical properties, so that volatilization and leaching of mercury can be avoided;

(d) They should have a blast furnace slag percentage of over 60 per cent, a Portland clinker component C3A content lower than 3 per cent and an alkali content below 0.6 per cent.

223. The process involves mixing of mercury-contaminated waste with the selected sulphur microcement and with water; the mixture is then discharged into the desired mould and matured over a 24 - 48 hour period in watertight and leak-protected areas. The final product can take different forms; the ones with fewer exposed surfaces, such as large cubic blocks, are recommended for the most contaminated waste.

224. The sulphur microcement treatment technology has been tested on, among others, mercury waste obtained from the dredging of contaminated sludge from the Flix dam in the province of Tarragona in Spain. The final products ensure a high level of strength and durability and enable a safe handling and transport. The leaching values following tests according to standard EN 12457-4 (CEN, 2002a) with a water/solid ratio of 10/1 are below 0.003 mg/kg, well below the EU acceptance criteria for landfills for inert solid wastes (<0.01 mg/kg, as per Decision 2003/33/EC). It is an inert product, and has high strength and durability enabling a safe mechanical handling and transport.

Amalgamation

225. Amalgamation is the dissolution and solidification of mercury in other metals such as copper, nickel, zinc and tin, resulting in a solid, non-volatile product. It is a subset of S/S process. Two generic processes are used for amalgamating mercury in wastes: aqueous and non-aqueous replacement. The aqueous process involves mixing a finely divided base metal such as zinc or copper into a wastewater that contains dissolved mercury salts; the base metal reduces mercuric and mercurous salts to mercury, which dissolves in the metal to form a solid mercury-based metal alloy called amalgam. The non-aqueous process involves mixing finely divided metal powders into waste mercury, forming a solidified amalgam. The aqueous replacement process is applicable to both mercury salts and mercury, while the non-aqueous process is applicable only to mercury. However, mercury in the resultant amalgam is susceptible to volatilization and leaching. Therefore, amalgamation is typically used in combination with an encapsulation technology, although based on concerns regarding possible volatilization and leaching, it should not be considered as a first option for treating wastes consisting of mercury (USEPA, 2007b).

(ii) Soil washing and acid extraction

226. Soil washing is an *ex situ* treatment of soil and sediment contaminated with mercury. It is a water-based process that uses a combination of physical particle size separation and aqueous-based chemical separation to reduce contaminant concentrations in soil. The process is based on the concept that most contaminants tend to bind to the finer soil particles (clay and silt) rather than the larger particles (sand and gravel). Physical methods can be used to separate the relatively clean larger particles from the finer particles because the finer particles are attached to larger particles through physical processes (compaction and adhesion). This process thus concentrates the contamination bound to the finer particles for further treatment. Acid extraction is also an *ex situ* technology that uses an extracting chemical such as hydrochloric acid or sulphuric acid to extract contaminants from a solid matrix by dissolving them in the acid. The metal contaminants are recovered from the acid leaching solution using techniques such as aqueous-phase electrolysis. More detailed information can be found in *Treatment technologies for mercury in soil, waste, and water* (USEPA, 2007b).

(b) Disposal in specially engineered landfills (DS)

227. Wastes consisting of mercury or mercury compounds that result from S/S that meet the acceptance criteria for specially engineered landfills defined by national or local regulations may be disposed of in specially engineered landfills. Additional measures should be taken at such landfills to minimize releases and the methylation of mercury, for instance through the prevention of rainwater

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and groundwater inflows, the prohibition of mixing of different kinds of waste at the landfill site, the maintenance of records of waste amounts and areas landfilled, the collection of leachate and the long-term monitoring of releases of mercury and methylmercury from landfill sites into, e.g., air and groundwater (UNEP, 2022b).

228. When wastes consisting of mercury or mercury compounds that result from S/S are disposed of in a specially engineered landfill, special consideration should be given to thermal decomposability of such wastes. The final cover of a landfill may be permeable to air in the long term. Mercury sulphide can then come into contact with atmospheric oxygen and become oxidised to mercury and sulphate. The formation of methylmercury may occur under certain geochemical conditions. Both gaseous mercury and methylmercury can leave the landfill via the gas circuit (landfill gas) (German Federal Environment Agency, 2014).

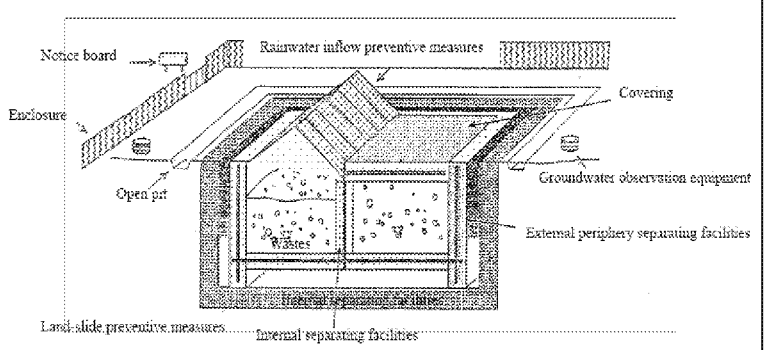
229. In addition to fire prevention, methods to stabilize and solidify wastes consisting of mercury or mercury compounds as well as the structure and final cover of the landfill accepting them should respond to mechanism referred to in the preceding paragraphs to ensure mercury releases from the disposed wastes are be minimized.

230. Box 10 provides an example of disposal of wastes consisting of mercury in Japan.

Box 10 Country Examples: Japan

As an option for the disposal of wastes consisting of mercury, Japan has identified specific treatments and types of landfills that can be combined to dispose of such wastes, namely: 1) stabilization of mercury as mercury sulphide (HgS), followed by solidification (e.g., through the use of modified sulphur as described in paragraph 220); and disposal in a leachate-controlled type of landfill for industrial wastes, with additional measures taken to minimize releases and methylation of mercury, for instance through the prevention of rainwater and groundwater inflow, the prohibition of mixing of different types of waste at the landfill, and the maintenance of records of waste amounts and areas landfilled; and 2) stabilization of mercury as HgS followed by solidification and disposal in an isolated type of landfill for hazardous industrial wastes (see figure below). Further specifications on these combinations will be determined based on further experiments and studies (Ministry of the Environment of Japan, 2015).

Figure: Landfill for hazardous industrial wastes (isolated type) (Ministry of the Environment of Japan, 2007a)



231. It should be noted that wastes of products containing mercury or mercury compounds may be disposed in engineered landfills for household wastes despite best efforts to keep them separate. For information on methods to reduce mercury releases from these landfills, see section H.2 below.

232. Wastes contaminated with mercury or mercury compounds that meet the acceptance criteria for specially engineered landfills, as defined by national or local regulations, may be disposed of in specially engineered landfills.

233. Some jurisdictions have defined landfill acceptance criteria for wastes contaminated with mercury or mercury compounds. Boxes 11 to 14 provide examples of such criteria in the European Union, China, Japan, and USA. In addition, disposal of certain mercury wastes in landfills is banned in some countries.

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A specially engineered landfill is an environmentally sound system for solid waste disposal and is a site where solid wastes are capped and isolated from each other and from the environment. All aspects of landfill operations should be controlled to ensure that the health and ... [14]

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Box 11 Regional Example: European Union

Under European Union legislation, only wastes with leaching limit values of 0.2 and 2 mg Hg/kg dry substance at a liquid-solid ratio of 10 l/kg can be accepted into landfills for non-hazardous and hazardous wastes, respectively (European Union, 2003).

Box 12 Country Example: China

Under Chinese legislation, only hazardous wastes with total mercury leaching value equal to or less than 0.12 mg/l (Chinese Leaching Test Method: HJ/T 299) can be accepted into landfills for hazardous wastes (MEE China, 2019), and non-hazardous wastes with total mercury leaching value equal to or less than 0.05 mg/l (Chinese Leaching Test Method: HJ 557) can be accepted into non-hazardous industrial solid waste storage and landfill facilities (GB 18599) (MEE China, 2020).

Box 13 Country Example: Japan

Under Japanese legislation, treated wastes with mercury concentration equal to or less than 0.005 mg/l (Leaching Test Method: Japanese Standardized Leaching Test No. 13 (JLT-13) (Ministry of the Environment Notification No. 13) can be accepted into landfills for industrial wastes (leachate-controlled type), and those with mercury concentration in excess of 0.005 mg/l, should be disposed of at landfills for hazardous industrial wastes (isolated type) (see figure in Box 10) (Ministry of the Environment of Japan, 2007b).

Box 14 Country Example: USA

Under United States mercury waste treatment regulations, only low concentration mercury wastes can be treated and landfilled (high concentration waste must be retorted for mercury recovery). Treated mercury waste must leach less than 0.025 mg/l mercury (by TCLP testing) to be accepted for landfill disposal (USEPA, undated).

234. For further information on specially engineered landfills, see Basel Convention *Technical guidelines on the environmentally sound disposal of hazardous wastes and other wastes in specially engineered landfill* (D5) (UNEP, 2022).

(c) Disposal in permanent storage (underground facilities) (D12)

235. After having been solidified or stabilized, where appropriate, mercury wastes that meet the acceptance criteria for permanent storage (disposal operation D12) may be permanently stored in special containers in designated areas in underground storage facilities such as salt mines. Box 14 provides an example of national provisions for permanent storage.

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Box 14 Regional Example: European Union

The *Regulation (EU) 2017/852 of the European Parliament and of the Council of 17 May 2017 on mercury, and repealing Regulation (EC) No 1102/2008* (European Union, 2017) provides that mercury waste that underwent conversion and, if applicable, solidification shall only be permanently disposed of in the following permanent storage facilities licensed for disposal of hazardous waste:

(a) salt mines that are adapted for the permanent storage of mercury waste that underwent conversion, or deep underground hard rock formations providing a level of safety and confinement equivalent to or higher than that of such salt mines; or

(b) above-ground facilities dedicated to and equipped for the permanent storage of mercury waste that underwent conversion and solidification and that provide a level of safety and confinement equivalent to or higher than that of the facilities referred to in point (a).

236. The technology for underground storage is based on mining engineering, which uses technologies and methodologies to excavate mining areas and construct mining chambers[52]. Decommissioned mines could be used for the permanent storage of solidified and stabilized waste once they have been evaluated and specifically adapted for that purpose.

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[52] Germany, for example, has significant experience with underground storage of hazardous waste.

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237. In addition, the principles of and experience obtained with underground disposal of radioactive waste can be applied to the underground storage of mercury wastes. While the excavation of deep underground repositories can be achieved using standard mining or civil engineering technologies, such operations can only be conducted when locations are accessible (e.g., below surface or nearshore locations), rock units are reasonably stable and there is no major groundwater flow, and the excavation depth ranges between 250 m and 1,000 m. At a depth greater than 1,000 m, excavations become increasingly technically difficult and correspondingly expensive (World Nuclear Association, 2020).

238. The following publications, among others, contain detailed information on permanent underground storage for mercury wastes:

(a) European Union, 2003. "Safety Assessment for Acceptance of Waste in Underground Storage", Appendix A to *Council Decision 2003/33/EC of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC*;

(b) BiPRO, 2010. *Requirements for Facilities and Acceptance Criteria for the Disposal of Metallic Mercury*;

(c) International Atomic Energy Agency (IAEA), 2009. *Geological Disposal of Radioactive Waste: Technological Implications for Retrievability*;

(d) World Nuclear Association, 2020. *Storage and Disposal of Radioactive Waste*.

239. Permanent storage in facilities located underground in geohydrologically isolated salt mines and hard rock formations is an option for separating hazardous wastes from the biosphere for geological periods of time. A site-specific risk assessment in accordance with pertinent national legislation, such as the provisions regarding safety assessment for acceptance of waste in underground storage contained in Appendix A to the Annex to Council Decision 2003/33/EC (European Union, 2003), which establishes criteria and procedures for the acceptance of waste at landfills, should be performed for every planned underground storage facility.

240. Wastes should be disposed of in a manner that (a) excludes any undesirable reaction between different types of wastes and between stored wastes and storage linings; and (b) prevents the release and transport of hazardous substances. Operational permits should define the types of wastes that should be generally excluded. Wastes should be isolated through a combination of engineered barriers and natural barriers (rock, salt, clay), also known as a "multi-layer" approach to waste disposal. Facilities should be checked or monitored periodically to assure that the containment remains secure and stable. This is often termed a multi-barrier concept, with the waste packaging, the engineered repository and the geology all providing barriers to prevent any mercury leakage from reaching humans and the environment (BiPRO, 2010; European Union, 2003; IAEA, 2009; World Nuclear Association, 2020).

241. Specific factors that can affect the behaviour of mercury in the host rocks and geological formations used for permanent storage, such as the layout of storage facilities, types of containments used, storage location and conditions, monitoring, site access conditions, storage closure strategy, sealing and backfilling and depth of storage facilities, need to be considered separately from the properties of the wastes to be stored and the storage system to be used. Potential host rocks for permanent storage of mercury wastes include salt rock and hard rock formations (igneous rocks such as granite, metamorphic rocks, and gneiss sedimentary rocks such as limestone or sandstone; (BiPRO, 2010; European Union, 2003; IAEA, 2009; World Nuclear Association, 2020).

242. The following issues should be borne in mind when selecting a permanent underground storage site for the disposal of mercury wastes:

(a) Caverns or tunnels used for storage should be completely separated from active mining areas and areas that may be reopened for mining;

(b) Caverns or tunnels should be located in geological formations that are well below zones where groundwater is present or in formations that are completely isolated from water-bearing zones by impermeable rock or clay layers;

(c) Caverns and tunnels should be located in geological formations that are extremely stable and not in areas subject to earthquakes.

243. In order to guarantee the complete inclusion of wastes in permanent storage facilities, the disposal mine and any area around it that might be affected (geomechanically or geochemically) by

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disposal operations should be surrounded by a host rock (known as an "isolating rock zone") of sufficient thickness and homogeneity, with suitable properties and at a suitable depth (see figure). As a basic principle, a long-term risk assessment should enable parties to prove that the construction and operational and post-operational phases of underground disposal facilities do not lead to any degradation of the environment. Consequently, appropriate models must be used to analyse and assess all technical barriers (e.g., waste forms, backfilling, sealing measures), the behaviour of the host and surrounding rock, overburden rock formations and the sequence of possible events in the overall system.

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Figure: Concept of complete inclusion (schematic diagram) (courtesy: GRS)

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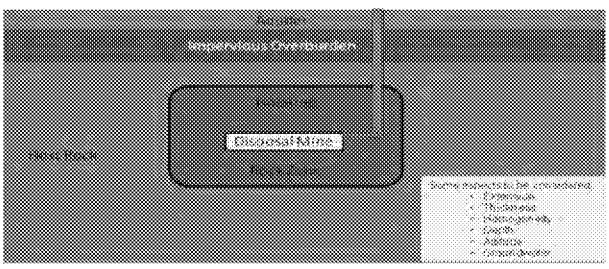

244. If the host rock under consideration shows any deficiencies (e.g., insufficient homogeneity or thickness), a multi-barrier system can compensate for the missing or inadequate barrier properties of the rock. In general, a multi-barrier system of this kind is composed of one or several additional barrier components (see table and figure) that can help to achieve the ultimate goal, i.e., to durably isolate stored wastes from the biosphere.

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245. A long-term safety assessment (see above) should be conducted to ascertain the need for a multi-barrier system, and the mode of action of barrier components, within the disposal system. By way of example, the geological formation(s) overlaying a disposal mine ("overburden") may be effective in:

(a) Protecting the underlying host rock from any impairments of its properties; and/or

(b) Providing additional retention capacities for contaminants that might be released from the disposal mine under certain circumstances.

Table: Possible components of a multi-barrier system and examples for their modes of action

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Barrier component	Example for mode of action
Waste content	Reduction of the total amount of contaminants to be disposed of
Waste specification	Treatment of waste in order to get a less soluble contaminant
Waste canister	Bridging of a limited time period until natural barriers become effective
Backfill measures	Backfilling of void mine spaces to improve geomechanical stability and/or to provide special geochemical conditions
Sealing measures	Shaft sealing should provide the same properties where the natural barrier(s) is(are) disturbed by mine-access
Host rock	Complete inclusion of contaminants (in ideal cases)
Overburden	Provision of an additional natural (geological) barrier, e.g., through overlaying a clay layer with sufficient thickness and suitable properties

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Figure 8: Main components of a multi-barrier system and their layout within the system (schematic diagram) (courtesy: GRS)

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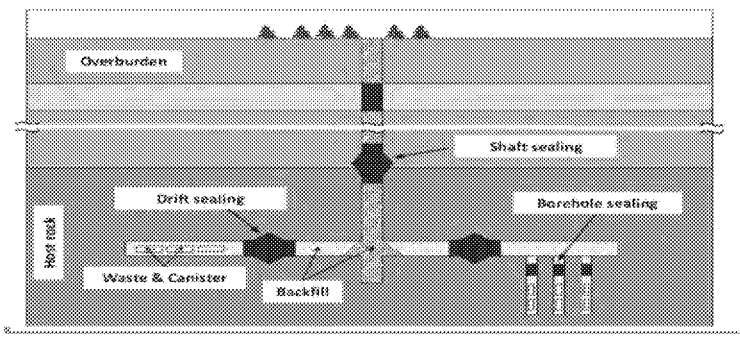

246. In general, an underground disposal system including all the criteria, requirements and final layout described above should be designed according to waste-specific and site-specific criteria, taking into consideration all relevant regulations (e.g., European Union, 2003). To give readers a rough idea of the depth and thickness of different types of host rocks suitable for underground storage, table 9 lists typical acceptable dimensions, based on past experience and current plans.

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Table 9: Typical values of vertical thickness of host rock body and potential disposal depth (Grundfelt et al., 2005)

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Geosystem		Thickness of host rock body	Potential disposal depth
Host rock	Variant		
Rock salt	Salt dome	up to > 1,000 m	800 m
Rock salt	Layered salt	app. 100 m	650 – 1,100 m
Clay / Claystone		up to 400 m	400 – 500 m
Rocks under clay cover		app. 100 m	500 – 1,000 m

H. Reduction of mercury releases from thermal treatment and landfilling of waste

1. Reduction of mercury releases from thermal treatment of waste

247. Mercury waste may be combusted with MSW because mercury waste may be contained in MSW despite best efforts to keep them separate. By reason of its low boiling point, almost all the mercury in the waste may be transferred to combustion gas and, to a lesser extent, bottom ash. Most of the mercury in the combustion gas fed into waste combustion units is elemental mercury and transforms to divalent mercury after passing through the units, and part of the divalent mercury transfers to fly ash. The divalent mercury is assumed to be mercuric chloride; consequently, flue gas treatment devices that can effectively remove mercuric chloride and mercury should be selected. In addition, waste that potentially contains or is contaminated with mercury, such as poorly segregated waste from healthcare facilities, should not be incinerated in incinerators that lack flue gas treatment devices (Arai et al., 1997). Emission and effluent standards for mercury should be set and mercury levels of treated flue gas and wastewater should be monitored to ensure that mercury releases into the

Deleted: Whenever possible, mercury-added products should not be disposed of together with municipal solid waste (MSW). Separate collection of mercury wastes leads to a reduction of overall mercury loads in mixed MSW, but separate collection rates of 100 per cent are not achieved in practice. As a result, wastes containing or contaminated with mercury or mercury compounds may be combusted with MSW and, by

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environment are kept to a minimum. Such practices should also be applied in other thermal waste treatment processes such as vacuum-sealed roasting facilities.

248. Primary techniques for reducing the inclusion of mercury in the waste stream include the following (European Commission, 2019):

(a) Efficient removal of products containing mercury or mercury compounds from the waste stream (e.g., through separate collection of certain types of batteries and dental amalgam (using amalgam separators) before mercury wastes are co-mingled with other wastes or wastewaters;

(b) Notification of waste producers of the need to segregate mercury;

(c) Identification and/or restriction of receipt of potential mercury wastes;

(d) When mercury wastes have been knowingly received, control of feeding of such wastes into abatement systems in order to avoid overloading system capacities.

249. Secondary techniques for preventing mercury releases to the air from the waste stream include treatment of flue gas. Box 15 provides an example of emission limit values for waste incineration plants.

Box 15 Regional Example: European Union

The European Commission Implementing Decision 2019/2010 establishing BAT conclusions for waste incineration (European Commission, 2019) sets BAT-associated emission levels for discharges of wastewater from the cleaning of flue (waste) gases and air emission limit values for waste incineration plants. Regarding the former, unfiltered samples must not contain more than 10µg/L mercury and its compounds, expressed as mercury (Hg); as for the latter, air emissions must not exceed 20µg/Nm^3 mercury and its compounds, expressed as mercury (Hg) for continuous monitoring (daily average or average over the sampling period), or 10µg/Nm^3 for a long-term sampling period.

250. The selection of a process to control mercury flue gas emissions depends on the chlorine and SO_2 concentrations (Vosteen, Kanelke and Köser, 2006) in the flue gas. When the chlorine concentration is high, the mercury contained in resultant crude flue gas may tend to be in the oxidized form depending on the SO_2 concentration (which consumes Cl_2), in which case it can be captured in the flue gas cleaning system. The addition of reagents for a more efficient removal of mercury can be necessary and provides a means for removing mercury from the process. It should be noted that, in the incineration of sewage sludge, mercury emissions will consist mostly of elemental mercury, due to the lower chlorine content of such sludge compared to that of municipal or hazardous waste. Consequently, special attention should be paid to capturing these emissions. Elemental mercury can be removed by transforming it into oxidized mercury; this can be done by adding oxidants to the mercury and then depositing the resultant mix in a scrubber or directly on sulphur doped activated carbon, hearth furnace coke, or zeolites depending on the flue gas cleaning system (dry, wet or semi-dry). The removal of heavy metals, including mercury, from wet scrubber systems can be achieved through flocculation, a process in which metal hydroxides are formed under the influence of flocculating agents (poly-electrolytes) and $FeCl_3$. For the removal of mercury, complex-builders and sulphides (e.g., Na_2S and Tri-Mercaptan) are added.

251. The removal of mercury in oxidised form from flue gas can be achieved through adsorption on activated carbon reagents in an entrained flow system in which activated carbon is injected into the gas flow and filtered from the gas flow with the use of bag filters. Activated carbon has demonstrated to have a high adsorption efficiency for mercury in oxidised form, as well as for dioxins and furans (PCDDs/PCDFs). Different types of activated carbon have different adsorption efficiencies, presumably due to the nature of various carbon particles and the influence exerted on the particles by manufacturing processes (European Commission, 2019a). Almost all emission relevant flue-gas components, in particular residual contents of hydrochloric acid, hydrofluoric acid, sulphur oxides and heavy metals (including mercury in oxidised form), can effectively be deposited in static bed filters of grained hearth furnace coke (HFC), a fine coke of 1.25 mm to 5 mm. The depositing effect of HFC is essentially based on mechanisms of adsorption and filtration. In general, incinerators should be equipped with flue gas treatment devices to capture NOx, SO_2, particulate matter, mercury vapour and particulate-bound mercury as a co-benefit. Powdered activated carbon injection is one of the advanced technologies used for mercury removal in incinerators and coal-fired power plants. Mercury adsorbed on activated carbon can be stabilized or solidified for disposal (see subsection III.G.2 (a) above).

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252. For the reduction of mercury emissions from waste incineration, the following documents provide additional technical information:

(a) UNEP, 2022. Technical Guidelines on the environmentally sound incineration of hazardous wastes and other wastes as covered by disposal operations D10 and R1;

(b) Minamata Convention, 2011. *Guidance on Best Available Techniques and Best Environmental Practices* (Chapter VI);

(c) UNECE, 1998. *Heavy Metals Protocol* to the *Long-range Transboundary Air Pollution* and 2013 *Guidance document on best available techniques for controlling emissions of heavy metals and their compounds from the source categories listed in annex II*;

(d) UNEP, 2010. *Study on mercury sources and emissions and analysis of cost and effectiveness of control measures: "UNEP Paragraph 29 study"* (doc. UNEP(DTIE)/Hg/INC.2/4);

(e) European Commission, 2019a. *Reference Document on the Best Available Techniques for Waste Incineration*;

(f) European Commission, 2019b. *Commission Implementing Decision (EU) 2019/2010 of 12 November 2019 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for waste incineration*;

253. For the reduction of mercury emissions from waste co-incineration, the following documents provide additional technical information:

(a) European Commission, 2017a. *Best Available Techniques (BAT) Reference Document for Large Combustion Plants*;

(b) European Commission, 2017b. *Commission Implementing Decision (EU) 2017/1442 of 31 July 2017 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for large combustion plants*;

(c) European Commission, 2013b. *Commission Implementing Decision of 26 March 2013 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for the production of cement, lime and magnesium oxide*.

254. When a wet scrubber is used as a flue gas treatment method, it is essential that wastewater from the wet scrubber be treated.

2. Reduction of mercury releases from engineered landfills for household wastes

255. Mercury waste may be deposited in engineered landfills for household waste despite best efforts to keep them separate. In such cases, there are three types of pathways through which mercury can be released into the environment: the working face of the landfill, leachate, and landfill gas. The most important sites of mercury emissions are landfill working faces and methane vents (Lindberg and Price, 1999).

256. Landfill cover should be applied every day to reduce the direct release of mercury from wastes that have been newly added to landfills (Lindberg and Price, 1999). Landfill fires can also result in increased mercury releases. For prompt application of soil cover in case of landfill fires, soil cover materials and machines used for applying soil cover for the purpose of extinguishing fires (e.g., dump truck, dozer shovel) should be readily available.

257. It is reported that mercury releases through leachate are fairly minimal compared to releases through landfill gas depending on the management practices of the landfill (Yanase, Hirato, and Matsufuji, 2009; Takahashi et al., 2004; Lindberg et al., 2001). Mercury transferred to leachate can be removed through leachate collection and treatment, as is the case for wastewater from wet scrubbers of waste incinerators.

258. A landfill gas capture system should be installed at the site to capture mercury vapour and if applicable methylmercury and thereby prevent their release into the atmosphere if appropriate.

I. Management of contaminated sites

259. Mercury-contaminated sites are widespread around the world. There is a range of possible sources of site contamination, including mercury storage, manufacturing of products containing mercury or mercury compounds, use of mercury in manufacturing processes, ASGM activities using mercury or primary ore rich in mercury in which the mercury is mobilized, primary mercury mining,

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UNEP, 2010. *Study on mercury sources and emissions and analysis of cost and effectiveness of control measures: "UNEP Paragraph 29 study"* (doc. UNEP(DTIE)/Hg/INC.2/4). Available from:

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UNEP, 2002. *Global Mercury Assessment*. Available at: http://www.unep.org/chemicalsandwaste/LinkClick.aspx?fileticket=Kpl4mFj7AJU%3d&tabid=3593&language=en-US; ¶

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Deleted: <#>For reduction of mercury releases from specially engineered landfills, see subsection III.G.2 (b) above. The following paragraphs provide directions for the reduction of mercury releases from municipal solid waste landfills. ¶
<#>When the disposal of wastes containing or contaminated with mercury or mercury compounds in landfills (operation D1) is unavoidable

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and abandoned, historical mines not managed in accordance with modern practices, point sources of emissions and releases, and waste treatment and disposal (UNEP, 2019d).

260. For guidance on the management of contaminated sites, see the *Guidance on the management of contaminated sites* adopted by the Conference of the Parties to the Minamata Convention in decision MC-3/9 (UNEP, 2019d). It provides guidance on managing sites contaminated with mercury or mercury compounds, from site identification and detailed site investigation to the decision process for site management and, where appropriate, remediation.

261. When decommissioning mercury cell plants, a plan for the remediation of contaminated chlor-alkali sites should be developed (European Commission, 2014b).

J. Health and safety

262. Employers should ensure that the health and safety of every employee are protected while they are at work. Every employer should obtain and maintain insurance, under an approved policy from an authorized insurer, providing a sufficient level of coverage in case of liability (compensation) for bodily illness or injury sustained by employees arising out of and in the course of their employment, in accordance with national law. Health and safety plans should be in place at all facilities that handle mercury wastes to ensure the protection of everyone in and around such facilities. Such plans should be developed for each facility by trained health and safety professionals with experience in managing health risks associated with mercury.

263. An exposure assessment should if appropriate be undertaken for all employees who are directly exposed to mercury or mercury compounds and appropriate monitoring and industrial hygiene practices adopted. Colorimetric badges and/or personal monitoring equipment (vapour sampling devices) are needed for this kind of comprehensive exposure assessment and monitoring programme. Pre-employment physical examinations should be carried out to establish a baseline for determining an individual's background mercury level and to ensure that the employee has normal body chemistry for mercury removal. Personnel may have other considerations that should be handled on a case-specific basis. Medical monitoring programmes should also include periodic physical exams (e.g., every one to three years), regular blood tests and regular urinalysis. Consideration should be given to offering alternative jobs to workers who become pregnant or who are breastfeeding.

264. The protection of workers who are engaged in the management of mercury wastes and the general public can be achieved through the following ways:

(a) By allowing access to facilities to authorized personnel only;

(b) By ensuring that occupational exposure limits for hazardous substances are not exceeded by making sure that all personnel use appropriate protective equipment;

(c) By ensuring appropriate ventilation of facilities to minimize risk from exposure to volatile substances or substances that can become airborne;

(d) By ensuring facility compliance with all national and regional laws on workplace health and safety.

265. Guideline values for mercury concentrations in drinking water and ambient air have established by WHO are 0.006 mg/L for inorganic mercury and 1 μg/m^3 for inorganic mercury vapour (WHO, 2006; WHO Regional Office for Europe, 2000). Governments are encouraged to monitor air and water in order to protect human health, especially near sites where mercury waste management activities take place. Some countries have established permissible levels of mercury in the working environment (e.g., 0.025mg/m^3 Hg for inorganic mercury, excluding mercury sulphide, and 0.01mg/m^3 Hg for alkylmercury compounds in Japan); waste management operations should be conducted so as to satisfy requirements regarding permissible levels of mercury in the working environment, and facilities where such operations are conducted should be designed and operated so as to minimize mercury releases to the environment as far as is technically possible.

266. Special attention should be paid to sites where products containing mercury or mercury compounds are handled. Within the waste stream, mercury emissions from products containing mercury or mercury compounds can lead to exposures that raise health concerns and contribute to environmental releases at multiple points. Waste collectors, truck drivers and workers at transfer stations can be exposed to brief peaks of mercury vapour when handling wastes of products containing mercury or mercury compounds. Waste management employees at the "working face" of a landfill – the active area where waste is dumped, spread, compacted and buried – can be repeatedly exposed to mercury vapour. Those in the informal waste sector involved in scavenging landfills for

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Deleted: result of ASGM in which mercury is used, an activity that has largely ceased or is subject to regulatory and engineering controls in developed countries but that continues in

Deleted: developing world. The existence of sites with mercury-contaminated soils and large mine tailing piles and of sites with widely dispersed areas

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Deleted: <#>The Minamata Convention contains provisions that require the development of detailed technical guidance for addressing contaminated sites (see paragraph 26 above).¶
<#> . **1. . Identification of contaminated sites and emergency response**¶
<#>The identification of a mercury-

Deleted: <#>site that poses a threat to human health or the environment can be achieved through:¶
<#>Records identifying past industrial or other activities at the site;¶
<#>Visual observation of site conditions and attendant contaminant sources;¶
<#>Visual observation of manufacturing or other operations known to have used or emitted a particularly hazardous contaminant;¶
<#>Observed adverse effects in humans, flora or fauna possibly caused by their proximity to the site;¶
<#>Physical or analytical results showing contaminant levels; and¶
<#>Community reports to the authorities regarding suspected releases.¶
<#>Sites contaminated with mercury are similar to other contaminated sites in that mercury can reach receptors in a variety of ways. Mercury is particularly problematic because of its hazardous vapour phase, its low level of observable effects on animals, and the different levels of toxicity of its different forms (e.g., mercury vs. methylmercury). Mercury is also readily detectable using a combination of field instruments and laboratory analyses. Sites contaminated with mercury may also be contaminated with other pollutants. During site assessments and remediation activities, all possible on-site pollutants

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<#>The first priority when dealing with mercury-contaminated sites is to isolate the contamination from contamination receptors in order to minimize their further exposure. In this respect, dealing with sites contaminated with mercury is similar to dealing w ... [15]

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reclaimable items can be chronically exposed. Venting points for methane gas generated by decaying organic wastes are additional sources of mercury release and exposure.

267. Disposal facilities, especially where mercury recovery processes are conducted, also present a high risk of mercury exposure to employees as well as a risk to people living and working near such facilities. Major activities presenting high risk of exposure include the crushing of fluorescent lamps, the extraction of mercury from products containing mercury such as thermometers and barometers, the thermal treatment of wastes containing or contaminated with mercury, and S/S of wastes consisting of mercury or mercury compounds.

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268. Employee training in effective ESM and workplace health and safety should be provided to, among other things, ensure employee safety against mercury exposure and accidental injury when managing waste.

269. The basic knowledge that employees need includes:

(a) The definition of mercury wastes and the chemical properties and adverse effects of mercury;

(b) How to identify mercury wastes and to segregate such wastes from other types of wastes;

(c) Occupational safety standards relevant to mercury and how to safeguard their health against mercury exposure;

(d) How to use personal protective equipment, such as body coverings, eye and face protectors, gloves and respiratory protectors;

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(e) Proper labelling and storage requirements, container compatibility and dating requirements, and closed-container requirements;

(f) How to safely handle mercury wastes, particularly used products containing mercury such as thermometers and barometers, using the equipment available at the facility in which they work;

(g) How to use engineering controls to minimize exposure;

(h) How to respond in an emergency if mercury in waste is accidentally spilled.

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270. It is important to have worker insurance and employer liability insurance in order to be better prepared for accidents or injuries sustained by workers in the facility, as appropriate under national law.

271. A mercury awareness-raising package developed by UNEP (UNEP, 2008d) is recommended for use in employee training. All training materials should be translated into local languages and made accessible to employees.

K. Emergency response

1. Emergency response plan

272. Emergency response plans should be in place at each stage of the mercury waste processing chain (e.g., generation, storage, transport, treatment or recovery, and disposal). While emergency response plans can vary depending on the activities carried out at each stage of waste management and the physical and social conditions of each management site, the principal elements of an emergency response plan include the identification of potential hazards; compliance with legislation governing emergency response plans; specification of actions to be taken in emergency situations, including mitigation measures, personnel training plans, communication targets (e.g., fire services, police, neighbouring communities, local governments, etc.) and methods to be used in case of emergency; and specification of the method and frequency of testing of emergency response equipment.

273. When an emergency occurs, the first step is to examine the site. The person in charge should approach the site cautiously from upwind, secure the scene and identify any hazards. Placards, container labels, shipping documents, material safety data sheets, car identification charts and/or knowledgeable persons on the scene are valuable information sources. The need for site evacuation, the availability of human resources and equipment, and possible immediate actions should then be assessed. In order to ensure public safety, an emergency response agency call should be made and, as an immediate precautionary measure, spill and leak areas should be isolated for at least 50 meters in

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all directions. In case of fire, a suitable extinguishing agent should be used, and the use of water should be avoided. For further information, the *Emergency Response Guidebook* (U.S. Department of Transportation et al., 2012) can be consulted.

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2. Special consideration for spillage of mercury or mercury compounds

274. Spillage of mercury or mercury compounds occurs primarily when waste of products containing mercury or mercury compounds are broken. Most cases of spillage seem to involve glass thermometers, which are easily broken. Although the mercury in each glass thermometer is about 0.5-3 g and does not usually lead to serious health problems, all mercury spills should be considered hazardous and should be cleaned up with caution. Indoor areas should be adequately ventilated. If a person experiences discomfort following a mercury spill, a medical doctor and/or the environmental health authorities should be contacted immediately.

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275. If the spill is small and simple (e.g., it occurs on a non-porous area such as linoleum or hardwood flooring, or on a porous item that can be thrown away, such as a small rug or mat), it can be cleaned up by an individual. If the spill is large or complex (e.g., it occurs on a rug that cannot be discarded, on upholstery, or in cracks or crevices), it may be necessary to hire a trained professional to contain it or clean it up. Large spills involving more than the amount of mercury found in a typical household product should be reported to the local environmental health authorities. If there is any uncertainty as to whether a spill should be classified as "large", the local environmental health authorities should be contacted as a precautionary measure. Under certain circumstances, it may be advisable to obtain the assistance of qualified personnel for professional clean-up or air monitoring, regardless of spill size (Environment Canada, 2016).

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276. Spills of mercury in the course of commercial activities and in households have the potential to expose workers and the general public to hazardous mercury vapours. In addition, the spills are both costly to clean up and disruptive. Clean-up procedures for small mercury spills are found in the USEPA's website (USEPA, 2007c).

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277. Critical to determining what type of response is appropriate for any mercury spill is evaluating the size of the spill and the extent of mercury dispersal and whether the necessary clean-up resources and expertise are available. Professional help should be sought in the following cases:

(a) The amount of mercury could be more than 2 tablespoons (30 millilitres): larger spills should be reported to the authorities for oversight and follow-up;

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(b) The spill area is undetermined: if the spill was not witnessed or the extent of the spill is hard to determine, there could be small amounts of mercury that are hard to detect and must be cleaned up;

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(c) The spill area contains surfaces that are porous or semi-porous: surfaces such as carpet and acoustic tiles can absorb the spilled mercury and make clean-up practically impossible;

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(d) The spill occurs near a drain, fan, ventilation system or other conduit: mercury and mercury vapours can quickly move away from the spill site and contaminate other areas without being easily detected.

278. Scattering of spilled mercury (e.g., with the use of water jets) should be avoided as much as possible because it significantly increases the mercury evaporation rate (Euro Chlor, 2004).

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L. Awareness and participation

279. Prior to a facility in which mercury wastes are disposed of beginning operations, there should be established procedures to communicate with local authorities regarding mercury releases. Facility operators should host community awareness forums to address questions concerning facility siting, operations, and emergency response plans, as well as other concerns the public may raise.

280. Public awareness and participation play key roles in implementing ESM of mercury wastes. Public participation is a core principle of the 1999 Basel Declaration on Environmentally Sound Management and many other international agreements. It is essential that the public and all stakeholders have a chance to participate in the development of legislation, policy, programmes and other decision-making processes related to mercury.

281. Articles 6, 7, 8 and 9 of the 1998 United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention) require specific action pertaining to public participation in specific government activities, the development of plans, policies and programmes,

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and the development of legislation, and call for access to justice for the public with regard to the environment.

282. When initiating activities such as the collection and recycling of mercury waste, it is advisable that participation and cooperation from the consumers who generate mercury-containing waste be obtained. Continuous awareness-raising is key to the successful collection and recycling of mercury waste. Encouraging public involvement in the design of a collection and recycling system for mercury waste by providing the public with information about potential problems caused by the environmentally unsound management of such waste would help to increase consumer awareness about the risks of mercury and mercury waste.

283. Public awareness and sensitization campaigns for local communities and citizens are important elements in promoting public participation in the ESM of mercury wastes. In order to raise the awareness of citizens, the authorities concerned, e.g., local governments, need to initiate various awareness-raising and sensitization campaigns to prompt citizens to take an interest in protecting themselves and others against the adverse effects of mercury on human health and the environment. It is important to involve community-based organizations in such campaigns because they have a close relationship with residents and other stakeholders in their communities (Honda, 2005).

284. Programmes for public awareness and public participation should generally be developed around a waste management situation at the national, local or community level. Table 19 shows examples of programmes for public awareness and participation. Such programmes have four elements: publications, environmental education programmes, public relations activities, and risk communication, to which citizens should have easy access in public places (Honda, 2005).

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Table 18: Programmes for public awareness and public participation

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	Contents	Expected results
Publications	• Booklets, pamphlets, brochures, magazines, posters, websites, etc., in various languages and dialects to explain mercury issues in simple terms • Guidebooks on how to dispose of mercury waste	• Knowledge sources • Explanation of how people can handle products containing mercury or mercury compounds and dispose of mercury waste
Environmental Education Programmes	• Voluntary seminars • Community gatherings • Linkages with other health workshops • Demonstrations of take-back programmes • Scientific studies • Tours to facilities, etc. • eLearning	• Raising knowledge • Sharing common issues • Opportunities to discuss environmental issues directly
Activities	• Take-back programmes • Mercury-free product campaigns • Waste minimization campaigns • Community gatherings • House-to-house visits	• Implementation of environmental activities among all partners • Environmental appeal for citizens • *One-on-one* communications
Risk Communication	• Mercury exposure in general living environments • Safe level of mercury exposure • Mercury pollution levels • PRTR • Fish consumption advisories • Rice consumption advisories • Response to mercury spills from products containing mercury or mercury compounds	• Proper understanding of safe- and risk levels of mercury exposure, in appropriate circumstances • Avoidance of overreaction

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285. As part of environmental education programmes, publications should provide basic knowledge of mercury properties, mercury toxicology, the adverse effects of mercury on human health and the environment, and mercury waste-related issues, including how to manage and avoid possible exposure to mercury from such waste. Publications should be translated into locally relevant languages and dialects to ensure the information is communicated efficiently to the target population.

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286. The components of an environmental education programme on mercury wastes are as follows (Honda, 2005):

(a) Awareness-raising and sensitization regarding the environment and environmental challenges;

(b) Building of knowledge and understanding of the environment and environmental challenges;

(c) Development of attitudes of concern for the environment and a motivation to improve or maintain environmental quality;

(d) Development of skills to identify and help resolve environmental challenges;

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(e) Participation in activities that lead to the resolution of environmental challenges.

287. The partners of programmes on public participation can be summarized as follows (Honda, 2005):

(a) Government officials and staff in governments who work on environmental issues;

(b) People who are interested in environmental problems and have the ability to quickly understand and disseminate information to others:

(i) Children and students;

(ii) Teachers and professors;

(c) Leaders and representatives from local communities and groups and others working in the field of the environment at the local or community level:

(i) People who work in non-governmental organizations;

(ii) People who work in small and medium-sized enterprises;

(iii) Local producers, collectors and recyclers, disposal facility owners, operators, and workers who handle mercury waste;

(d) People who are, or reside, in proximity to waste management or mercury contaminated sites;

(e) Local organizations;

(f) City residents;

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(g) Enterprises.

288. To ensure that mercury releases from collection, transportation and disposal of waste are kept to a minimum, it is important to raise the awareness of the parties concerned (e.g., transporters, recyclers, and treatment operators) about the risks of mercury. This can be achieved through awareness-raising activities, such as seminars, that can provide information about new systems and regulations and opportunities for information exchange; the preparation and distribution of leaflets; and the dissemination of information via the Internet.

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Annex to the technical guidelines

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APPLIED ECOLOGY

Risks of mining to salmonid-bearing watersheds

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Acknowledgments: This review is based on an October 2019 workshop held at the University of Montana Flathead Lake Biological Station (more information at https://flbs.umt.edu/newflbs/research/working-groups/mining-and-watersheds/). We thank E. O'Neill and other participants for valuable contributions. A. Beaudreau, M. LaCroix, P. McGrath, K. Schofield, and L. Brown provided helpful reviews of earlier drafts. Three anonymous reviewers provided thoughtful critiques that greatly improved the manuscript. The views expressed in this article are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency. Our analysis comes from a western science perspective and hence does not incorporate Indigenous knowledge systems. We acknowledge this gap and highlight that the lands and waters we explore in this review have been stewarded by Indigenous Peoples for millennia and continue to be so. **Funding:** The workshop was cooperatively funded by the Wilburforce Foundation and The Salmon Science Network funded by the Gordon and Betty Moore Foundation. **Author contributions:** C.J.S. led the review process, writing, and editing. C.J.S. and E.K.S. co-organized the workshop. E.K.S. and J.W.M. extensively contributed to all aspects of the review conceptualization, writing, and editing. A.R.W., S.A.N., J.L.E., D.M.C., S.L.O., R.L.M., F.R.H., D.C.W., and J.W. significantly contributed to portions of the review conceptualization, writing, and editing. J.C., M.Ca., M.Co., C.A.F., G.K., E.D.L., R.M., V.M., J.K.M., M.V.M., and N.S. provided writing and editing and are listed alphabetically. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials.

Submitted 30 November 2021
Accepted 11 May 2022
Published 1 July 2022
10.1126/sciadv.abn0929

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ED_013708_00001234-00112

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Sci. Adv., 8 (26), eabn0929. • DOI: 10.1126/sciadv.abn0929

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In secret recordings, Pebble Mine execs say Donlin mine is too expensive to build

By **Krysti Shallenberger, Alaska's Energy Desk - Bethel** - September 21, 2020

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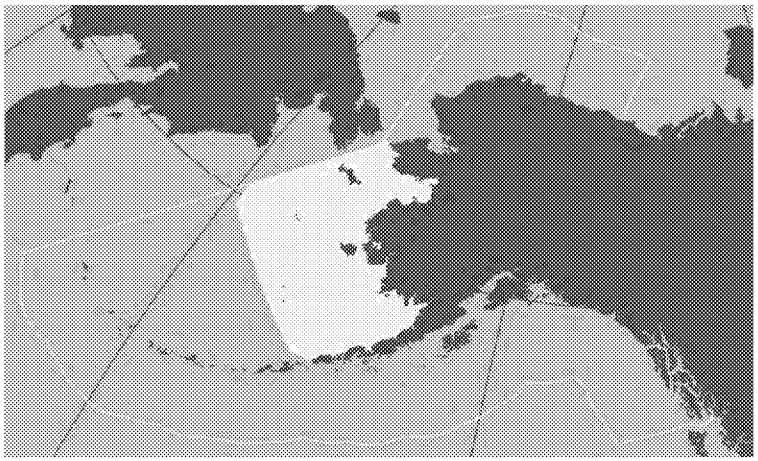
Ecosystem Status Report 2021
Eastern Bering Sea



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Grant Adams, Don Anderson, Alexander G. Andrews III, Kerim Aydin, Steve Barbeaux, Cheryl Barnes, Lewis Barnett, Sonia Batten, Shaun W. Bell, Nick Bond, Peter Boveng, Lyle Britt, Caroline Brown, Gregory Buck, Matt W. Callahan, Wei Cheng, Bryan Cormack, Jessica Cross, Deana Crouser, Curry J. Cunningham, Seth Danielson, Andrew Dimond, Lauren Divine, Elizabeth Dobbins, Jane Dolliver, Sherri Dressel, Darcy Dugan, Anne Marie Eich, Lisa Eisner, Evangeline Fachon, Ed Farley, Thomas Farrugia, Sarah Gaichas, Jeanette C. Gann, Sabrina Garcia, Colleen Harpold, Jordan Head, Ron Heintz, Tyler Hennon, Kirstin K. Holsman, Kathrine Howard, Tom Hurst, Jim Ianelli, Tim Jones, Robb Kaler, Kelly Kearney, Esther Kennedy, Mandy Keogh, David Kimmel, Alexander Kitaysky, Christine Kondzela, Joseph Krieger, Kathy Kuletz, Ashley Kushin, Tonia Kushin, Elizabeth Labunski, Geoffrey M. Lang, Ben Laurel, Elizabeth Lee, Jean Lee, Kathi Lefebvre, Aaron Lestenkof, Zachary W. Liller, Jackie Lindsey, Christopher Long, Barbara Mahoney, Sara Miller, Calvin W. Mordy, Jamal Moss, Franz Mueter, James Murphy, Jens Nielsen, Travis Niksik, John V. Olson, Olav Ormseth, Clare Ostle, Jim Overland, Veronica Padula, Emma Pate, Noel E. Pelland, Darren Pilcher, Alexei Pinchuk, Cody Pinger, Bianca Prohaska, Heather Renner, Jon Richar, Sean Rohan, Natalie Rouse, Kate Savage, Gay Sheffield, Punguk Shoogukwruk, Kalei Shotwell, Elizabeth Siddon, Kevin Siwicke, Adam Spear, Ingrid Spies, Phyllis Stabeno, Robert Suryan, Rick Thoman, Grant Thompson, Stacy Vega, Muyin Wang, Jordan Watson, George A. Whitehouse, Alexis Will, and Ellen Yasumiishi.

ED_013708_00001234-00116

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Support for the assembly and editing of this document was provided jointly by NOAA Fisheries and the NOAA Integrated Ecosystem Assessment (IEA) program.
This document is NOAA IEA program contribution #2021_6.

The recommended citation for this document is as follows:
Siddon, E. 2021. Ecosystem Status Report 2021: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

2021 Contributing Partners

ED_013708_00001234-00118

Purpose of the Ecosystem Status Reports

This document is intended to provide the North Pacific Fishery Management Council, including its Scientific and Statistical Committee (SSC) and Advisory Panel (AP), with information on ecosystem status and trends. This information provides context for the SSC's acceptable biological catch (ABC) and overfishing limit (OFL) recommendations, as well as the Council's final total allowable catch (TAC) determination for groundfish and crab. It follows the same annual schedule and review process as groundfish stock assessments, and is made available to the Council at the annual December meeting when Alaska's federal groundfish harvest recommendations are finalized.

Ecosystem Status Reports (ESRs) include assessments based on ecosystem indicators that reflect the current status and trends of ecosystem components, which range from physical oceanography to biology and human dimensions. Many indicators are based on data collected from NOAA's Alaska Fishery Science Center surveys. All are developed by, and include contributions from, scientists and fishery managers at NOAA, other U.S. federal and state agencies, academic institutions, tribes, nonprofits, and other sources. The ecosystem information in this report will be integrated into the annual harvest recommendations through inclusion in stock assessment-specific risk tables (Dorn and Zador, 2020), presentations to the Groundfish and Crab plan teams in annual September and November meetings, presentations to the Council in their annual October and December meetings, and submission of the final report to the Council in December.

The SSC is the primary audience for this report, as the final ABCs are determined by the SSC, based on biological and environmental scientific information through the stock assessment and Tier process[1],[2]. TACs may be set lower than the ABCs due to biological and socioeconomic information. Thus, the ESRs are also presented to the AP and Council to provide ecosystem context to inform TAC and as well as other Council decisions. Additional background can be found in the Appendix (p. 231).

[1] https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf
[2] https://www.npfmc.org/wp-content/PDFdocuments/fmp/BSAI/BSAIfmp.pdf

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Eastern Bering Sea 2021 Report Card

For more information on individual Report Card indicators, please see 'Description of the Report Card indicators' (p. 246). For more information on the methods for plotting the Report Card indicators, please see 'Methods Description for the Report Card Indicators' (p. 249).
* indicates Report Card information updated with 2021 data.

- * The **North Pacific Index (NPI)** effectively represents the state of the Aleutian Low. Above (below) average winter (November–March) NPI values imply a weak (strong) Aleutian Low and generally calmer (stormier) conditions. The NPI was above average during the winter of 2020–2021 before returning to near average again in summer 2021.
- * The mean **sea ice extent** across the Bering Sea (ice year is defined as 1 August to 31 July; western and eastern) exhibited no long term trend, although a **steep decline in ice extent** was observed from 2012 (highest extent on record) to 2018 (lowest extent on record). Sea ice extent increased from 2018 to present, with the 2020–2021 daily mean extent of 268,748 km^2 being **near the long-term mean**. Seasonal sea ice extent has implications, for example, to the cold pool, spring bloom strength and timing, and bottom-up productivity.
- * The areal **extent of the cold pool** in the eastern Bering Sea (EBS), as measured during the bottom trawl survey (June–Aug; including strata 82 and 90), has increased since 2018, yet the 2021 extent (58,975 km^2) was **the 4th lowest on record** and remained more than one standard deviation below the grand mean of the time series.
- * The biomass of **aggregate forage fish** (i.e., eulachon, Pacific capelin, sand lance species, rainbow smelt, Pacific sandfish, and a group of minor smelt species) declined steeply between 2015 and 2017, and remained **below their long term mean in 2021**.
- * The biomass of **motile epifauna** measured during the bottom trawl survey (June–Aug) peaked in 2017 and remained **above their long term mean in 2021**. Trends in motile epifauna biomass **indicate benthic productivity**, although individual species and/or taxa may reflect varying time scales of productivity. Collectively, brittle stars, sea stars, and other echinoderms account for more than 50% of the biomass in this guild. The recent (2016–2021) mean biomasses for all three of these functional groups are well above their long term means. The current mean biomasses for all crab functional groups, including hermit crab, king crab, tanner crab, and snow crab are all below their long term means.

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- * The biomass of **benthic foragers** measured during the bottom trawl survey (June–Aug) is at the **lowest level over the times series**, more than one and a half standard deviations below 1982–2021 levels. Trends in benthic forager biomass are variable over the time series and **indirectly indicate availability of infauna** (i.e., prey of these species). Dominant species in the benthic foragers guild include Yellowfin sole and Northern rock sole, both of which are below their long-term means in 2021.

- * The biomass of **pelagic foragers** measured during the bottom trawl survey (June–Aug) was generally stable from 2016 to 2019, but dropped in 2021 to their **second lowest value over the time series** (1982–2021). The trend in the pelagic forager guild is largely driven by Walleye pollock which, on average, account for more than 66% of the biomass in this guild. Trends in pelagic forager biomass indicate availability of forage fish (i.e., prey to upper trophic levels) as well as **predator abundance** within the ecosystem. In 2021, the survey index for pollock was the third lowest over the time series. With the exception of Pacific herring, the 2021 index for all other species and functional groups in the pelagic forager guild were below their long term means.

- * The biomass of **apex predators** measured during the bottom trawl survey (June–Aug) was **within normal limits** in 2021. Trends in apex predator biomass reflect relative **predation pressure on zooplankton and juvenile fishes**. The trend in the apex predator guild is largely driven by Pacific cod, whose recent (2016–2021) mean biomass is below their long term mean (1982–2021). In contrast, the current mean biomass of Arrowtooth flounder, Sablefish, and Alaska skate are all above their long-term means.

- * Seafloor **habitat impacted by trawls** (pelagic and non-pelagic trawl, longline, and pot) as of December 2020 showed interactions have remained below the disturbance levels previous to the implementation of sweep modifications on non-pelagic trawl gear in 2009. However, both pelagic and non-pelagic trawling effort has been at or above average since 2013. This increase, as well as the inclusion of 2003–2014 unobserved fishing events (see p. 202), has resulted in an **increase to habitat disturbance**. Fishing gear can affect habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity.

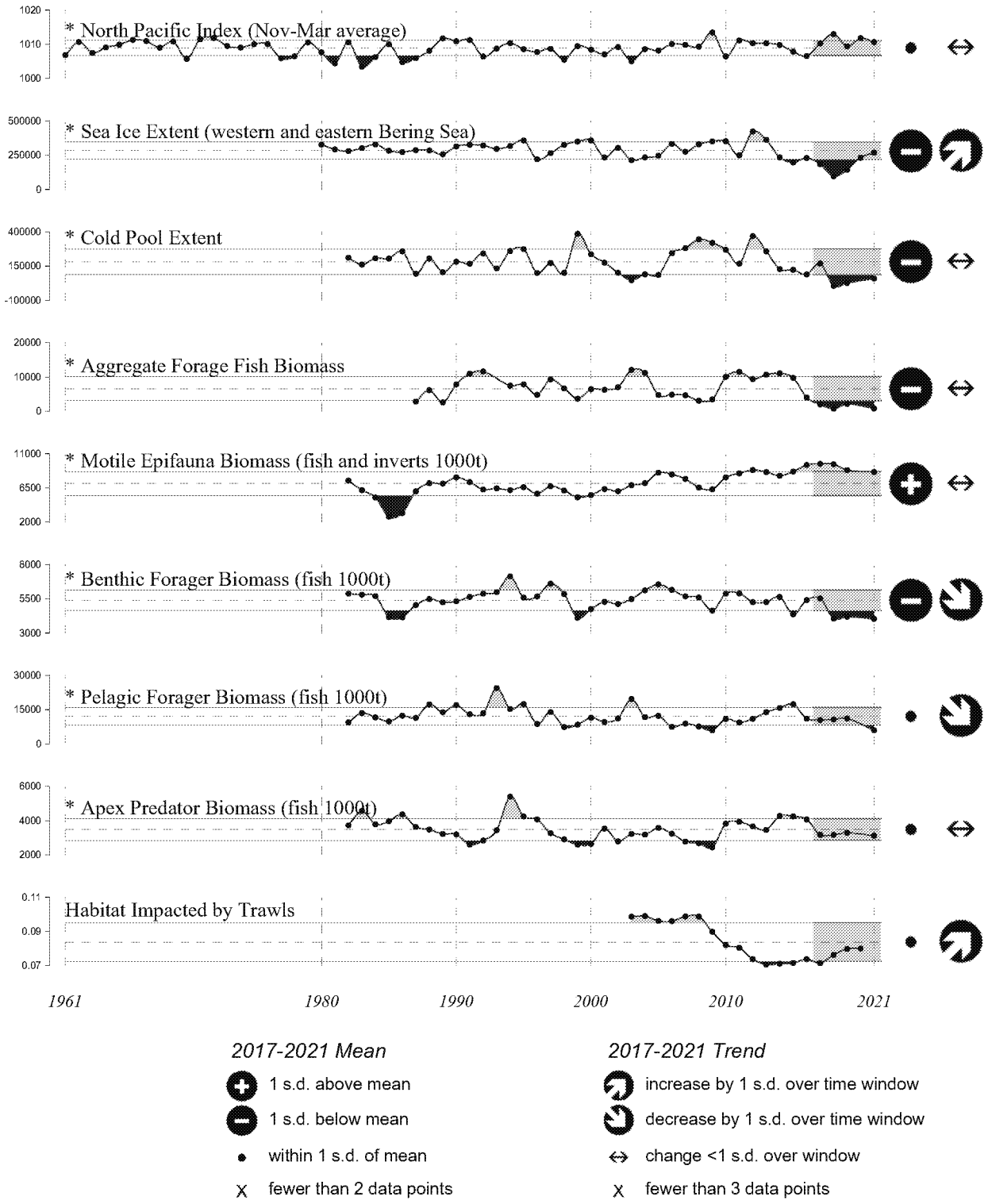

Figure 1: 2021 Eastern Bering Sea report card; see text for indicator descriptions.
* indicates time series updated with 2021 data.

Ecosystem Assessment

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Last updated: November 2021

Current Conditions: 2021

During 2021, continued COVID-related data loss impacted research efforts and had a moderate impact on information used in this report. Examples of data loss include survey cancellations, lab processing delays due to limited building access over the past year, and data processing delays due to survey logistics. Similar to 2020, NOAA scientists, state/university partners, tribal governments, and coastal community members provided contributions to mitigate these losses. Nevertheless, these interruptions to data acquisition in 2020 and 2021 provide evidence of the increase in uncertainty when data streams are interrupted and of the importance of a robust, uninterrupted data acquisition program.

It takes Two to Tango: Sea-ice dynamics are driven by both temperature and winds.
Protracted Warmth
Beginning in approximately 2014, the eastern Bering Sea (EBS) entered a warm phase of unprecedented duration (Figures 25 and 30). The EBS remains in this warm phase, though to a lesser degree compared to the extreme years of 2018 and 2019. Sea-ice formation in fall of 2020 was delayed due to residual warmth in the system, which has become the 'new normal' during this protracted warm phase. Delayed freeze-up leads to shortened ice seasons that has impacts on ice thickness, ice algae, and thermal modulation as well as impacts to transportation and subsistence activities. While the areal extent of sea ice over the Bering Sea (western and eastern) in winter 2020-2021 was closer to the pre-2014 levels than at any point in the last 7 years (Report Card, Figure 1), over the eastern shelf the ice thickness differed between the northern (thicker ice) and southern (thinner/no ice) regions due to opposing prevailing winds (Physical Environment Synthesis, p. 37).

Winds
Tracking the seasonal progression and retreat of sea ice over the shelf highlights the interactive roles of water temperature (i.e., residual warmth in the system) and winds. Atmospheric conditions can have a strong influence on sea surface temperature and ice formation. Wind patterns in February 2021 highlight the decoupling of ecosystem dynamics between the northern and southern Bering

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Sea. Over the northern shelf, cold northerly winds prevailed and contributed to ice formation and stability/thickness. Over the southern shelf, warm southerly winds prevailed that contributed to reduced sea ice (Figure 20).

Bottom temperatures and Cold Pool
Summer bottom temperatures varied spatially over the shelf. The northern Bering Sea (NBS) shelf bottom waters were very warm in the inner domain with an area of cold bottom waters over the middle domain to the southwest of St. Lawrence Island. The southern shelf had moderately warm bottom water conditions (Figure 35). The summer 2021 cold pool remained significantly reduced in area and its southern boundary was shifted northwestward. The areal extent of the cold pool has increased since 2018, yet the 2021 extent was the 4th lowest on record and remains more than one standard deviation below the mean (Report Card, Figure 1).

Ecosystem Impacts
Northern Bering Sea
Following two winters (2017/2018 and 2018/2019) of little sea ice in the NBS, and two summers (2018 and 2019) of reduced cold pool extent, ecosystem-wide shifts were observed. NOAA bottom trawl surveys indicate northward shifts in the distribution of groundfish species since 2017. Concerns about the food web dynamics and carrying capacity of the NBS have existed since 2018, highlighted by the gray whale Unusual Mortality Event and short-tailed shearwater mass mortality event. Lagged (delayed) impacts of poor feeding conditions experienced during 2018 may partially explain these mortality events. Both species feed in the Bering Sea during summer; gray whales feed in the northern Bering and Chukchi seas and are benthic feeders (e.g., amphipods, crab larvae) while shearwaters are planktivorous (e.g., euphausiids). Both species embark on long migrations south for breeding. The 2019 mortality events may reflect 2018 feeding conditions in the Bering Sea, conditions experienced during the breeding season, or lack of available prey to complete the migration to the Bering Sea in 2019.

In 2021, multiple ecosystem 'red flags' occurred in the NBS: (1) crab population declines (p. 145), (2) salmon run failures in the Arctic-Yukon-Kuskokwim region (p. 26), and (3) seabird die-offs combined with low colony attendance and poor reproductive success (p. 147). In addition, (4) results from the 2021 NOAA bottom trawl survey demonstrate a substantial drop in total CPUE in the NBS between 2019 and 2021 that reflected large decreases in all of the dominant species, including pollock (p. 162). Although the collapses are coincident, the underlying mechanisms, or suite of mechanisms, resulting in the collapses reflect cumulative dynamics over the last few years. The mechanisms are not fully understood, but a common thread in these collapses is the marine environment in the NBS, which underwent an abrupt and dramatic change starting in late 2017. A brief discussion of possible mechanisms is provided below under "What Happened in the Northern Bering Sea?".

In 2018, more than 50% of Pacific cod biomass in the EBS was found over the northern portion of the shelf. The northward movement of Pacific cod, among other stocks, into the NBS altered the food web through predation pressure as well as fishery dynamics. For example, the impact of Pacific cod predation on snow crab is one hypothesis that may partially explain the decline in snow crab observed in 2021 (Szuwalski (2021)). It is worth noting here that, at this time, there is no evidence that ocean acidification can be linked to recent declines in surveyed snow crab and red king crab populations (see p. 179 for more on ocean acidification).

Corresponding northward shifts in fishing vessel activity and an increased harvest of Pacific cod in the northern regulatory areas occurred from 2016 through 2020. As the fishing fleet shifted northward following the fish, patterns in groundfish discards also shifted. Fixed gear discards in the NBS trended upward from 2016–2018 as some vessels targeting Pacific cod moved their fishing activity northward; these increases were offset by declines in discard biomass in the southern portion (p. 190). Notably, the first reported interaction between fishing vessels from the BSAI groundfish fishery with threatened spectacled eider may be a direct result of this abrupt ecological change (p. 196), as fishing vessels increase in areas near spectacled eider designated critical habitat.

Total CPUE of all fish and major invertebrate taxa sampled during the 2021 NOAA bottom trawl survey decreased in both the northern and southern portions of the survey (p. 162). In the NBS, CPUE increased between 2010 and 2019, but decreased substantially between 2019 and 2021 (Figure 95). Total CPUE in the southern portion decreased between 2019 and 2021 to the lowest level since 2009. The center of gravity for the groundfish community (p. 168) shifted to the north and into shallower water between 2014–2019 with a substantial shift to the northwest in 2016. The groundfish community distribution shifted slightly to the south in 2017, but remained near its northern maximum through 2019. Between 2019 and 2021, the mean distribution across species shifted back to the southeast again (Figure 102).

What Happened in the Northern Bering Sea?
The coincident collapses in the NBS reflect conditions experienced in the marine environment over the last few years. Researchers will continue to investigate possible mechanistic explanations, but some linkages across these collapses may help inform the need for near-term precautionary management decisions. The current protracted warm phase has resulted in cumulative impacts of increased thermal exposure and metabolic demands. Such multi-year stress means population declines observed in 2021 may be the result of impacts occurring over previous years. For example, the lack of a cold pool in 2018 and 2019, and subsequent northward shift of Pacific cod into the NBS, have been proposed as explanations for the snow crab decline observed in 2021[3].

Similarly, salmon run failures in the Arctic-Yukon-Kuskokwim Region included Chinook, chum, and coho salmon (p. 26). The 2021 salmon runs were impacted by environmental conditions over multiple years based on life history strategies, including ocean years 2016–2020 for Chinook salmon, 2017–2020 for chum salmon, and 2020 for coho salmon (Figure 5). Several juvenile salmon abundance indices can be used to forecast future run sizes. Juvenile Chinook salmon abundance in the NBS was below average in 2021 and has been below average since 2017 (p. 117). The juvenile pink salmon index, which is generally higher in warmer years, decreased dramatically in 2021 (p. 119). A new indicator based on juvenile chum salmon may be used to forecast adult returns. However, uncertainty in the current juvenile to adult relationship precludes reliable forecasts until additional years of returns are observed (p. 121). In contrast, the 2021 Bristol Bay inshore run of 67.7 million sockeye salmon is the largest on record since 1963 (Figure 64). The large 2021 sockeye salmon run suggests these stocks experienced positive conditions at entry into the EBS in the summers of 2018 and 2019, and winters of 2018–2019 and 2019–2020 (p. 115).

[3] https://meetings.npfmc.org/Meeting/Details/2631

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The loss of sea ice during the current protracted warm phase has impacted water column stratification and the vertical distribution of prey (p. 106). Historically, salinity and temperature contribute equally to the vertical stratification of the water column in the NBS. Without increased salinities due to brine rejection as ice forms, the lack of salinity structure results in weaker vertical stratification, permitting greater vertical mixing. If primary and secondary production is mixed deeper in the water column, a vertical mismatch of prey for surface-foraging seabirds or juvenile salmon may limit prey availability, thus exacerbating increased metabolic demands under increased thermal conditions.

The protracted warmth in the NBS, with an increased frequency and duration of marine heatwaves from fall 2017 through winter 2019 (Watson, 2020), and shifts in species distributions (p. 162) has led to concerns about the food web dynamics and carrying capacity of the NBS. Ecosystem response to the 2014–2016 marine heatwave in the Gulf of Alaska resulted in abrupt changes across multiple trophic levels and there were indications the post-marine heatwave system had reduced resiliency (Suryan et al., 2021). Resiliency existed in 'functional redundancy' – an example being the ability to switch prey – and without that buffer, ecosystem components could not recover from the marine heatwave perturbation. Evidence of prey switching has been observed in seabirds (i.e., least and crested auklets, p. 147), age-0 pollock in the southeastern Bering Sea, and in the diet of Pacific cod in the southeastern Bering Sea reflecting changes in prey availability. For example, in the southeast middle domain, pollock were the dominant prey of Pacific cod in most years, but when pollock abundance was low from 2008–2012, pollock were replaced in Pacific cod diets with a mix of *Chionoecetes* spp. and flatfish. Can ecosystem reorganization keep pace with the rate of environmental changes?

Southeastern Bering Sea

Impacts of the loss of sea ice include increases in water temperature (i.e., lack of cold pool), decreases in ice-associated algae, and increases in salinity, and subsequent changes in water density and water column stratification (p. 57). Community-led monitoring of temperature and salinity on St. Paul Island shows an increasing trend in salinity since 2014 (Figure 32). The long-term increase in water density at St. Paul Island is driven primarily by the increase in salinity (Figure 33). Salinity variability on the shelf is driven by ice melt and advection, river discharge, precipitation, evaporation, in flows from the Gulf of Alaska, and cross-slope exchanges with the basin.

Water density and water column stratification can impact the vertical distribution of organisms, including age-0 fish. Age-0 pollock appear to occur deeper in the water column during colder years and closer to the surface during warmer years (p. 106), affecting their availability to predators. In 2021, age-0 pollock may therefore have occurred higher in the water column. Visual predators, such as seabirds, however, may have had reduced foraging success due to a coccolithophore bloom over the southern shelf (Figure 48). The coccolithophore bloom index remained above average in 2021 (p. 87).

Chlorophyll-a biomass, an indicator of primary productivity over the shelf (p. 80), was low along the shelf-break, continuing that trend since 2014 (i.e., start of current protracted warm phase; Figure 44). Along-shelf winds through 2021 were variable and did not consistently demonstrate upwelling or downwelling favorable conditions (Figure 23). Summer 2021 primary production as measured at mooring M2 appeared to be higher than in previous years (2016, 2017, 2019), but lower than in 2018 (p. 85). Secondary production of zooplankton was assessed in spring along the 70-m isobath (p. 94). Small copepod abundance was slightly reduced, although within historical ranges, therefore unlikely to impact food availability for larval fish. Large copepods are less critical in the

spring, but very important by fall. Observations of *Calanus* spp. suggest they were developing more slowly due to the relative colder temperatures, which would result in an increased availability later in the year and potentially support increased overwinter success for age-0 pollock (p. 94).

Species guilds are grouped by functional roles within the ecosystem and trends inform dynamics across these roles (i.e., predation pressure, prey availability) (Report Card, Figure 1). Motile epifauna, which indicate benthic productivity, remained above their long term mean in 2021. Above-average biomass of brittle stars, sea stars, and other echinoderms off-set below-average biomass for all crab functional groups. Benthic foragers were at their lowest level over the times series and indirectly indicate availability of infauna (i.e., prey of these species). A new guild comprised of small forage fishes describes available prey for seabirds and larger fish (i.e., adult pollock). This aggregate forage fish guild indicates a decline in the availability of forage species to predators that may have contributed to other substantial ecosystem changes in the southeastern Bering Sea. In 2021, pelagic foragers, largely driven by adult pollock biomass, dropped to their second lowest value over the time series. Trends indicate availability of forage fish as well as predator abundance within the ecosystem. With the exception of Pacific herring, the 2021 index for all other species and functional groups in the pelagic forager guild were below their long-term means. Togiak herring are an important prey species for piscivorous fish, seabirds, and marine mammals. The high Prohibited Species Catch in the pollock fishery in 2020 supports a strong increase in young EBS herring, as does preliminary Togiak herring data from 2021 (p. 108). Apex predators, largely driven by adult Pacific cod, are below their long term mean in 2021.

For groundfish in the southeastern Bering Sea, bioenergetic indices estimated through 2019 point towards continued increases in thermal exposure and a resulting increase in metabolic demands, as well as declines in foraging and growing conditions (p. 131). For juvenile and adult pollock and Pacific cod, metabolic requirements for prey increased between 2015–2019 relative to historical (1982–2010) rates. Meanwhile, the relative foraging rates for juvenile pollock and Pacific cod declined markedly. Of particular note, from 2015–2019 juvenile Pacific cod scope for growth remained well below the long-term average (1982–2010) (Figure 77). Fish condition, as measured by length-weight residuals, trended downward from 2019 to 2021 for multiple groundfish species, including benthic, pelagic, and apex predators (Figure 72), indicating poor feeding conditions across trophic niches. Conversely, juvenile pollock (100–250 mm) condition has trended upward since 2017, indicating positive bottom-up drivers. Additionally, based on results from the multispecies model CEATTLE (p. 136), juvenile pollock experienced improved top-down conditions through predation release (i.e., due to declining biomass of groundfish predators) (Figure 79).

Complete Recap of the 2020 Ecosystem State

Some ecosystem indicators are updated to the current year (2021), while others can only be updated to the previous year (or earlier) due to the nature of the data collected, sample processing, or modeling efforts. Therefore, some of the "new" updates in each Ecosystem Status Report reflect information from the previous year(s). Below is a complete summary of 2020 that includes information from both previous and current indicators.

During 2020, the vast majority of NOAA Fisheries surveys were canceled in the eastern and northern Bering Sea due to COVID-19 travel restrictions. 2020 was an on-year for the biennial NOAA ecosystem and acoustics surveys, in addition to annual trawl surveys. Therefore numerous contri-

butions of ecosystem information for this Report were unable to be updated last year. Due to these survey limitations, the interpretation of the ecosystem state bridged from basin-scale, satellite-derived indicators to local-scale community observations. While gaps existed, NOAA scientists, state/university partners, tribal governments, and coastal community members provided new and innovative contributions to inform our understanding of the ecosystem status. For example, coastal community members, tribal governments, and state/university partners provided all information on seabird dynamics in 2020 and the U.S. Fish and Wildlife Service biologists helped to synthesize the information and provide implications.

Following two years of physical oceanographic perturbations, the EBS experienced a return to near-normal climatic conditions in 2020. The winters of 2017/2018 and 2018/2019 had unprecedentedly low sea ice and reduced spatial extent of the cold pool, removing the thermal barrier between the southern and northern Bering Sea shelves. Distributional shifts in groundfish stocks were observed (e.g., more than 50% of the overall biomass of Pacific cod biomass occurred in the NBS in 2018). Ecosystem impacts in response to these conditions include changes in overall productivity and the potential for new trophic pathways.

Considerable cooling during winter 2019/2020 allowed for rapid build-up of sea ice, exceeding median ice extent in parts of February and March 2020. However, ice thickness was low, and retreated quickly in spring. Based on Bering 10K Regional Ocean Modeling System (ROMS) hindcast simulation, this ephemeral ice was estimated to be sufficient to form a cold pool of average spatial extent. After two years of little to no sea ice over the Bering Sea shelf, the near-normal ice extent observed in 2020 appeared to have only minimal mitigating effects on the warmth in the upper water column (i.e., sea surface temperatures). This vertical stratification of the water column is more typical of shelf conditions and affects predator/prey dynamics.

Above-average sea surface temperatures returned in spring 2020 and remained above average through summer 2020. Satellite-derived indicators of sea surface temperature (SST) facilitated examination of marine heatwave thresholds for the EBS. Heatwaves occurred during early years of the time series that begins in 1985, but the frequency and duration of heatwaves have increased dramatically, especially in the NBS, where residual heat and low sea ice extent has resulted in significantly increased cumulative annual thermal exposure since 2017.

Chlorophyll-a concentrations were lower in 2020 than 2019 in all regions except the southern outer domain. Chl-a concentrations over the southern inner and middle shelves had been below average since 2016. In the NBS, the concentrations over the inner and middle shelves were below average and the outer shelf was low and continued a decreasing trend since 2014. Primary producers provide fundamental energy and nutrients for zooplankton grazers and higher trophic level species; these trends indicate lower energy transfer to support the food web over the southern and northern Bering Sea shelves in 2020. The timing of the peak spring bloom in 2020 was earlier than the long-term average; for the southern inner and middle shelves it occurred about a week earlier. This contrasts with 2018 which was among the latest, while 2017 was among the earliest spring blooms. New information derived from the Continuous Plankton Recorder (p. 91) shows that the copepod community size and mesozooplankton biomass anomalies for 2020 were negative, where they had been positive in 2019. The mean diatom abundance anomaly was also negative in 2020. Such changes in abundance or biomass, together with size of the copepod community, influences the quantity and quality of prey available to predators. The coccolithophore bloom index was below average in 2018 and 2019 but increased, particularly on the middle shelf, in 2020. Coccolithophores may be a less desirable food source for microzooplankton in this region and smaller coccolithophores result in

longer trophic chains. The striking milky aquamarine color of the water during a coccolithophore bloom can also reduce foraging success for visual predators. Combined, these indicators of primary production suggest limited and/or poor quality of the prey base to support trophic energy transfer (e.g., juvenile fish, seabirds) in 2020.

The 2020 Togiak herring population was predominantly comprised of age-6 and age-7 fish (the 2013 and 2014 year classes). Oceanographic conditions over the southeastern Bering Sea shelf transitioned from below-average (i.e., cold) in 2013 to above-average (i.e., warm) in 2014. While the recruitment of age-4 fish to the spawning population in 2018 was still the largest estimated recruitment since 1982, the magnitude of that recruit class was estimated in the 2020-forecast model to be lower than was previously estimated. The incidental catch of herring in the 2020 directed pollock fishery was unusual because it occurred during a period of relatively high nominal CPUE values for pollock fishing and also was highest in the winter fishing A season. Several hypotheses were explored in the Noteworthy "Incidental Catch of Herring in Groundfish Fisheries Increased in 2020" in Siddon et al. (2020); the pollock fleet may have encountered high numbers of Togiak age-4 fish that provides partial explanation of the abrupt increase of incidental catch in 2020.

Commercial salmon harvests in 2020, based on preliminary data from ADF&G, indicated that statewide total harvests were below the preseason forecast, but nearing the 2018 total harvest. The 2020 Bristol Bay salmon inshore run was the 5th largest on record and 74.5% higher than the 1963–2019 average. A projected decrease in the number of pink salmon in 2020 may have had a positive impact on fish-eating seabirds (i.e., less competition for prey).

In 2020, at the Pribilof Islands, seabird attendance appeared similar to that in recent years while breeding observations suggested it was an average, to slightly below average, year for most fish-eating species (e.g., kittiwakes, murres). Planktivorous species (i.e., auklets) had been declining and continued to be low in 2020, at least at St. Paul Island. Warmer water temperatures from 2014–2019 seem to have negatively affected least auklets, and likely parakeet auklets. In the NBS, on St. Lawrence Island, reproductive success and colony attendance differed among fish-eating and planktivorous seabirds suggesting foraging impacts differed across trophic levels. In the Bering Strait region, emaciation and starvation were observed in some seabirds throughout the summer and beach-cast carcasses of several species of seabirds were observed on the eastern and western sides of the Bering Strait.

Seabird bycatch estimates from the groundfish fisheries (p. 196) decreased 52% from 2019 to 2020. While a reduction in seabird bycatch in the Federal fisheries off Alaska is positive, several events occurred during the 2020 fishing seasons which may partially explain this reduction: (i) the COVID-19 pandemic disrupted normal fishing operations throughout Federal Fisheries, including lost fishing days; (ii) an expansion of the fleet over space (i.e., into the NBS), and (iii) reductions in catch over time (e.g., from 247,000 t in 2016 to ~150,000 t in 2020). Additionally, the first reported interaction between a fishing vessel from the BSAI groundfish fishery with threatened spectacled eider may be a direct result of ecological change in the EBS. Recent changes in ocean temperatures and the resulting ecological response of commercially valuable fish species, mainly Pacific cod, has led to an increase in the amount of fishing vessel traffic in areas near spectacled eider designated critical habitat.

Direct and indirect indicators of groundfish recruitment success provided information on the status of 2020 year classes. The 2020 springtime drift pattern was mixed, indicating larvae (e.g., age-0 pollock) may have been retained over the southern middle shelf. However, lower primary production in spring 2020 may have limited the prey base to support trophic energy transfer to large, lipid-rich copepod taxa. The abundance of large copepods is positively correlated with the recruitment success of pollock. Years of low recruitment for pollock portend lower rates of cannibalism as adult pollock biomasses decreases. The climate-enhanced multispecies model (CEATTLE) estimates of age-1 predation mortality for pollock was at the long-term mean in 2020 as declines in total predator biomass are contributing to reduced predation rates and mortality.

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Ecosystem Indicators

Noteworthy Topics

Here we present items that are new or noteworthy and of potential interest to fisheries managers.

Adult Salmon Run Failures Throughout the Arctic-Yukon-Kuskokwim Region

The Arctic-Yukon-Kuskokwim (AYK) Region experienced unprecedented salmon run failures during the 2021 season. Chinook, chum, and coho salmon runs were extremely weak throughout the entire region (Figures 2, 3, and 4). The 2021 Yukon River salmon season was particularly dire due to concurrent record low run sizes of Chinook, summer chum, fall chum, and coho salmon. For the first time since statehood, all Yukon River salmon directed gillnet fisheries were closed for the entire season, leading to extreme food security and social, cultural, and economic hardships. Even with fishery closures, it is unlikely that the Yukon River salmon run sizes were adequate to meet minimum spawning escapement goals or U.S./Canada Treaty objectives. Fishery restrictions were also required throughout the Kuskokwim and Norton Sound Management Areas, but the situation was mitigated somewhat by Chinook and coho salmon runs within historical ranges and adequate abundances of other salmon species to allow for limited harvest opportunities.

The record low chum salmon runs are of particular concern because chum salmon are the most abundant salmon species returning to the AYK Region and are a critical subsistence, personal use, and commercial resource. Historically, AYK chum salmon have shown resilience and the ability to bounce back from years of low run abundance. Since the mid-2000's, AYK chum salmon runs have been healthy, characterized by several years of record large run sizes, sustainable fisheries, and consecutive years of meeting or exceeding escapement objectives. Failure of age-4 chum salmon returning to AYK rivers in 2020 forewarned the multiple age-class failure that was observed in 2021. The potential for continued low chum salmon abundance over the coming years should not be overlooked given the changing marine conditions, unprecedented low escapements in 2021, generally low escapements in 2020, and numerous pre-spawn mortality events documented in 2019.

The cause of poor Chinook, chum, and coho salmon runs throughout the AYK Region are not known, but prevailing hypotheses are focused on sub-optimal conditions for growth and survival in the marine environment. AYK salmon species display a wide range of life history strategies and residency times in freshwater and marine environments (Figure 5). The number of spawners

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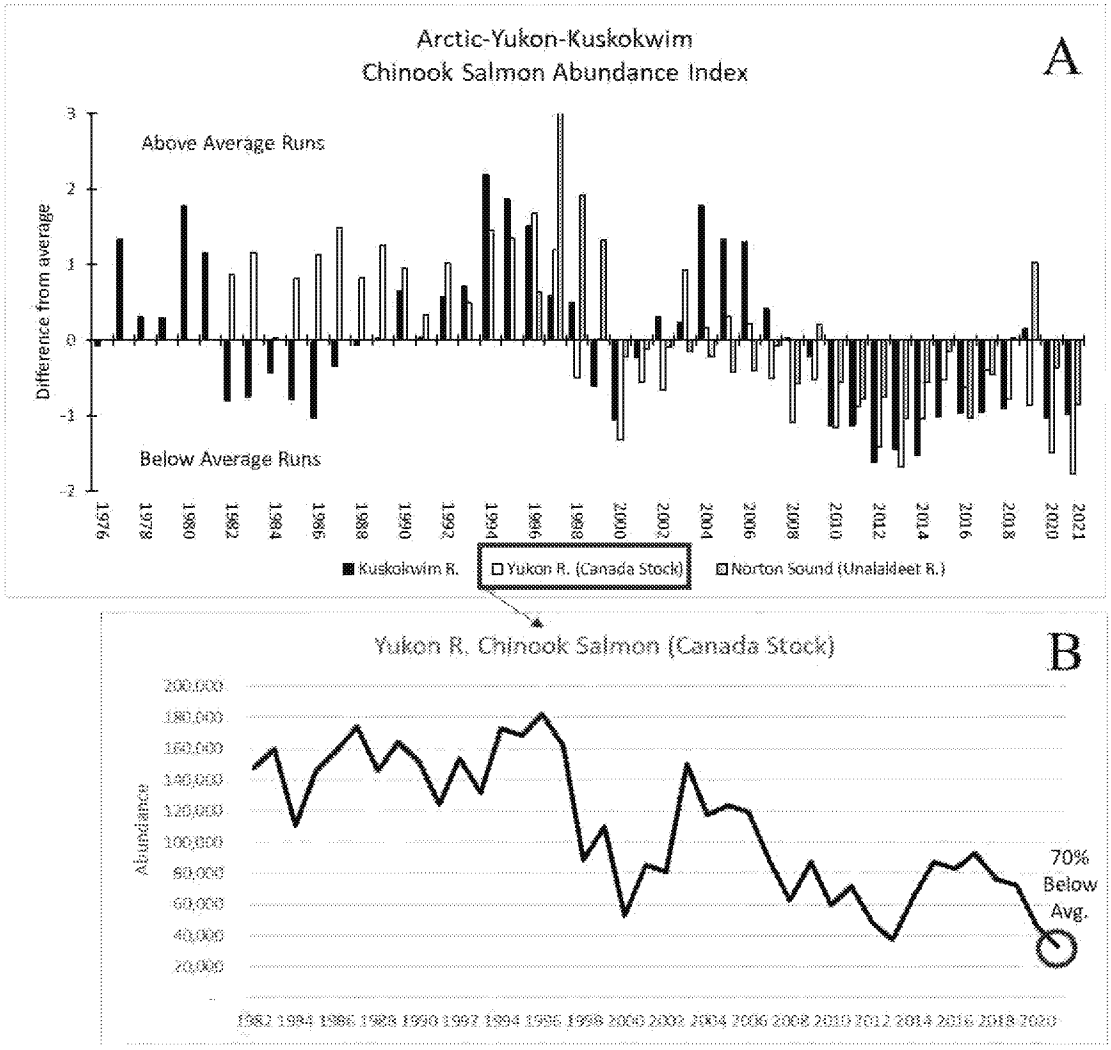

Figure 2: Relative changes in Chinook salmon adult run abundance throughout the Arctic-Yukon-Kuskokwim Region based on three indicator stocks (A), with a focus on the Canadian-origin Yukon River stock (B).

that contributed to the 2021 AYK Chinook, chum, and coho salmon runs were generally within or exceeded escapement goals, and there are no known freshwater environmental factors that easily explain the concurrent poor returns observed in 2021. AYK salmon age and size trends lend some support for marine influences. AYK Chinook salmon have trended towards earlier age-at-maturation and smaller sizes-at-age (e.g., Lewis et al. (2015) and Ohlberger et al. (2018)) and that pattern was again observed in preliminary 2021 data. Yukon River chum salmon and Yukon and Norton Sound coho salmon displayed record low body size, at age, in 2021, suggesting poor growth conditions in the marine environment.

An additional concern for Yukon River Chinook salmon has emerged with the resurgence of ichthyophonus disease after many years of low prevalence. Infection occurs via diet consumed during the marine life stage, and the disease progresses during the adult in-river migration. In 2020

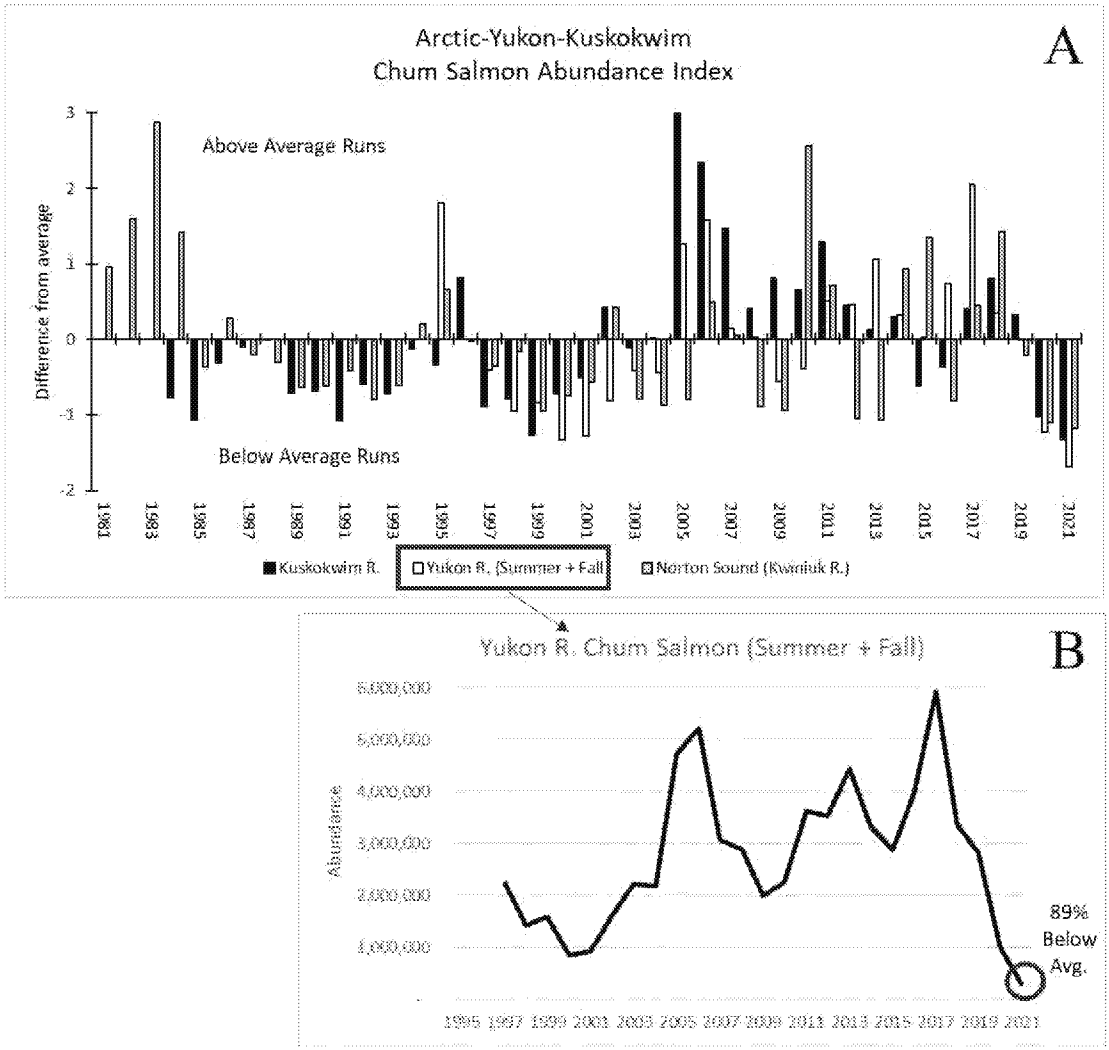

Figure 3: Relative changes in chum salmon adult run abundance throughout the Arctic-Yukon-Kuskokwim Region based on three indicator stocks (A), with a focus on the Yukon River stocks (B).

and 2021, the prevalence of ichthyophonus appears to be near record high levels (based on opportunistic and limited sampling) with currently unknown implications for in-river survival, migration, and spawning success.

The Alaska Department of Fish & Game is addressing the declining salmon runs across the AYK Region through a wide range of applied research initiatives. Efforts include adult salmon tagging programs, increased escapement monitoring, improvements to salmon forecast and total run estimation methods, investigations into the impact of ichthyophonus disease on adult pre-spawn mortality, and expanding the capacity of marine research programs to identify factors that may be affecting the productivity of AYK salmon. Long-term research prioritization and inter-agency collaboration will likely be required to address the needs of salmon fishery management agencies in a changing environment.

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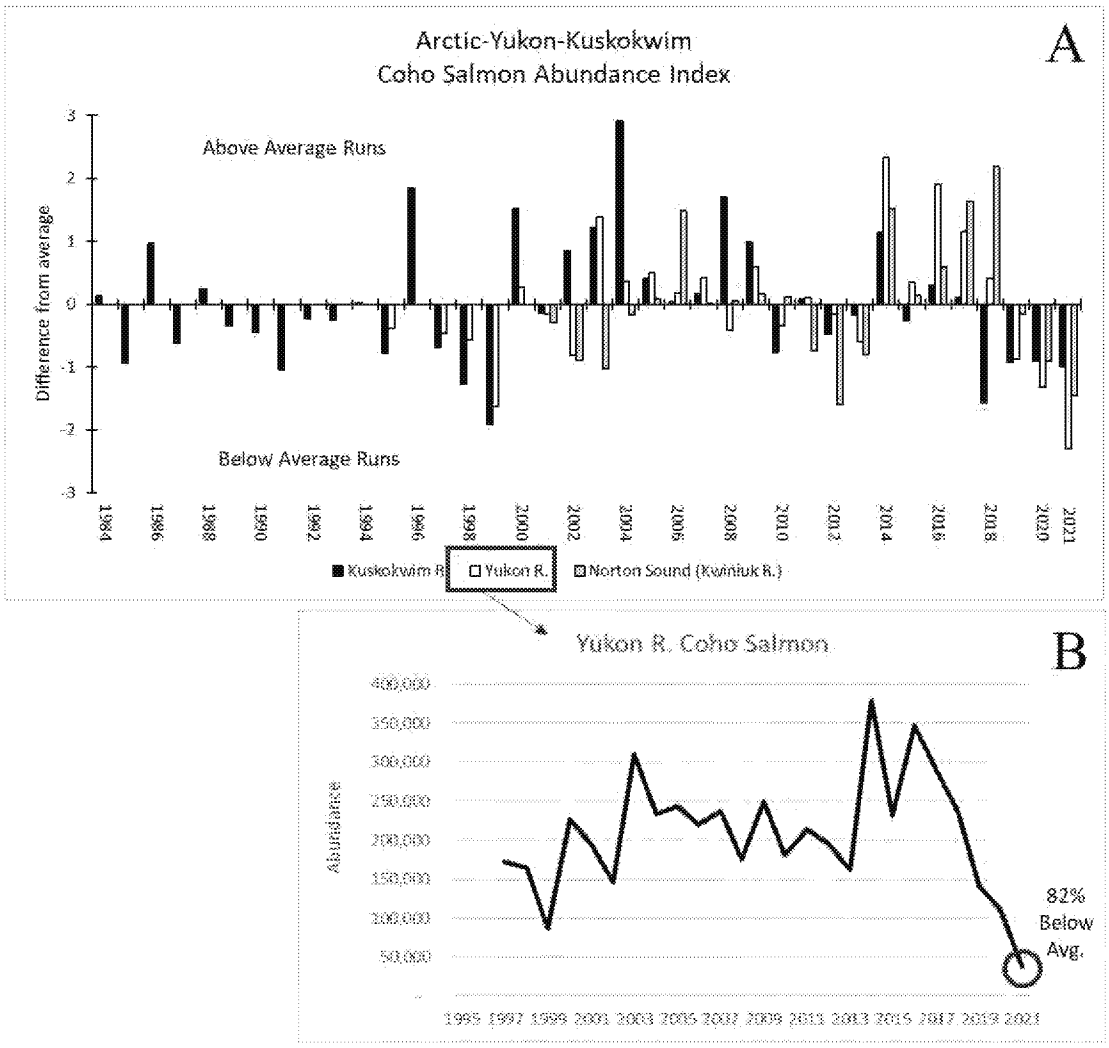

Figure 4: Relative changes in coho salmon adult run abundance throughout the Arctic-Yukon-Kuskokwim Region based on three indicator stocks (A), with a focus on the Yukon River stock (B).

Contributed by
Zachary W. Liller
Alaska Department of Fish & Game
Arctic-Yukon-Kuskokwim Region
Division of Commercial Fisheries

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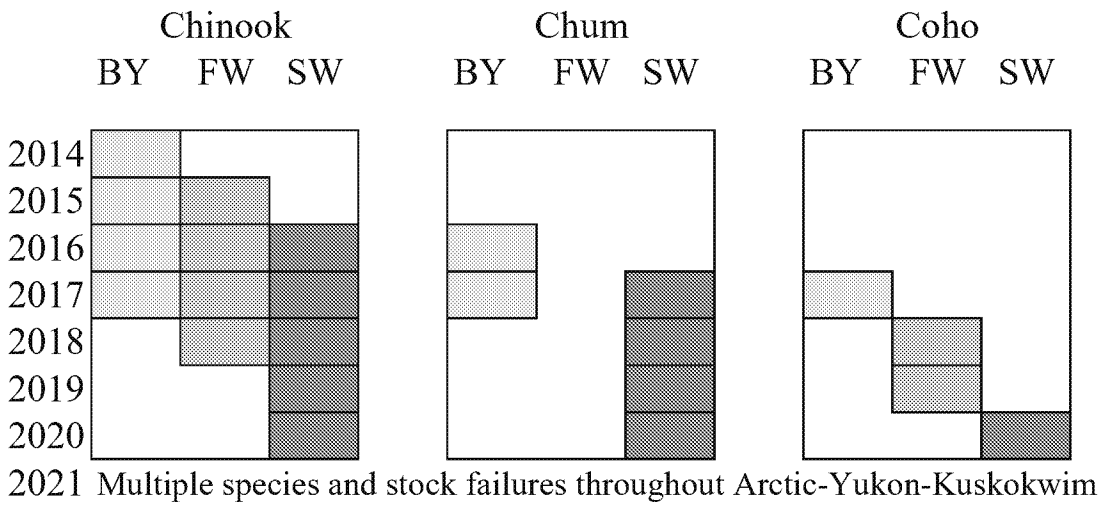

Note:
Figure 5: Common life history strategies displayed by Arctic-Yukon-Kuskokwim Region Chinook, chum, and coho salmon. Shaded boxes highlight the years during which salmon returning in 2021 were subject to freshwater and marine environments. **Note:** The 2021 salmon runs to AYK were impacted by environmental conditions experienced during the brood year (BY) spawning, freshwater (FW) rearing, and marine (SW) growth phases. AYK Chinook salmon typically spend 1 year in FW and 2–5 years in SW. Chum salmon out-migrate immediately after emergence and typically spend 3–4 years in the marine environment. Coho salmon typically spend 2 years in FW and 1 in SW.

The 2021 salmon runs to AYK were impacted by environmental conditions experienced during the br
spawning, freshwater (FW) rearing, and marine (SW) growth phases. AYK Chinook salmon typically
FW and 2-5 years in SW. Chum salmon out-migrate immediately after emergence and typically spend
marine environment. Coho salmon typically spend 2 years in FW and 1 in SW.

Getting to the Bottom of it: an Exploration of ROMS Bottom Temperatures

The Bering Sea ROMS model (Bering10K) originated as a subdomain of the larger Northeast Pacific ROMS model (NEP5) approximately a decade ago. Since that time, several peer-reviewed publications have documented its subsequent development along with quantitative and qualitative validation of the model's performance against physical and biogeochemical observations from the region. First, we highlight several of these publications that focus on various aspects of the coupled ocean-ice-biogeochemical model complex.

Because sea ice dynamics play such a key role in biophysical processes in this region, successful simulation of sea ice advance and retreat, and the interannual variations in both timing and magnitude of sea ice processes, were a necessary precursor for a regional model to be useful in the Bering Sea region. Danielson et al. (2011) discusses the performance of a 35-year hindcast simulation of the NEP5 model, focusing on modes of variability within the ocean and sea ice modules. While this paper predates the Bering10K model, many of its skill metrics, especially those demonstrating successful simulation of currents, stratification, tidal harmonics, and sea ice concentration, are applicable to the smaller Bering Sea domain as well.

Hermann et al. (2013) is the first paper to focus specifically on the Bering10K model. Model validation focused on climatological circulation patterns compared to *in situ* drifters, as well as water column hydrography (seasonal and interannual patterns in stratification, mixed layer depth, temperature, etc.) compared to long-term moorings located in the middle shelf region.

Biogeochemistry within the Bering10K model is currently simulated using the custom BESTNPZ model (Gibson and Spitz, 2011). Kearney et al. (2020) provides an in-depth evaluation of biophysical and biological metrics related to the implementation of this model within the three-dimensional Bering10K model. This includes a quantitative comparison of cold pool extent within the model compared to measurements from the annual groundfish survey. We also revisit many of the earlier validation metrics related to sea ice extent, mixed layer depth, stratification, and currents, and compare simulated primary production with both satellite-derived and *in situ* measurements. This paper also includes a history of the updates that were made to the coupled regional model over its 10-year history.

Finally, Kearney (2021) provides a more in-depth look at how the simulated surface and bottom temperatures within the Bering10K model compare to the data collected from the annual continental shelf groundfish survey over its 40-year history. This technical report expands upon the details underlying the cold pool validation metrics presented in Kearney et al. (2020), and presents several maps of skill metrics (such as bias, correlation, RMSE, etc.) for both bottom and surface temperature across the southeastern and northern shelf regions.

Next, we present several comparative examples of satellite-derived sea surface temperature and ROMS bottom temperature data that facilitate examination of spatial (i.e., vertical differences) and temporal (i.e., phenological) impacts of temperature dynamics between surface and bottom waters on organisms in the eastern Bering Sea.

Spatial patterns are evident when looking across depth-defined strata (i.e., inner vs. middle/outer shelf) (Figure 6). The left hand panels show temperature variability in the inner domain (10–50m) while the right hand panels show variability in the middle/outer domain (50–200m). The impact of mixing in the inner domain results in bottom waters having larger swings in temperature, whereas

stronger stratification in the middle/outer domain leads to more stable bottom water temperatures.

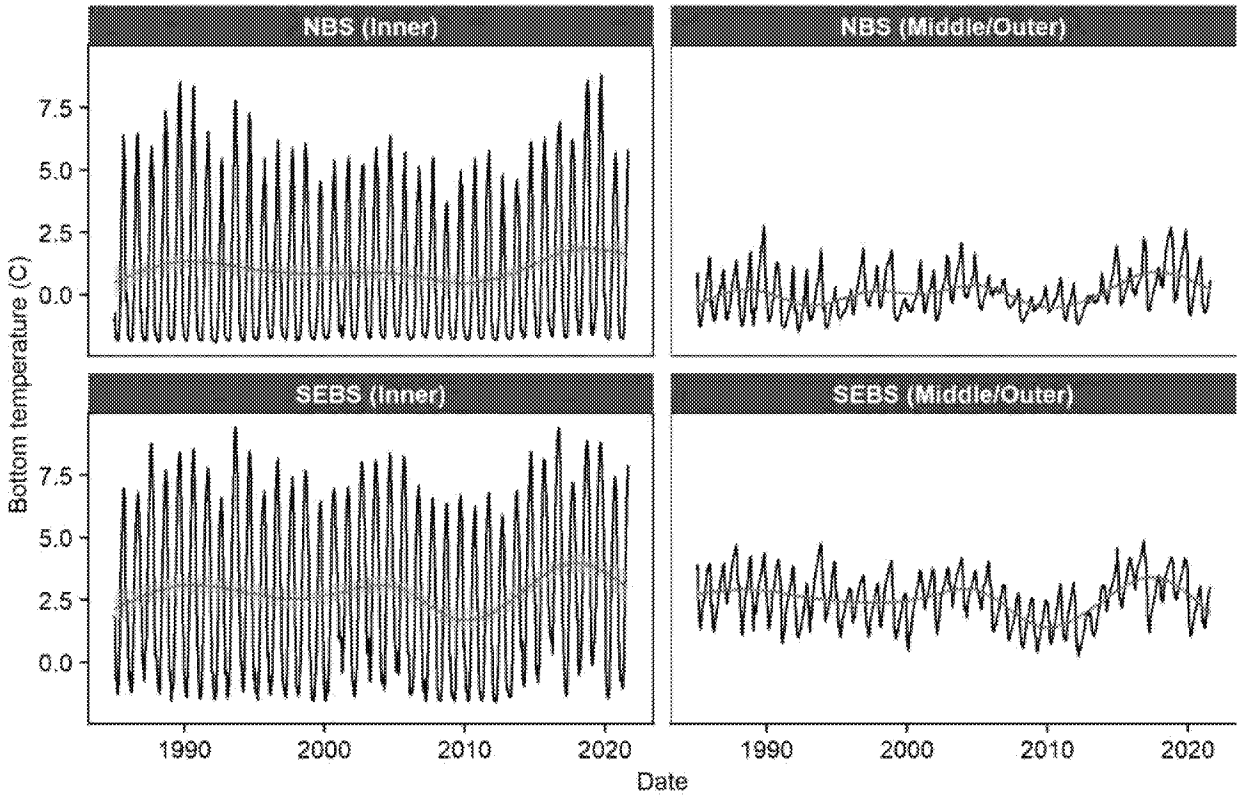

Figure 6: ROMS bottom temperatures averaged within depth-defined strata for the Northern and Southeastern Bering Sea regions.

Temporal patterns (within and across years) of water temperature dynamics have impacts on individual species' phenological responses and subsequent match/mismatch patterns. In Figure 7, the bottom panel shows warm waters persisted at depth through fall 2019 whereas surface waters were relatively cooler. Both surface and bottom temperatures were closer to the long-term mean in 2021.

Figure 8 highlights a potentially phenologically important trigger for organisms' early life history development as well as horizontal and vertical distributions. The relative timing each year when the surface water temperature drops below bottom water temperature has varied over the time series, with greater variability in the inner domain than in the middle/outer domains.

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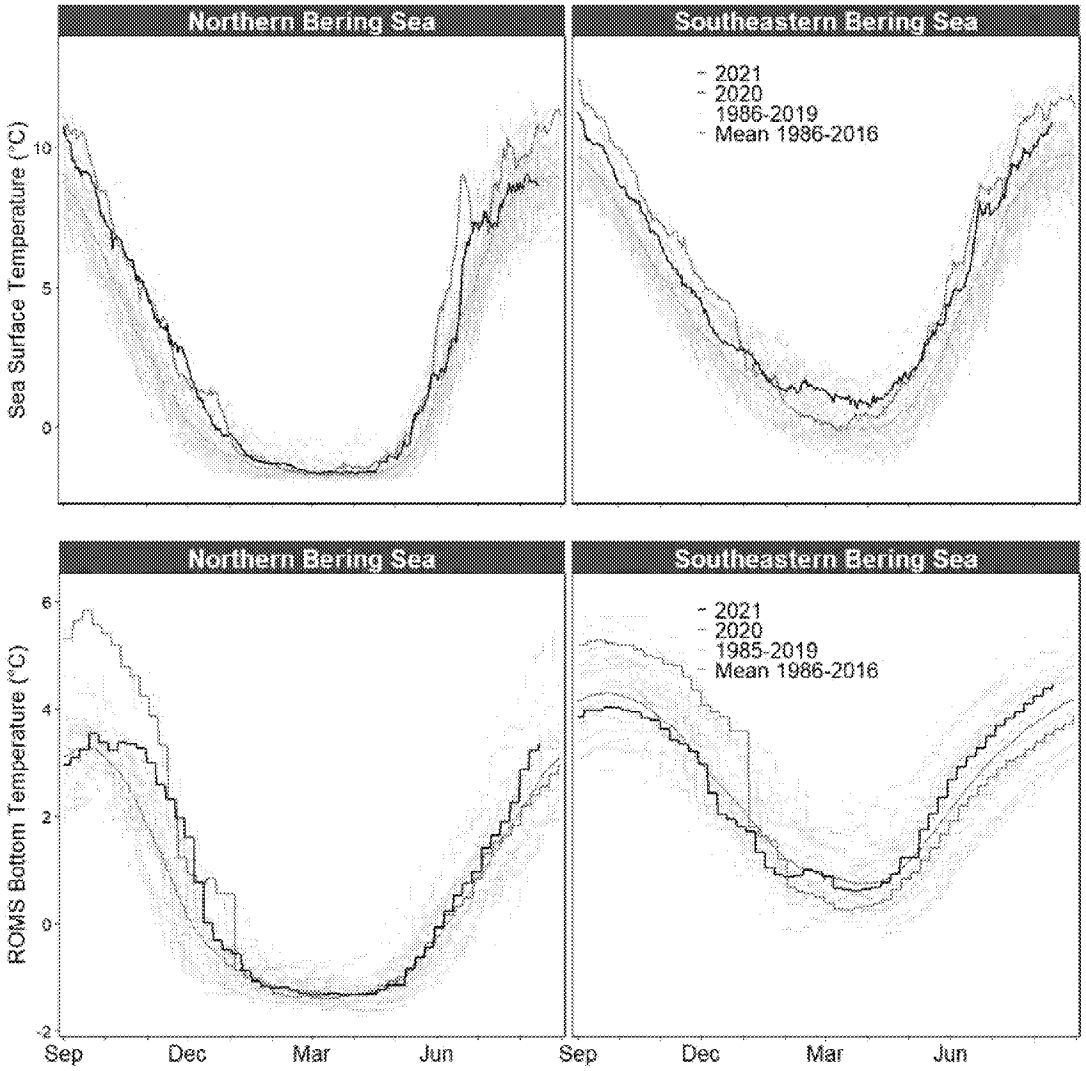

Figure 7: Phenology of SST (satellite-derived, source: Coral Reef Watch) and bottom temperature (derived from ROMS) in the northern and southeastern Bering Sea. Years are plotted Sept–Aug with Sept–Dec appended to the subsequent year. Frequency of data is daily for SST and weekly for ROMS. Depths are filtered to between 10–200m. **Note** different y-axis scales for SST and bottom temperatures.

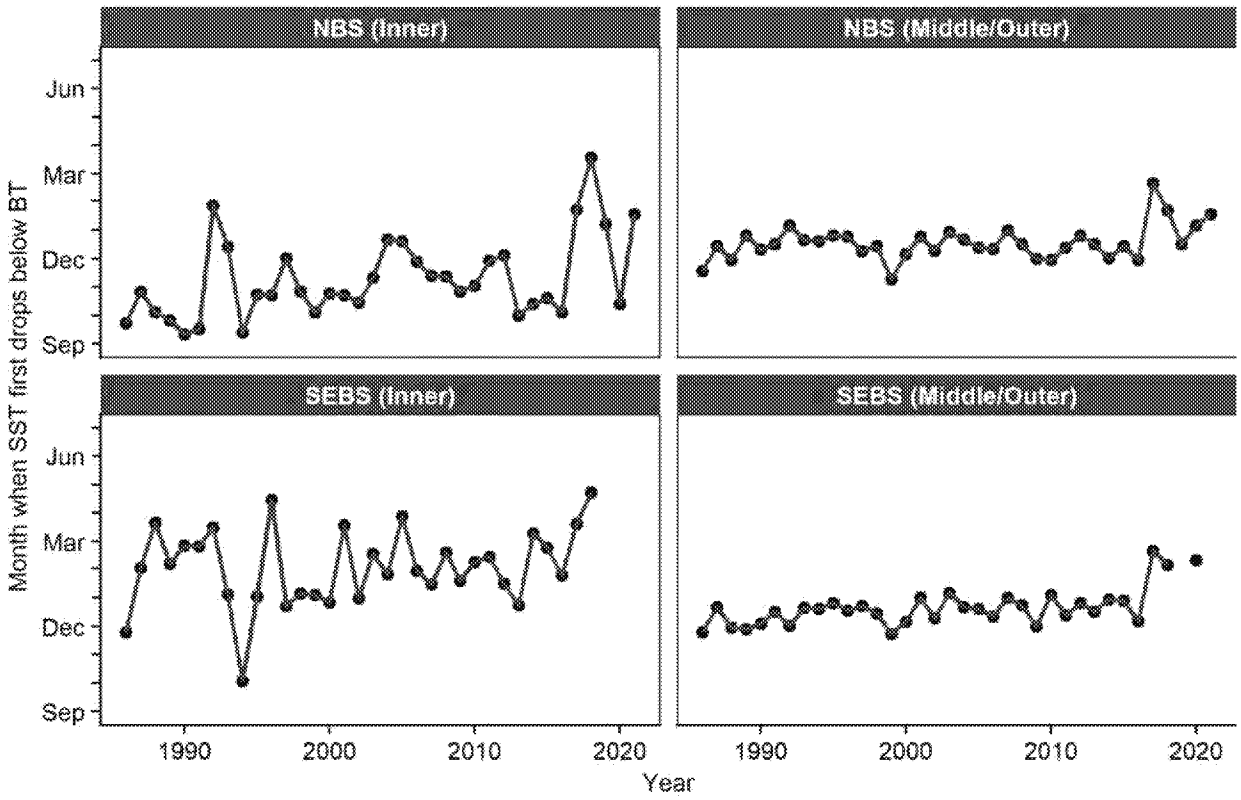

Figure 8: Relative timing within each year during which the average regional surface temperatures dropped below the bottom temperatures. Years are plotted Sept–Aug with Sept–Dec appended to the subsequent year. Missing values in 2019–2021 in SEBS regions demonstrate that the surface temperature never dropped below the bottom temperature in that year.

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Ice seal Unusual Mortality Event: an update

On September 12, 2019, NOAA Fisheries declared an Unusual Mortality Event (UME) for three species of ice seals in Arctic waters of Alaska. This declaration resulted from elevated numbers of dead bearded, ringed, and spotted seals on Alaska shores, which were reported, beginning in June 2018, from Kotlik in the northern Bering Sea to Utqiaġvik in the northern Chukchi Sea. The UME investigation continued in 2020 through 2021.

Prior to the 2019 ice seal UME declaration, strandings during 2010–2017 averaged 29 ice seals annually. For the next four years, confirmed strandings included 111 ice seals (June 1–December 31, 2018), 164 seals (2019), 34 seals (2020), and 41 seals (2021) (Table 1, Figure 9). These bearded, ringed, spotted, and unidentified stranded seals were confirmed from dedicated surveys and opportunistic sightings.

Table 1: Confirmed ice seal strandings related to the UME in the Bering and Chukchi seas.

Year	Bearded	Ringed	Spotted	Unidentified	Total
2010–2017 Average					29
2018[a]	35	29	20	27	111
2019	50	35	26	53	164
2020	9	7	7	11	34
2021	10	20	7	4	41
TOTAL[b]	104	91	60	95	350

[a] 1 June–31 December 2018
[b] 1 June 2018–8 October 2021

The reports from 2018–2019 indicated several seals were emaciated at the time of death. Stranding reports for seals from 2020–2021, however, did not identify emaciation as a factor in the seals' condition. Most photographs and reports identified the 2020–2021 stranded seals as healthy and robust.

In 2020, strandings in June (15 seals) were at the same level as in July and August (16 seals). In 2021, there were fewer strandings during June (14 seals), than in July and August (68 seals). Of note, photos and/or skin samples confirmed only 50% of stranding reports in 2020 and 47% of the stranding reports during 2021.

The ongoing COVID-19 pandemic severely limited NOAA's ability to travel to collect tissue samples, morphometric data, and/or conduct surveys during 2020–2021. Coastal residents were essential for the documentation and reporting of strandings while conducting their normal daily activities (ATV, boating, and walking). However, because of the remote locations, decomposition of the stranded seals, and a lack of traveling biologists/veterinarians, sampling and full necropsies of ice seals remained uncommon.

The increased mortality of seals reported during 2018–2019 coincided with the dramatic reduction in the extent, quality, and duration of sea ice habitat for pupping and nursing in the northern Bering Sea during both years (Boveng et al., 2020). The increased mortality of young seals during June 2018–2019 could also indicate impacts from the effects of a transitioning ecosystem, such as competition for prey. In a study by the Alaska Fisheries Science Center, spotted seal pups

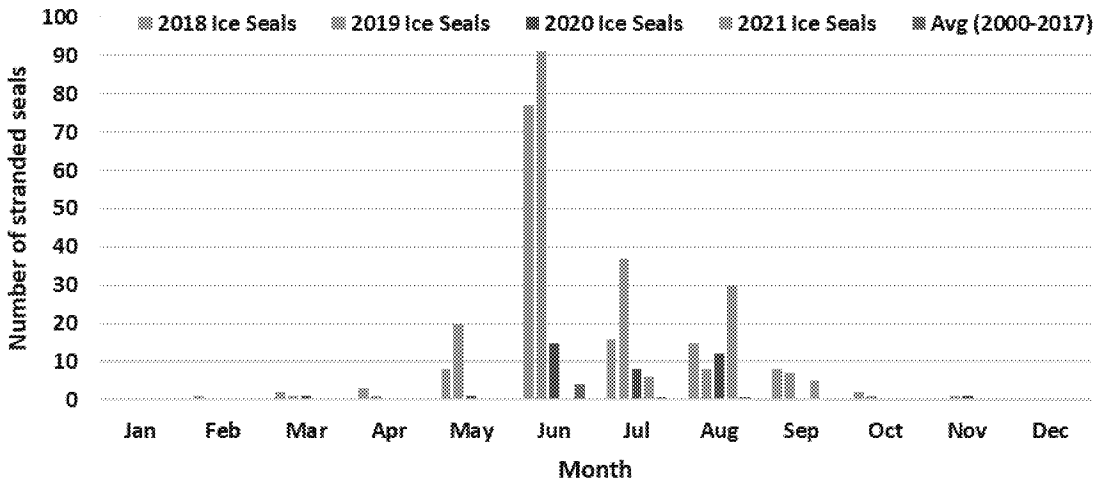

Figure 9: Number of confirmed ice seal strandings in Alaska by month.

and ribbon seals[4] of all age classes declined in body condition over a longer period (2007–2018), coincident with a decline in Bering Sea ice extent, quality, and duration (Boveng et al., 2020). The ice seal UME of 2018–2019 may therefore reflect an ecological shock from those two extreme years superimposed on a longer-term trend.

Contributed by
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[4]Ribbon seals were not among the identified strandings in the UME, but they typically are reported in much lower numbers than bearded, ringed, and spotted seals, likely due to their smaller population and more offshore habits.

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Ecosystem Status Indicators

Indicators presented in this section are intended to provide detailed information and updates on the status and trends of ecosystem components. Older contributions that have not been updated are excluded from this edition of the report. Please see archived versions available at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Physical Environment Synthesis

This synthesis section provides an overview of physical oceanographic variables and contains contributions from (in alphabetical order):

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Last updated: October 2021

Executive Statement

Beginning in approximately 2014, the eastern Bering Sea (EBS) entered a warm phase of unprecedented duration. As of August 31st, 2021, the EBS remained in this warm phase, though to a lesser degree compared to the extreme warm years of 2018 and 2019. Satellite observations of sea surface temperature remain in excess of one standard deviation above the long term average for much of the past year. These warm – but not extreme – conditions are mirrored in *in situ* observations of sea level air temperature and bottom temperature. Compared to normal conditions, the cold pool remains significantly reduced in area, and its southern boundary is shifted significantly northwestward. Sea ice formation in fall of 2020 was delayed due to residual warmth in the system, which has become the 'new normal' in this protracted warm phase. While the areal extent was closer to the pre-2014 levels than at any point in the last 7 years, ice thickness differed between the northern (thicker ice) and southern (thinner/no ice) shelves due to opposing prevailing winds.

Synthesis Summary

Along with much of the North Pacific, the EBS entered a continuous warm phase beginning in 2014 that, to present, has not subsided. Saint Paul Island has been the site of continuous air temperature records since 1920, and the intensity (2–6°C above average) and duration of the current warm phase is unmatched over the >100 year record (Figure 25). These trends are reflected in sea surface temperature (SST) observations from the NOAA Coral Reef Watch Program dating back to 1985. From 2014 onward, SSTs in both the northern and southern EBS have remained much higher than the average from 1985–2014 (Figure 28). However, after the extremely warm years of 2018 and 2019 (e.g., SST anomalies in the northern Bering Sea [NBS] of 2°C above average), conditions in 2020 and 2021 subsided to ~1°C above average (Figure 28). From February–April, 2021, SST was normal in the NBS (<-1°C), but above average (by ~1°C) outside those months, while in the southeastern Bering Sea, 2021 temperatures were about 1°C warmer than average throughout the entire year (Figure 27).

The current warm phase is also present at depth. Bottom trawl surveys conducted over the Bering Sea shelf show elevated temperature after 2014 (Figure 35). Although no survey data were collected in 2020, the 2021 data show that the bottom temperature anomaly was only ~0.5°C above normal in 2021, while in 2018 and 2019, these anomalies reached nearly +2°C (Figure 35). Longline surveys conducted every other year since 2009 along the shelf break (250–500m) indicate the temperature anomaly there was 0.10°C above average in 2021, which is lower than the 0.30°C and 0.15°C anomalies reached during the 2017 and 2019 surveys, respectively (Figure 40). These anomaly values may actually be higher, since the record only goes back to 2009 (impacting the short period-of-record average).

The area of the cold pool (bottom water <2°C) estimated from the bottom trawl survey in 2021 was 58,975 km^2, which is well below one standard deviation from average, yet significantly higher than the years of 2018 (~10,000 km^2) and 2019 (~35,000 km^2) (See Figure 1). The 2021 cold pool comprised ~10% of the total survey area, significantly less than the ~20–70% frequently found prior to 2018 (Figure 36). The southern boundary remains shifted significantly northwestward (59°N) from years prior to 2018. Regional Ocean Modeling System (ROMS) hindcast simulations corroborate the *in situ* trawling data, finding that bottom temperature in 2021 (3.30°C) was about 0.5°C warmer than the average from 1970–2020 (2.79°C) (Figure 38).

The extended warm phase in the EBS has also impacted ice formation and areal extent. Following the pattern of many years after 2014, the sea ice extent in the Bering Sea between October 15–December 15, 2020 was under $6x10^4$ km^2, approximately half the long term average (Figure 11).

Daily sea ice extent remained below average throughout virtually the entire sea-ice season, though later in the season extent recovered to a level typical of the "low ice" years of the early 2000s (Figure 13).

Reversing recent trends, the ice thickness in much of the NBS was substantially higher in March, 2021, than in the previous several years (Figure 15, a–d). A driving factor may be the origin of the prevailing wintertime winds. During February 2018 and 2019 there were extremely strong southerly winds over the entire Bering Sea, advecting heat from the south, which likely inhibited ice formation (Figure 19) throughout the region. In February, 2020, moderate northerly winds prevailed (advecting cold polar air from high latitudes). Interestingly, in February 2021, these northerly winds intensified over the northern portion of the shelf and likely contributed to the stability and thickness of sea ice in the north, while southerly winds prevailed over the southern portion of the shelf and likely inhibited ice formation in the south (Figure 20).

Introduction

In this section, we provide an overview of the physical oceanographic conditions impacting the EBS, describe conditions observed during 2021, and place 2021 in context to recent years. The physical environment has implications for ecosystem dynamics and productivity important to fisheries within the system and their management. We merge across information sources, from broad-scale to local-scale, as follows:

Outline

1. Climate Overview
2. Regional Highlights
3. Sea Ice
4. Winds and Ocean Currents
5. Surface and Bottom Temperatures
6. Seasonal Projections of SST from the National Multi-Model Ensemble (NMME)

1. Climate Overview

Contributed by Nick Bond, *nicholas.bond@noaa.gov*

Climate indices provide a means of characterizing the state of the North Pacific atmosphere-ocean system. Five commonly used indices are presented here: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, PDO index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO), and Arctic Oscillation (AO). The time series of these indices, with the application of three-month running means, from 2011 into spring/summer 2021 are plotted in Figure 10. Two indices, the NPI and the AO, best represent conditions impacting the EBS shelf and are described in more detail below.

The state of the Aleutian low is often summarized in terms of the NPI, with negative (positive) values signifying relatively low (high) SLP. Following a near-neutral state in fall 2020, the NPI was strongly positive during the winter of 2020–2021 before returning to an average of near-neutral

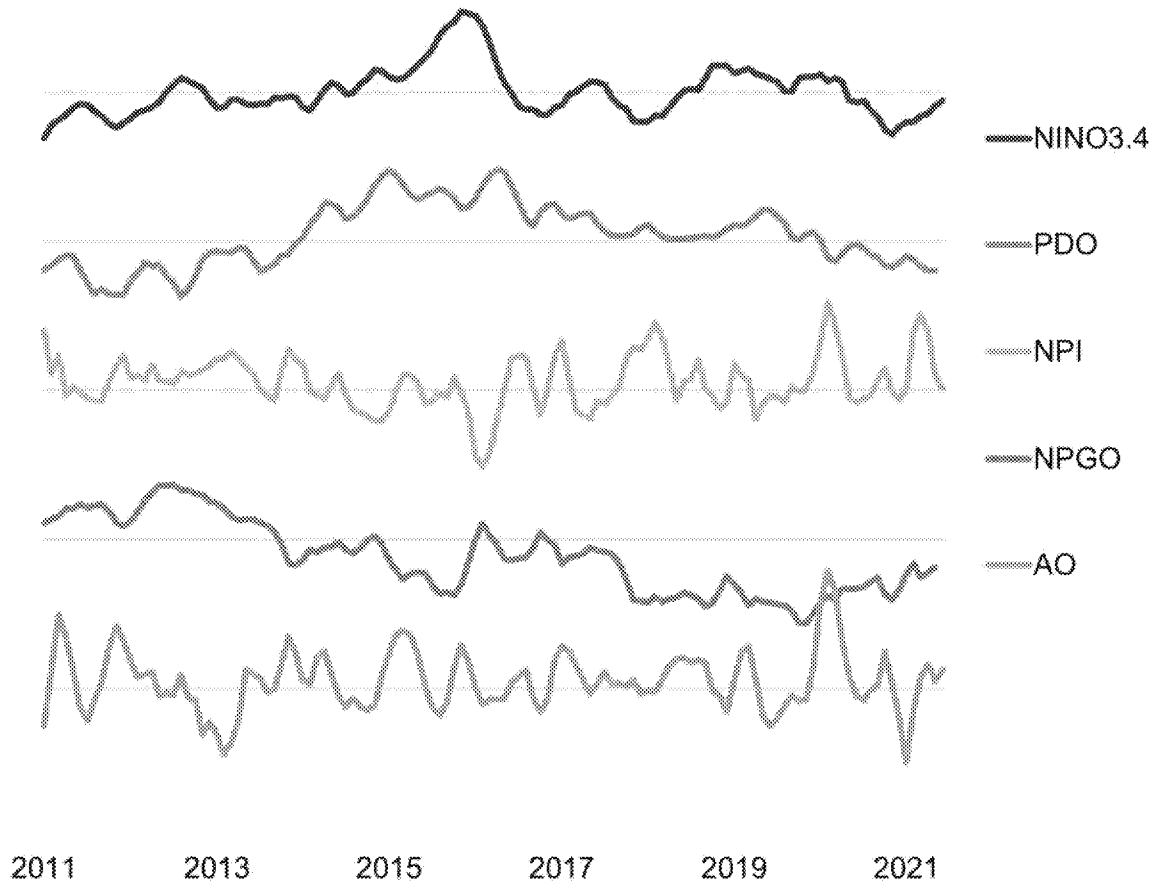

Figure 10: Time series of the NINO3.4, PDO, NPI, NPGO, and AO indices (ordered from top to bottom) for 2011–2021. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Physical Sciences Laboratory at `https://psl.noaa.gov/data/climateindices/`.

again in summer 2021. The NPI has been positive during 4 out of the last 5 winters; this aspect of the atmospheric forcing of the North Pacific helps account for the overall decline in the PDO over the interval.

The AO represents a measure of the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the North Pacific at a latitude of roughly 45°N. The AO switched from strongly positive early in 2020 to temporarily negative during the winter of 2020–2021, followed by mostly positive values in spring and summer 2021 with considerable month-to-month variability.

2. Regional Highlights

Contributed by Nick Bond, *nicholas.bond@noaa.gov*

Summary

The North Pacific atmosphere-ocean climate system during autumn 2020 through summer 2021 featured generally higher than normal sea level pressure (SLP) across a broad band between roughly 25° and 50°N and lower than normal SLP from eastern Siberia into the southern Chukchi Sea. The region of positive SLP anomalies in the middle latitudes of the North Pacific generally corresponded with positive sea surface temperature (SST) anomalies. This high pressure, particularly during the winter of 2020–2021, meant that the Aleutian Low was weaker than normal, which is consistent with the moderate La Niña that was co-occurring in the tropical Pacific. The PDO was negative during the period of interest here, in large part due to the persistent positive SST anomalies in the western and central North Pacific. The climate models used for seasonal weather predictions are indicating elevated odds of La Niña conditions re-developing in the latter part of 2021. These models as a group are indicating SST distributions in early 2022 that include colder than normal temperatures for the Gulf of Alaska and near-normal temperatures for the Aleutian Islands and EBS. For the latter region, sea ice is expected to extend south over the shelf to at least 60°N.

Alaska Peninsula

Positive SST anomalies were present in this region during the latter portion of 2020, especially on the Bering Sea side. The weather early during the winter of 2020–2021 was warmer than normal, followed by cooler air temperatures in late winter and early spring 2021. The late summer of 2021 included some cool and occasionally stormy weather accompanied by upper ocean temperatures that were warm on the north side of the peninsula and near normal on the south side.

Aleutian Islands

The winter of 2020–2021 was stormy for the Aleutian Islands. Anomalous winds from the west were associated with suppressed poleward flow through Unimak Pass. A relatively calm period followed during the spring of 2021. Near normal values of SST prevailed in this region from late 2020 through the spring of 2021, with warming during the following summer.

Eastern Bering Sea

The EBS shelf was quite warm in the autumn 2020, and experienced a late arrival of sea ice. The following winter of 2020–2021 included wind anomalies from the northeast and initially warm air temperatures, with a cooler period in late winter. This winter along with the previous winter of 2019–2020 featured much cooler weather than those of the previous four years. One result was the development of considerable ice north of 60°N; the southern part of the southeast Bering shelf had a light ice year. The summer of 2021 appears to have been somewhat stormy with the wind mixing perhaps resulting in nutrient fluxes and ultimately bursts of primary production after the spring bloom.

Bering Sea Deep Basin

The western, deep portion of the Bering Sea transitioned from warmer than normal (0.5 to 1°C) SSTs in the latter part of 2020 to near normal temperatures during the first half of 2021. Warm anomalies developed in the western portion of this region in summer 2021. Similar to the EBS shelf, its northern portion experienced a relatively stormy summer in 2021.

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Arctic
The Arctic region of northern Alaska is undergoing rapid warming in association with global climate change, and the period of fall 2020 through summer 2021 was no exception. The ice cover during the summer of 2021 was low relative to historical norms, but not nearly to the extent of the record-setting year of 2012. The decline in ice extent during August 2021 was less than usual due to persistent low SLP, and cool air temperatures, over the Beaufort Sea. The ice edge in the Chukchi and Beaufort Seas during late summer 2021 was not that far from its median position for the period of 1981–2010, but the pack north of this edge had ice of unusually low concentration and it is possible that the greater proportion of open water will tend to slow the freezing during the fall of 2021.

3. Sea Ice

Contributed by Rick Thoman, *rthoman@alaska.edu*
Early Season Ice Extent
While mean annual ice extent in the Bering Sea (both eastern and western) has shown no significant trend until recently, this is not the case for early season ice. The presence or absence of early sea ice in the Bering Sea is important because, at least during the passive microwave era, nearly all ice in the Bering Sea is first year ice, therefore Bering Sea ice thickness is related to both the air temperature and the age of the ice.

Trends
The mean daily extent for the two months from October 15 through December 15 shows considerable interannual variability, but with a strong negative linear trend during the past 40 years (Figure 11). This trend was robust even prior to the two recent low ice seasons and is a realization of delayed ice formation due to residual warmth in the system. Fall 2020 ice extent continued the post-2012 pattern of very late development of sea ice. Overall, this was the fourth lowest early season ice extent since 1979–1980.

Annual Bering Sea Ice Extent
The Bering Sea has historically been ice-free in the middle and late summer, with ice developing during the second half of October. To account for this seasonal cycle, the Bering Sea ice year is defined as 1 August to 31 July. Bering Sea ice extent data are from the National Snow and Ice Center's Sea Ice Index, version 3 (Fetterer et al., 2017), and use the Sea Ice Index definition of the Bering Sea (effectively south of the line from Cape Prince of Wales to East Cape, Russia).

Trends
The mean sea ice extent exhibited no long term trend, although a steep decline in ice extent was observed from 2012 (highest ice extent on record) to 2018 (lowest ice extent on record) (Figure 12). 2020–2021 seasonal extent recovered to a level typical of the "low ice" years of the early 2000s. This was due to the strength of a slow melt-out in the spring.

Bering Sea Daily Ice Extent
Tracking the seasonal progression and retreat of sea ice highlights the interactive roles of water temperature (i.e., warmth in the system) and winds (Figure 13). After a very slow start, ice extent increased rapidly in January only to stall out by the end of the month, and then was unusually steady from February into early April. After mid-March ice extent was highest since 2017 (March), 2016 (April), and 2013 (May).

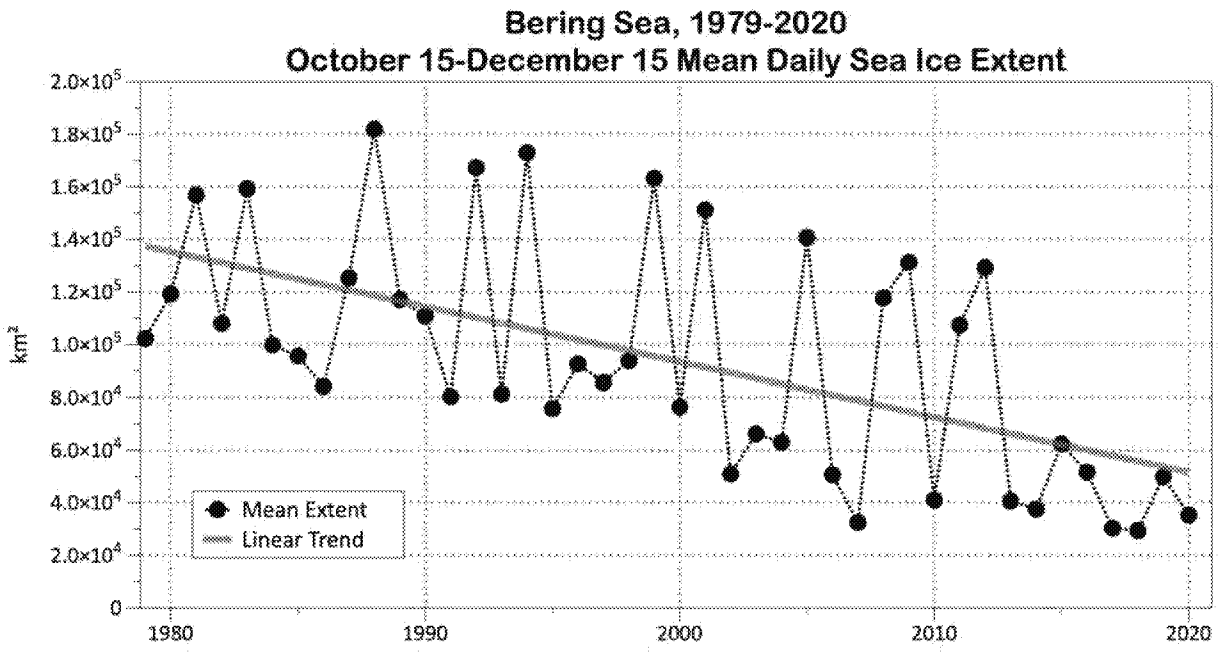

Figure 11: Early (15 Oct–15 Dec) mean sea ice extent in the Bering Sea, 1979–2020. Source: National Snow and Ice Data Center Sea Ice Index version 3.

Sea Ice Thickness

Bering Sea ice thickness was calculated for the 3rd week in March using merged SMOS/CryoSat-2 sea ice thickness estimates. SMOS is the Soil Moisture and Ocean Salinity satellite and CryoSat-2 is the Sea Ice Radar Altimetry from the European Space Agency CryoSat-2 satellite. SMOS estimates are most reliable at ice thickness ≤1m, CryoSat-2 at ice thickness ≥1m. Ice thickness was calculated for five areas over the Bering Sea: Gulf of Anadyr (Bering W), Bering Strait, Norton Sound, St. Lawrence Island to St. Matthew Island (Bering NC), and St. Matthew Island and St. Paul Island (Bering S) (Figure 14).

Trends

Ice thickness was near the higher levels of 2012 and 2013 in the northern and western Bering Sea regions (Figure 15), but very low south of St. Matthew Island (Figure 16). This reflected the unusual weather pattern that prevailed from late January into March, which allowed ice in the north to thicken but prevented ice from moving very far south of St. Matthew Island. While the 11-year period of record is much too short to establish any kind of trend, this period is likely indicative of the modern era range of interannual variability that can be expected at this time of year, as both 2012 (high ice extent year) and 2018 and 2019 (low extent) are represented in the period of record. However, it is important to notice that in some areas, estimated uncertainty of the thickness estimates are a significant fraction of estimated mean thickness, especially pre-2016, suggesting that the estimates should be used with caution.

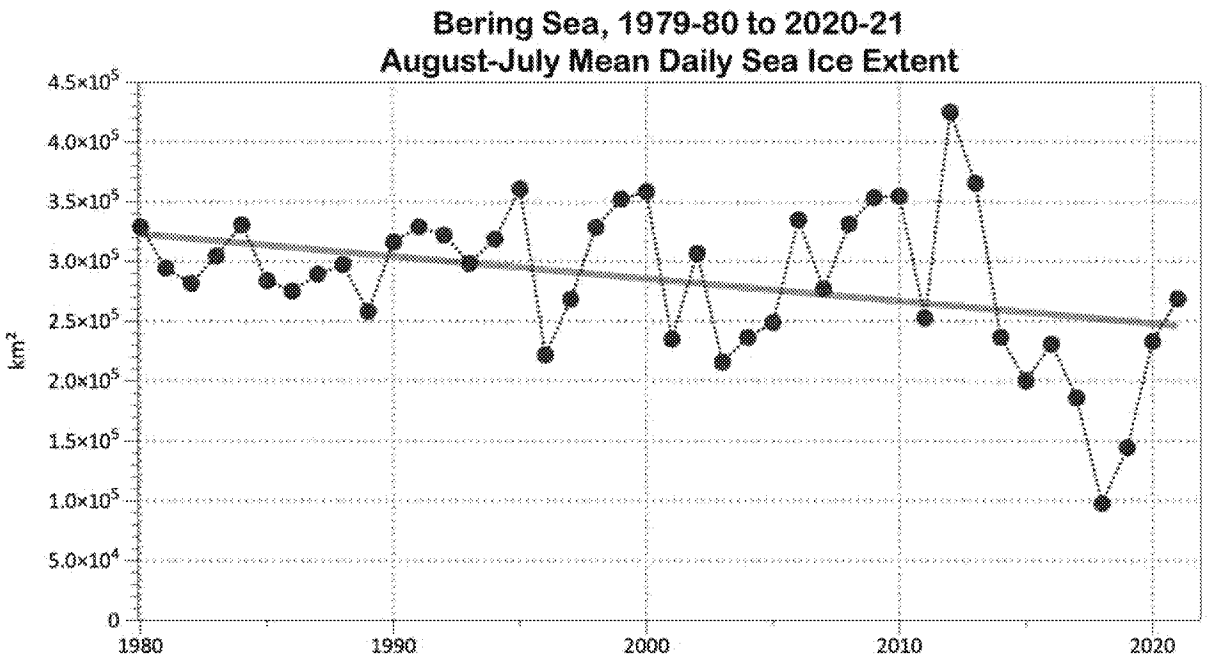

Figure 12: Mean sea ice extent in the Bering Sea from 1 August to 31 July, 1979/1980–2020/2021.

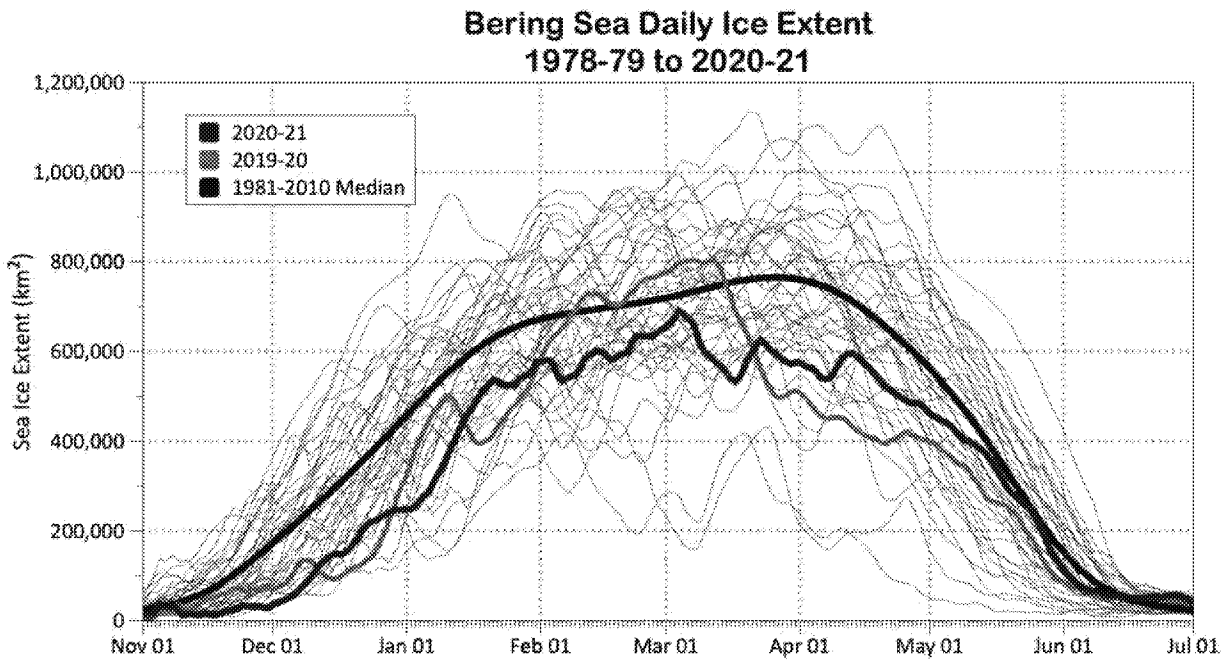

Figure 13: Daily ice extent in the Bering Sea. The most recent year (2020–2021) is shown in blue, 2019–2020 in green, and the historical median in black. Individual years in the time series are shown in gray.

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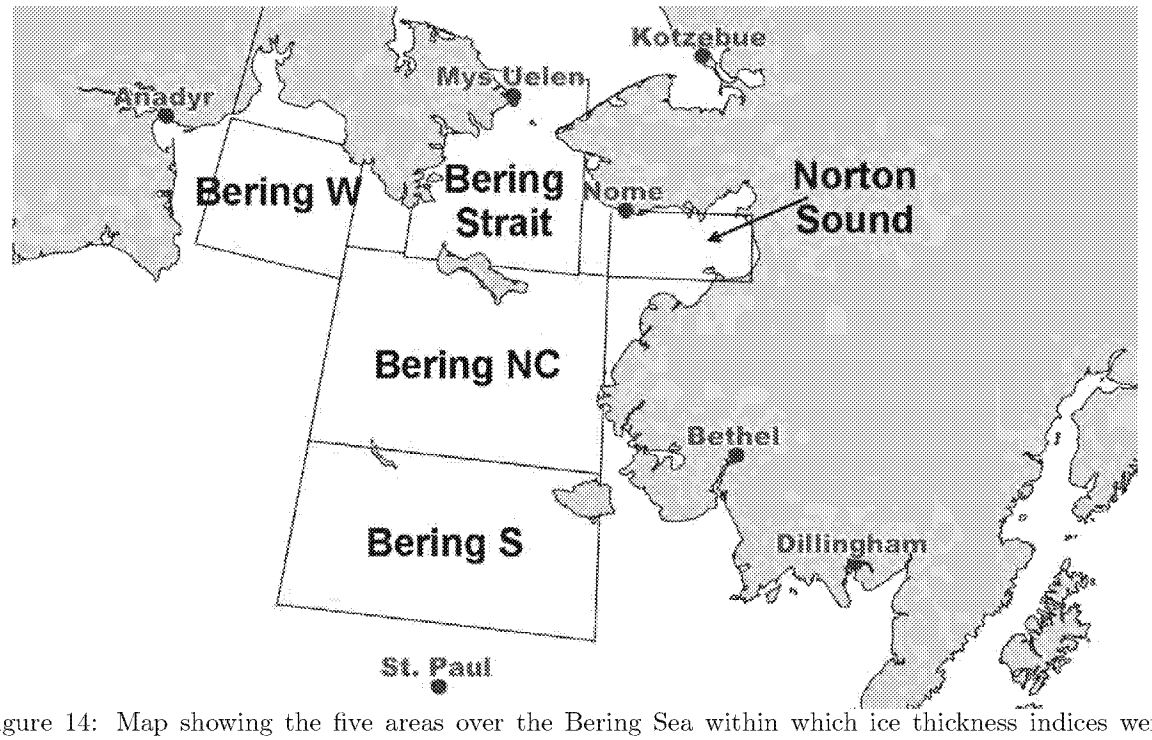

Figure 14: Map showing the five areas over the Bering Sea within which ice thickness indices were calculated: Gulf of Anadyr (Bering W), Bering Strait, Norton Sound, St. Lawrence Island to St. Matthew Island (Bering NC), and St. Matthew Island and St. Paul Island (Bering S)

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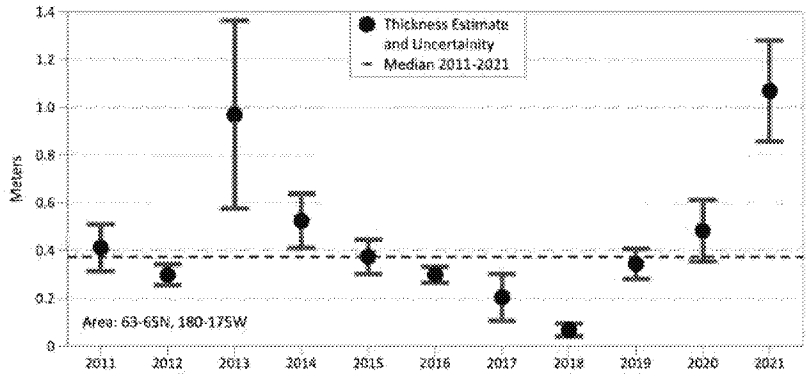
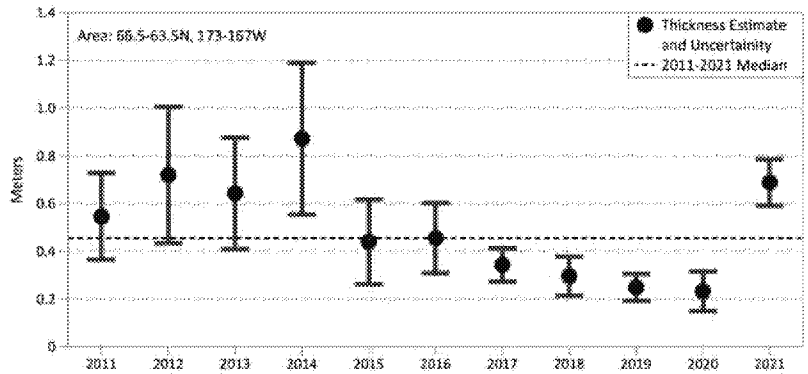
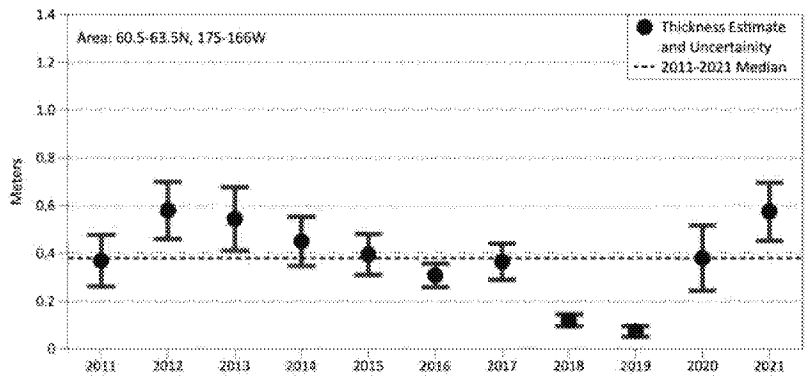


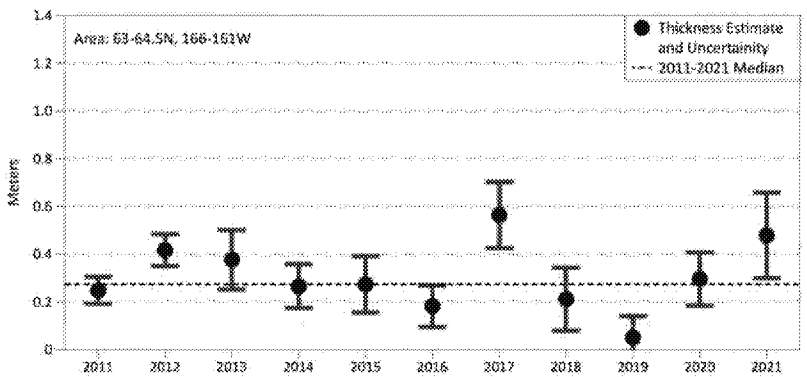
(a) Gulf of Anadyr



(b) Bering Strait



(c) St. Lawrence Island to St. Matthew Island



(d) Norton Sound

Figure 15: Sea ice thickness in the Bering Sea for (a) Gulf of Anadyr, (b) Bering Strait, (c) St. Lawrence Island to St. Matthew Island, and (d) Norton Sound. Source: Alfred Wegener Institute, `https://www.meereisportal.de/en/`

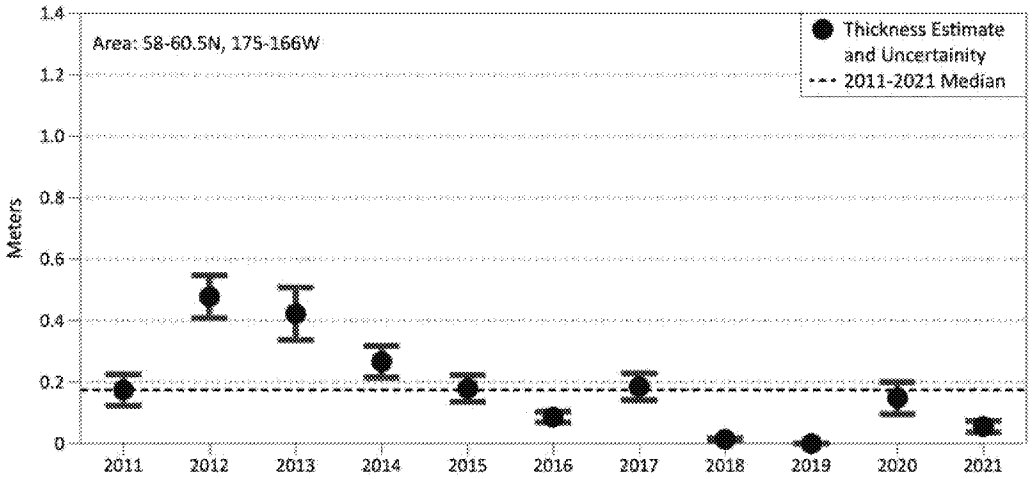


Figure 16: Sea ice thickness between St. Matthew Island and St. Paul Island. Source: Alfred Wegener Institute, `https://www.meereisportal.de/en/`

4. Wind and Ocean Currents

Sea Level Pressure Anomalies
Contributed by Nick Bond, *nicholas.bond@noaa.gov*
The state of the North Pacific climate from autumn 2020 through summer 2021 can in part be summarized in terms of seasonal mean sea level pressure (SLP) anomaly maps. The SLP anomalies are relative to mean conditions over the period of 1981–2010. The SLP data are from the NCEP/NCAR Reanalysis project and are available by NOAA's Physical Sciences Laboratory (PSL)[5].

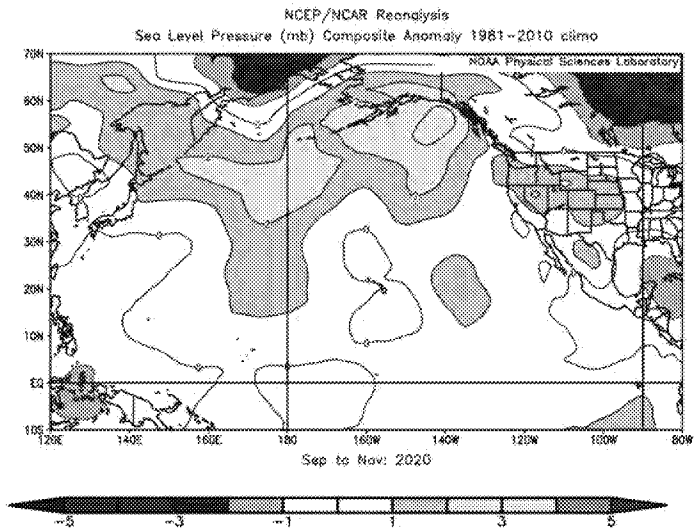
The SLP pattern during autumn (Sep–Nov) 2020 (Figure 17a) included positive anomalies south of the Aleutians and negative anomalies over northeastern Siberia. This SLP distribution resulted in anomalous winds from the southwest for the Bering Sea and suppressed storminess for the southeast Bering Sea shelf.

The winter (Dec–Feb) of 2020–2021 (Figure 17b) featured strongly negative SLP anomalies in the southwestern Bering Sea and positive SLP anomalies in the eastern part of the mid-latitude North Pacific. The consequence was enhanced westerlies stretching from the Aleutians to the GOA.

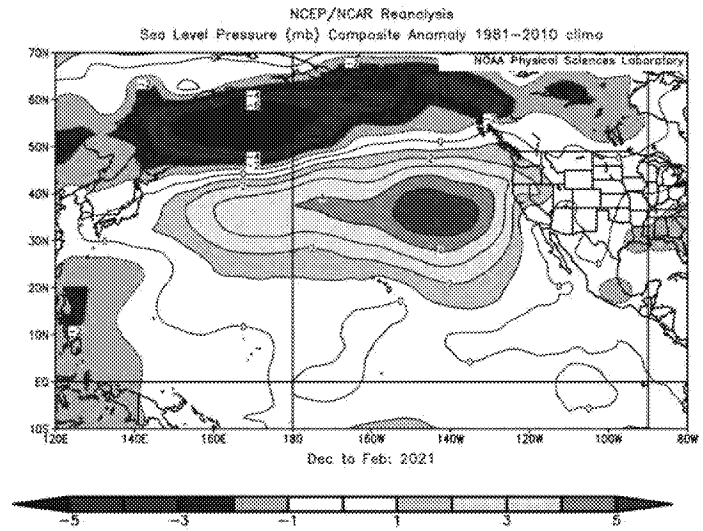
The positive SLP anomalies in the NE Pacific persisted through spring (Mar–May) of 2021 (Figure 17c), with their spatial extent expanding west of the dateline and northward into the Bering Sea and GOA. The highest pressures were at roughly a latitude of 45°N, again resulting in westerly wind anomalies for the Bering Sea and GOA.

The distribution of SLP anomalies across the North Pacific during summer (Jun–Aug) of 2021 is shown in Figure 17d. As is often the case during this time of year, the seasonal mean anomalies were generally of moderate amplitude. The negative SLP anomalies over the NBS extending across the Chukchi Sea to north of Alaska implies enhanced storm activity for those regions.

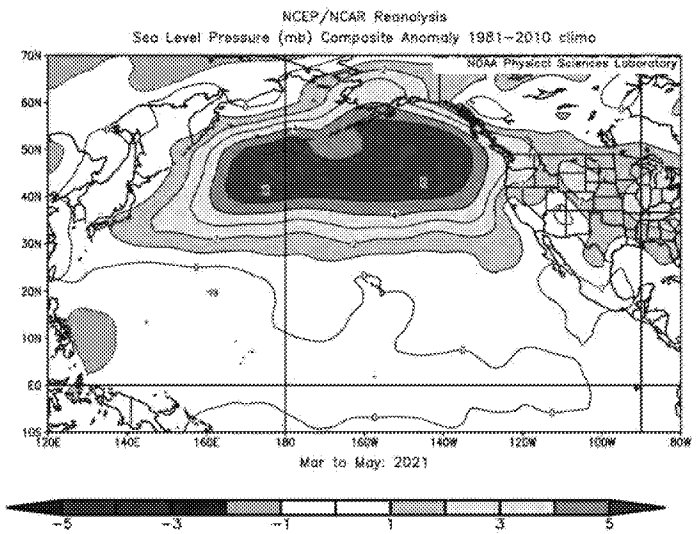
[5] `https://www.psl.noaa.gov/cgi-bin/data/composites/printpage.pl`.



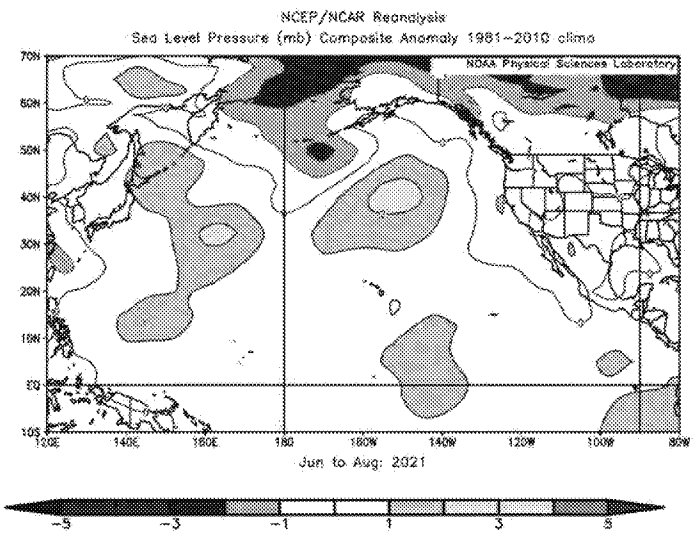
(a) Autumn



(b) Winter



(c) Spring



(d) Summer

Figure 17: Sea level pressure anomalies for autumn (Sept–Nov 2020), winter (Dec 2020–Feb 2021), spring (Mar–May 2021), and summer (Jun–Aug 2021).

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Winter Wind Speed and Direction
Contributed by Rick Thoman, *rthoman@alaska.edu*
The average winter (Nov–Mar) wind speed categorizes years as having prevailing north winds or south winds. No long-term trend is exhibited, although winters ending in 2018 and 2019 were among 5 years with the strongest south winds, which contributed to low sea ice extent in those years. For winter 2020–2021, the south wind component was the 10th strongest in the 73 year record, and this contributed to the low max sea ice extent (Figure 18).

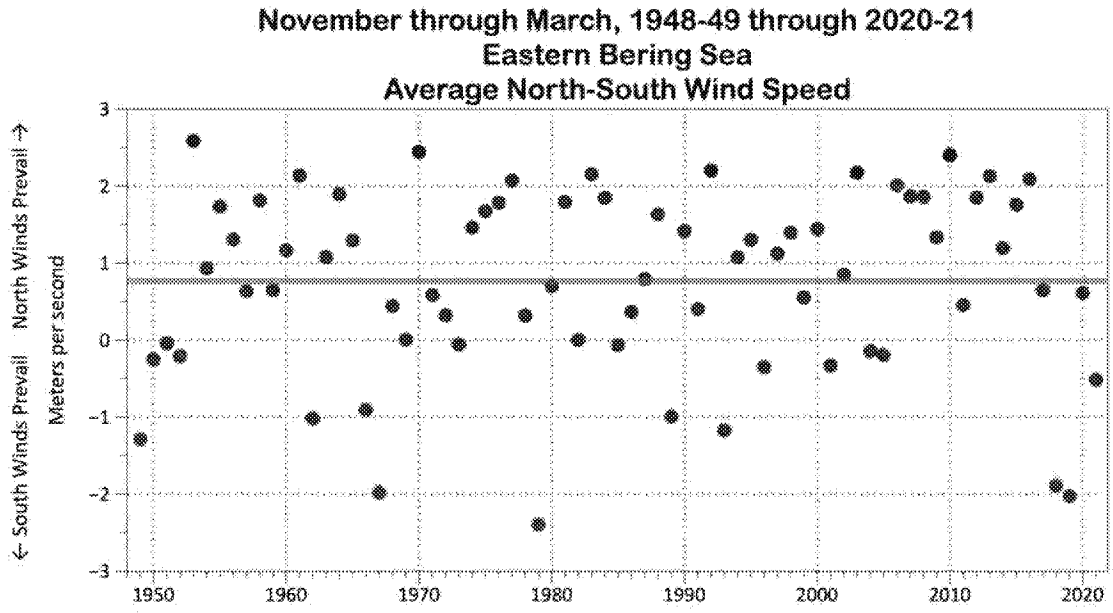

Figure 18: Winter (Nov–Mar) average north-south wind speed in the Bering Sea, 1949–2021. Red dots denote five years with strongest south winds, blue dots the five strongest north winds. **Note:** the north-south (meridional) component of the wind is plotted inverse to meteorological convention with south to north as negative values and north to south as positive values. Source: NCEP/NCAR reanalysis.

Spatial Variability of Prevailing February Winds
Contributed by Tyler Hennon, *tdhennon@alaska.edu*
NCAR/NCEP 10m wind reanalysis was used to examine the spatial variability of the prevailing winds during the month of February. *Nota bena:* wind speed and the length of velocity vectors do not have a 1:1 correlation in Figures 19 and 20. For example, strong winds that oscillate between northerly and southerly will have high speed but a short velocity vector (velocities average near zero), whereas steady strong southerlies will have both a high speed and long velocity vector.

Trends
In 2018, February winds were nearly universally strong and southerly over much of the Bering (Figure 19), which was also the case for 2019 (not shown). These strong southerly winds advected warm air from lower latitudes to the Bering Sea. In February, 2020 (not shown), moderate northerly winds prevailed (advecting cold polar air from high latitudes). Interestingly, in February 2021, these northerly winds intensified (Figure 20) over the northern portion of the shelf while southerly winds prevailed over the southern portion of the shelf. These different atmospheric conditions can have a strong influence on sea surface temperature and ice formation.

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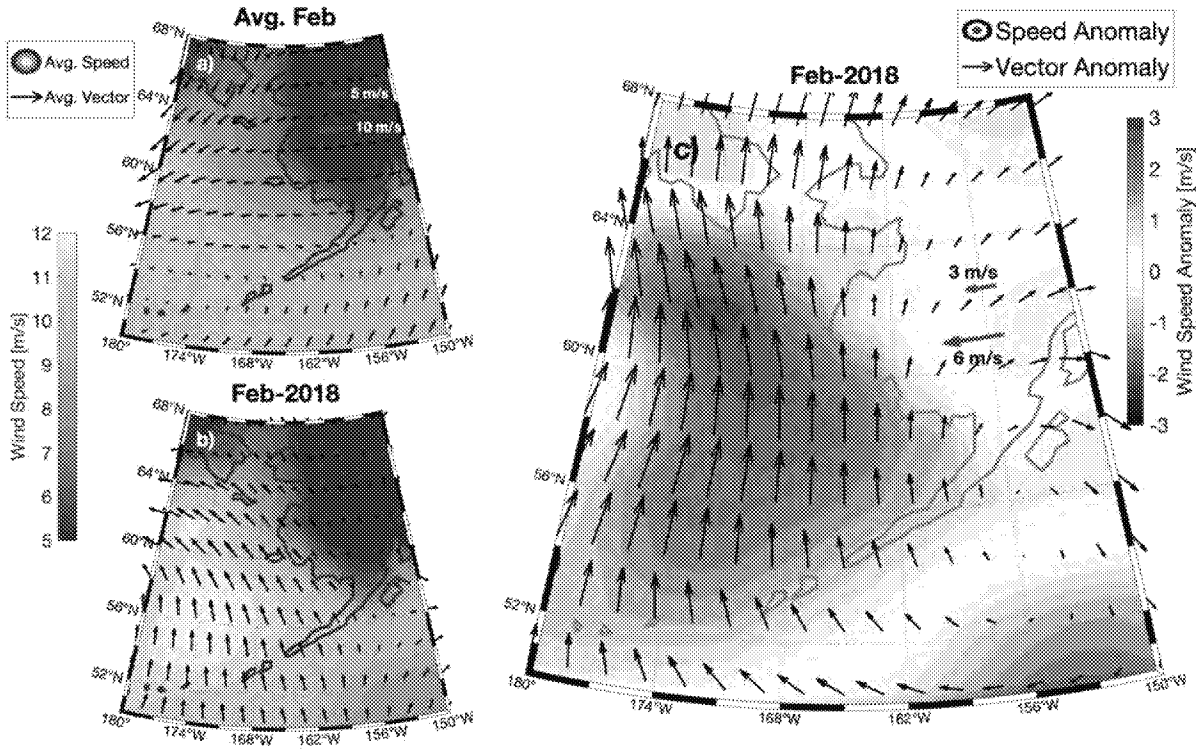

Figure 19: Spatial variability of prevailing winds. a) Average 10m wind vectors (black arrows) and wind speed (color map) during February 2000–2021. Magenta arrows indicate vector scale. b) As in a), but the average for only February 2018. c) The wind vector anomalies (black arrows) and speed anomalies (color map) for February 2018, which is the difference between (b) and (a).

Spring Jet Stream and Sea Level Pressure

Contributed by James Overland, *james.e.overland@noaa.gov*

NCEP/NCAR reanalysis from March to May 2021 shows a weak sea level pressure gradient that is suggestive of a counterclockwise circulation cell over the Bering Sea (Figure 21, top left), which may explain the warmer than average near-surface air over the same time frame (Figure 21, top right). While no obvious circulation cell is present from June to August 2021 (Figure 21, bottom left), again the weak gradients suggest southwesterly air currents transporting heat to the southern Bering Sea, a pattern which is also generally reflected in the sea surface air (Figure 21, bottom right).

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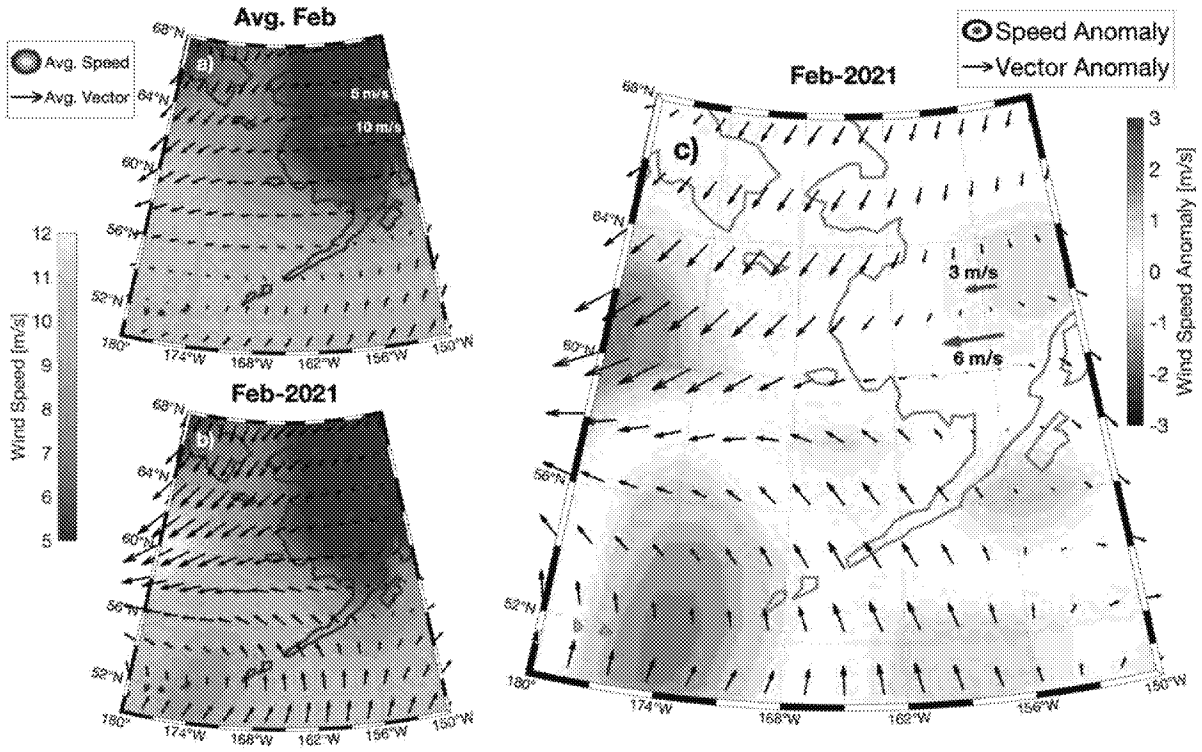

Figure 20: Spatial variability of prevailing winds. a) Average 10m wind vectors (black arrows) and wind speed (color map) during February 2000–2021. Magenta arrows indicate vector scale. b) As in a), but the average for only February 2021. c) The wind vector anomalies (black arrows) and speed anomalies (color map) for February 2021, which is the difference between (b) and (a).

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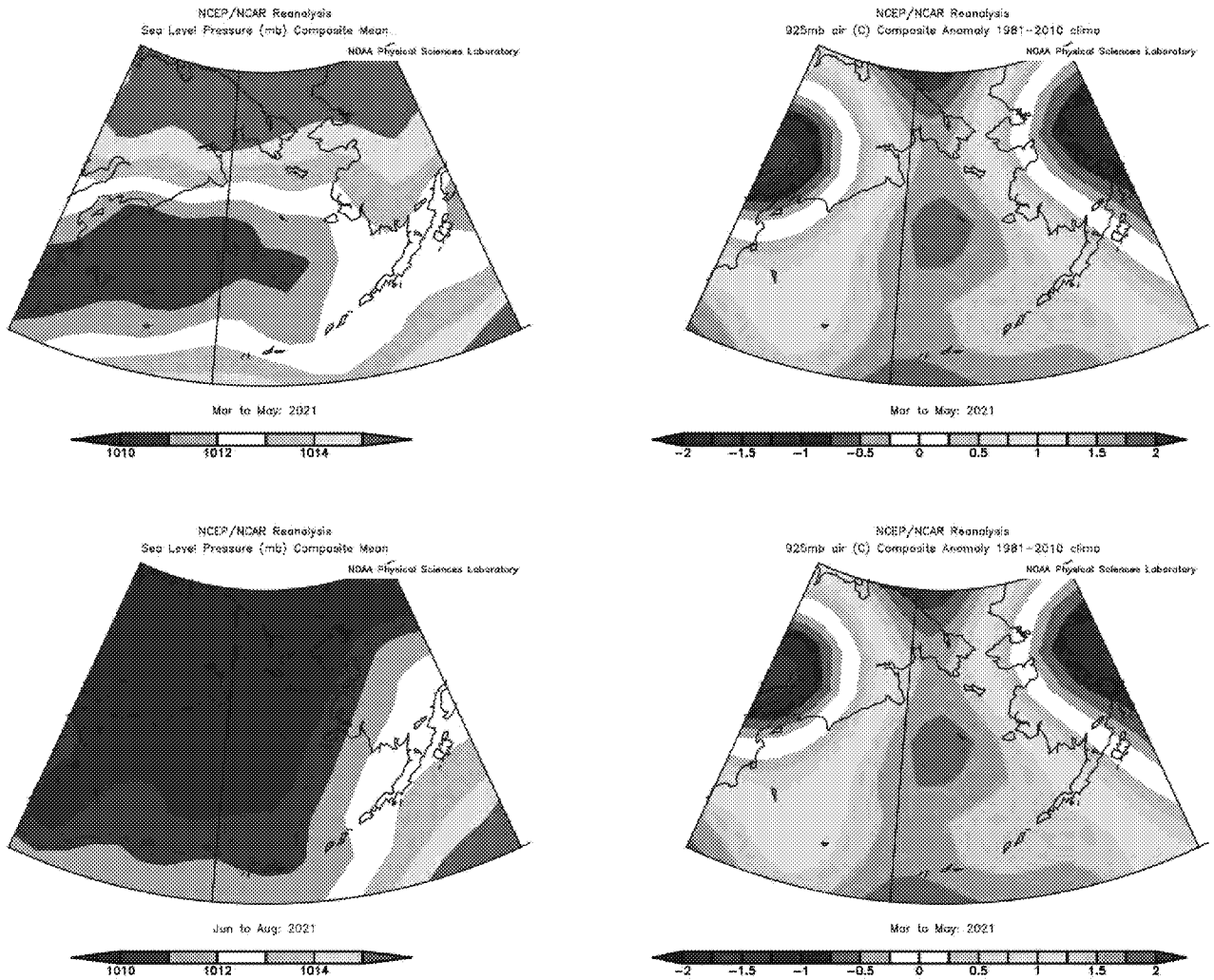

Figure 21: Left panels: Sea level air pressure from March–May 2021 (top) and June–August 2021 (bottom). Right panels: Air temperature at 925 mb from March–May 2021 (top) and June–August 2021 (bottom).

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Winds at the Bering Sea Shelf Break
Contributed by Tyler Hennon, *tdhennon@alaska.edu*
NCEP/NCAR wind reanalysis was used to look at the along- and cross-slope wind components at the Bering shelf break. Four-times daily wind data dating back to January 2000 were interpolated to a transect approximating the shelf break (Figure 22), and the zonal and meridional components were rotated into along- and cross-shelf components. These components of wind were then averaged across the whole transect for each month dating back to 2000.

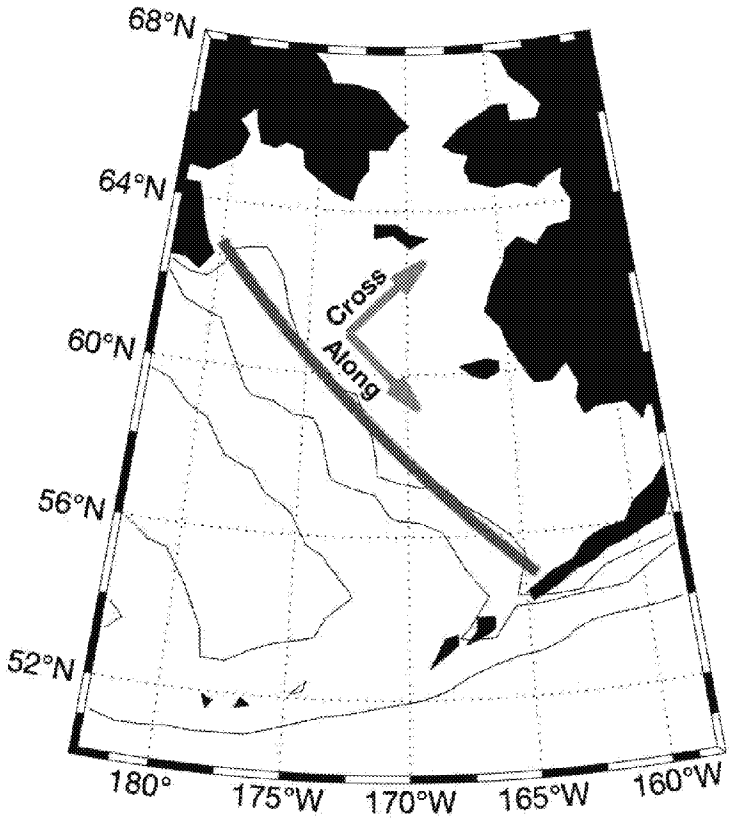

Figure 22: The magenta line shows the line chosen to evaluate along-shelf and cross-shelf wind components in the Bering Sea. Annotation arrows show the direction used to define positive cross and along shelf components of wind. Contours show isobaths at 100m, 500m, and 3500m.

The average annual cycle (2000–2021) is more apparent in the cross-shelf component than the along-shelf, and wind speeds are generally higher for the cross-shelf component as well (Figure 23, top panel). January to May of 2020 was marked by weak, but consistent, along-shelf winds coming from the southeast (negative in Figure 23), which is favorable for upwelling (Ekman transport is 90° to the right of wind direction in the northern hemisphere). Thereafter and through October 2021 along-shelf wind did not consistently demonstrate upwelling or downwelling favorable conditions. The behavior of the cross-shelf winds, which provoke currents that are along-shelf, generally resembled the average annual cycle (the 2000–2021 mean), albeit with considerably more scatter.

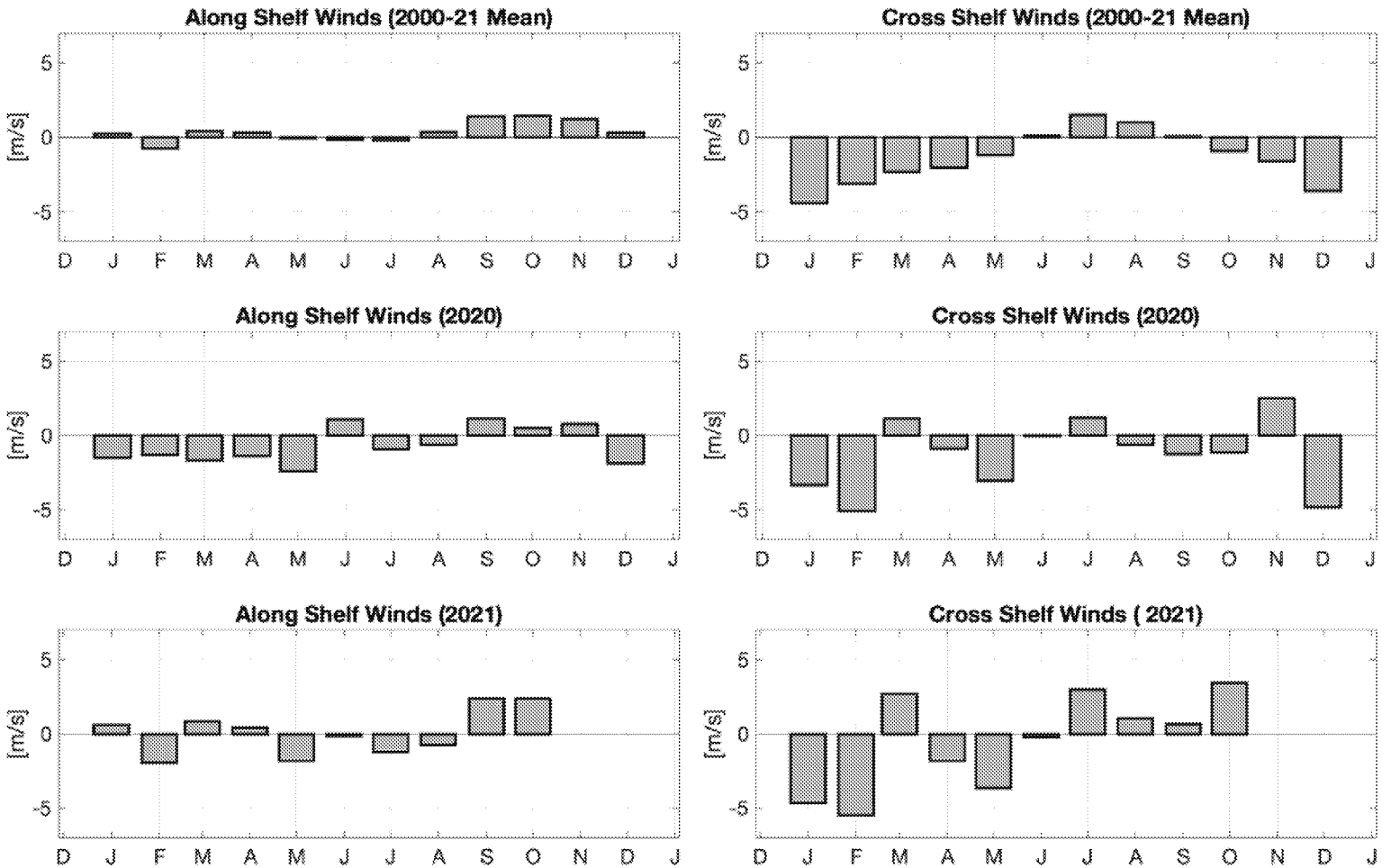

Figure 23: Along-shelf (left set of panels) and cross-shelf (right set of panels) wind components averaged along the magenta line in 22. Top panels show the monthly averages across the period of record. Middle panels show the monthly averages for 2020, and bottom panels show the average monthly average for 2021. Positive along-shelf winds are defined as blowing to the southeast, and positive cross-shelf winds are defined as blowing to the northeast.

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Eddy Kinetic Energy

Contributed by Wei Cheng, *wei.cheng@noaa.gov* and Tyler Hennon, *tdhennon@alaska.edu*

Eddy kinetic energy (EKE) measures the variability from mean currents, and is defined as $(u'^2 + v'^2)/2$, where u' and v' are anomalies from the long term averages of zonal and meridional velocities, respectively. There are numerous processes that can elevate EKE, such as meandering currents, a change in current speed, or the occurrence of a classic oceanic eddy. All of these processes can potentially impact the transport of heat, nutrients, as well as planktonic matter.

The source of velocity anomaly estimates is based on altimetric data from the Copernicus programme, which has archived daily observations from 1993 to the present. Average EKE on the Bering Sea shelf is very low, while the average values of EKE associated with the Bering Sea shelf break current are weak compared to regions of the Aleutian Islands or Gulf of Alaska, where the currents are stronger. Figure 24 highlights several regions of the shelf break with moderately strong EKE. In each region, there is significant seasonality, with the highest EKE usually occurring in the spring to early summer.

During 2020, EKE on the shelf break was quite low, particularly from January through April in the northwest regions (Figure 24). Wind conditions were fairly average during this time frame, which may act to suppress EKE (current variability can be induced by anomalous winds). In the first half of 2021, however, winds were slightly stronger than average (Figure 24), which may be a factor in explaining why EKE was generally higher in the first half of 2021 compared to the first half of 2020.

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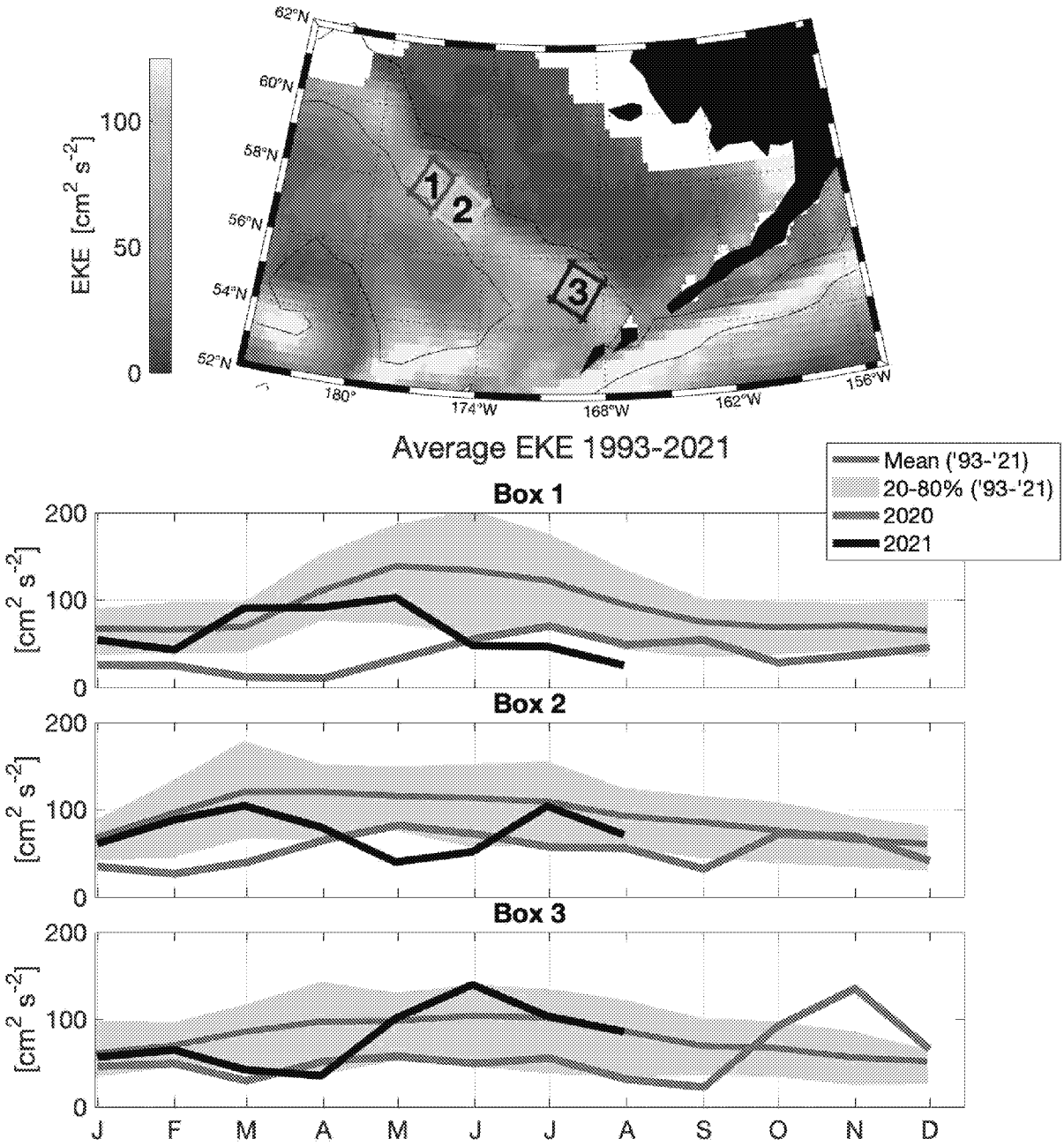

Figure 24: Top: Boxes show the spatial boundaries used for averaging eddy kinetic energy (EKE) for three areas along the Bering Sea shelf break. Lower panels: EKE from 1993–present. The gray line represents the mean for each month from 1993–2021 and the shaded region represents the 20th–80th percentile for each month for the same time frame. Blue lines show EKE for 2020, and black lines show 2021.

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St. Paul Air Temperature Anomalies
Contributed by James Overland, *james.e.overland@noaa.gov* and Muyin Wang, *muyin.wang@noaa.gov*
Monthly surface air temperature anomalies at St. Paul Island (WMO ID 25713) are shown in Figure 25. The anomaly is computed relative to the 1981–2010 period mean. Data are obtained from `https://data.giss.nasa.gov/gistemp/station_data_v4_globe`.

Trends
A linear trend of 0.57°C/decade has been observed since 1980 in addition to continuous positive anomalies that have dominated the region since 2014, with a maximum temperature anomaly of 6.66°C reached in February 2019.

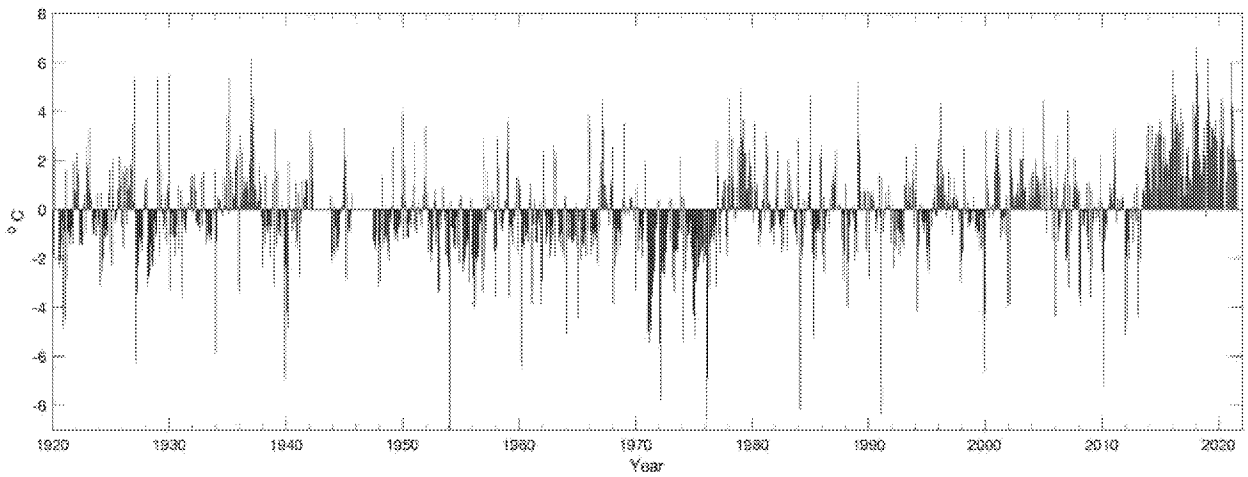


Figure 25: St. Paul Air Temperature Anomalies.

5. Surface and Bottom Temperatures

North Pacific Sea Surface Temperature (SST) Anomalies
Contributed by Nick Bond, *nicholas.bond@noaa.gov*
The state of the North Pacific climate from autumn 2020 through summer 2021 can in part be summarized in terms of seasonal mean sea surface temperature (SST) anomaly maps. The SST anomalies are relative to mean conditions over the period of 1981–2010. The SST data are from NOAA's Optimum Interpolation Sea Surface Temperature (OISST) analysis and are available by NOAA's Physical Sciences Laboratory (PSL)[6].

The autumn of 2020 (Figure 26a) included warmer than normal SSTs across virtually the entire North Pacific Ocean. Particularly warm waters with anomalies exceeding 2°C were present east of Hokkaido, in the northwestern Bering Sea near the Gulf of Anadyr, and in the eastern portion of the basin along 40°N from 160° to 130°W. The equatorial Pacific east of the dateline was cooler than normal in association with the development of moderate La Niña conditions.

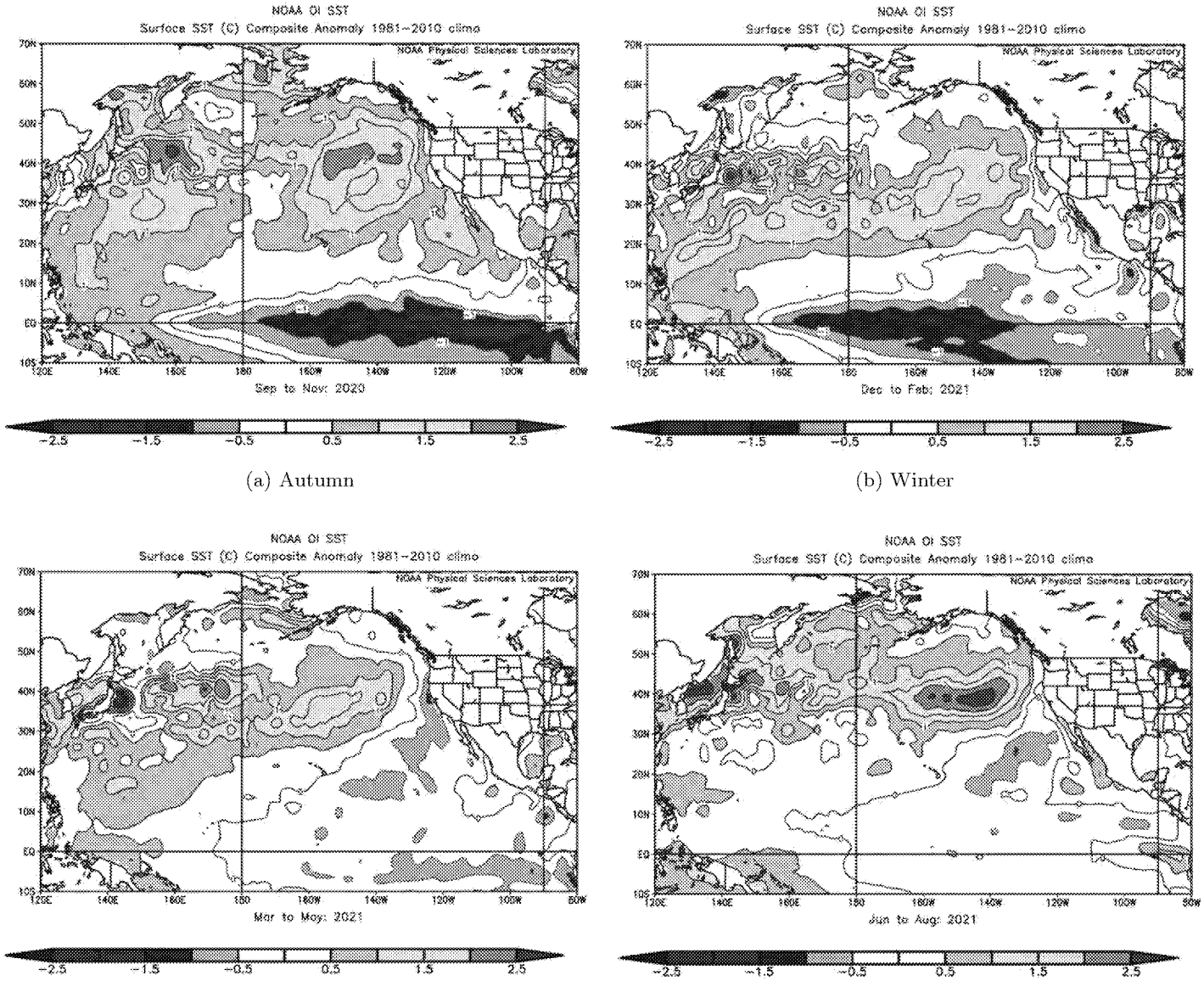
The magnitude of the positive SST anomalies in the North Pacific moderated late in 2020. For the winter (Dec–Feb) of 2020–2021 as a whole, Figure 26b shows that the region of relative warmth

[6] `https://www.psl.noaa.gov/cgi-bin/data/composites/printpage.pl`.

was confined largely to a basin-wide band between 15° and 45°N, with mostly minimal anomalies (< 0.5°C magnitude) on the Bering Sea shelf and in the GOA. La Niña remained present, with the most prominent anomalies occurring in the central tropical Pacific.

The large-scale SST anomaly pattern in the North Pacific during spring (Mar–May) of 2021 (Figure 26c) was similar to that of the previous winter. There were increases in the magnitudes of the warm anomalies in the western North Pacific from Japan to the dateline, and to a lesser extent for the southeastern Bering Sea. The tropical Pacific returned to near-neutral ENSO conditions, with slightly cool SSTs east of the dateline.

During the summer (Jun–Aug) of 2021 (Figure 26d), the positive SST anomalies in the mid-latitudes of the North Pacific increased to the east of the dateline well off the coast of the US lower 48 states. There were minor warm SST anomalies on the southeastern Bering Sea shelf. The tropical Pacific was in a near-neutral state.



(a) Autumn (b) Winter

(c) Spring (d) Summer

Figure 26: Sea surface temperature anomalies for autumn (Sept–Nov 2020), winter (Dec 2020–Feb 2021), spring (Mar–May 2021), and summer (Jun–Aug 2021).

Bering Sea SST Trends and Anomalies
Contributed by Jordan Watson, *jordan.watson@noaa.gov*,
and Matt Callahan, *matt.callahan@noaa.gov*
Satellite SST data (source: NOAA Coral Reef Watch Program) were accessed via the NOAA CoastWatch West Coast Node ERDDAP server[7]. Daily data were averaged within the southeastern (south of 60°N) and northern (60°–65.75°N) Bering Sea shelf (10–200m depth). Detailed methods are available online[8].

SST Trends
The northern and southeastern Bering Sea regions continue to experience SSTs that are warmer than the 30-year baseline (1985–2014) conditions. While the southeastern Bering Sea saw conditions in 2021 that were generally cooler than during the previous year, much of the fall and winter in the NBS were similarly warm as the previous year. The exception to this has been the summer of 2021, which has been cooler than that of the summer 2020 in general (Figure 27).

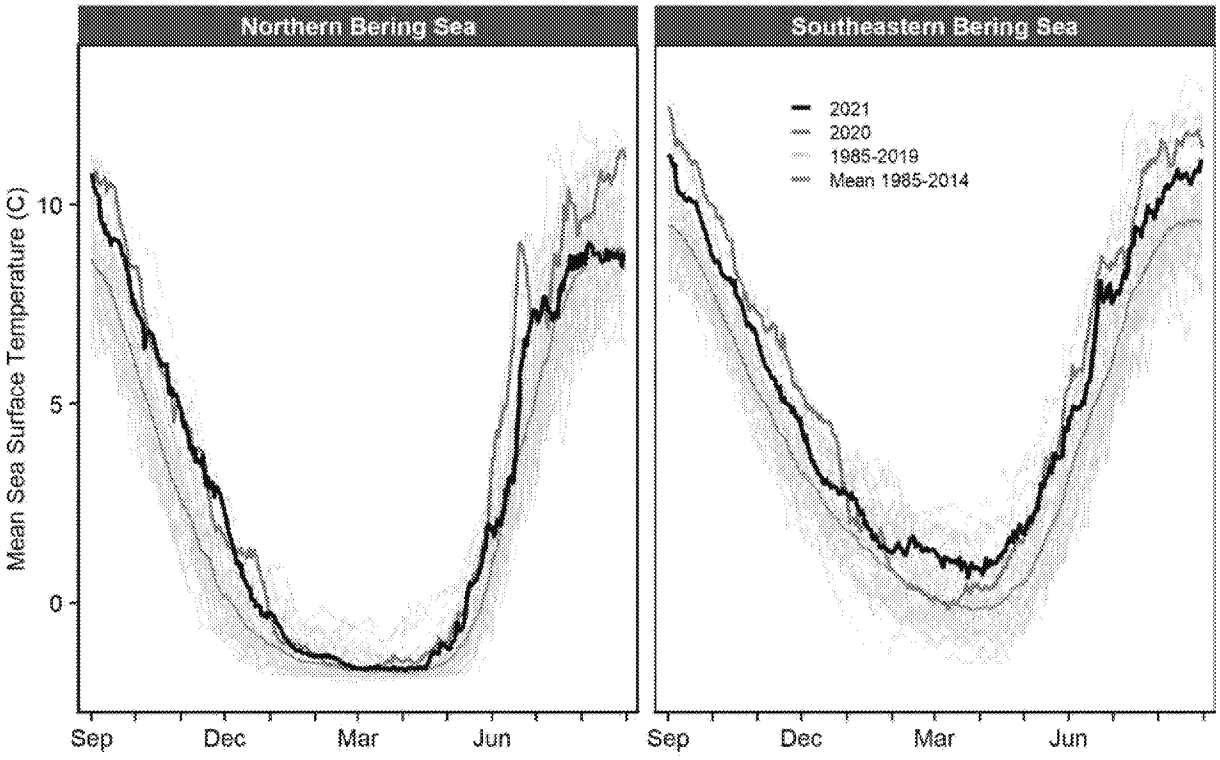


Figure 27: Mean SST for the northern (left) and southeastern (right) Bering Sea shelves. The most recent year (2020–2021; through August 31, 2021) is shown in black, winter 2019/2020 is shown in blue, and the historical mean is shown in purple. Individual years in the time series are shown in light gray.

[7] https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html
[8] github.com/jordanwatson/EcosystemStatusReports/tree/master/SST

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SST Time Series Trends

Trend analysis removed seasonality and noise from the SST time series (Edullantes, 2019) to better illustrate the long term trends in the SST data (Figure 28). Trends are compared to the mean (±1 SD) from a 30-yr baseline (1985–2014) and demonstrate that both the northern and southeastern Bering Sea are experiencing a persistent warm stanza, greater in both magnitude and duration than that of the early 2000s. In the most recent data, the intensity of the warm stanza has softened relative to the previous few years of data. **Note:** The time series trend analysis requires truncation of the ends of the time series (due to differencing) so the trend line extends only into March 2021.

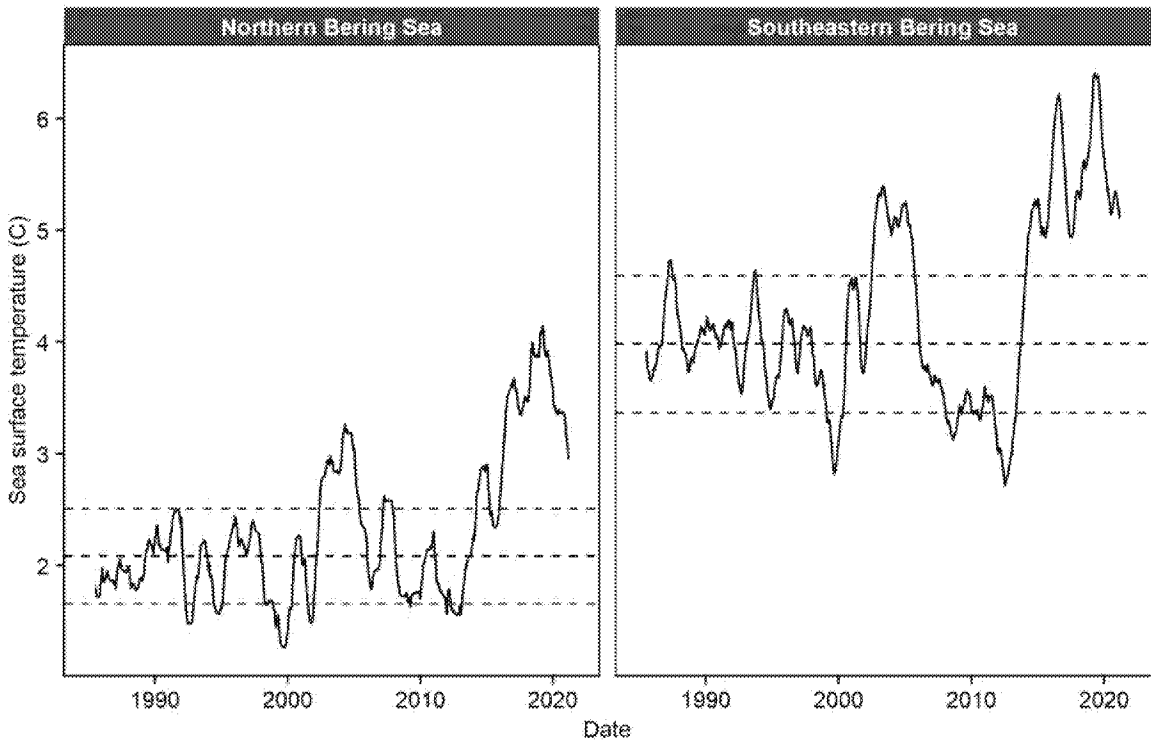

Figure 28: Time series trend of SST (seasonality and noise removed) for the northern (left) and southeastern (right) Bering Sea shelves. The black horizontal dotted line is the 30-year mean (1985–2014) of the trend and the red lines are ±1 SD.

Marine Heatwave Index

Marine heatwaves in 2021 have been relatively minor compared to recent years, with only a few brief and relatively mild events (Figure 29). Notably however, while actual marine heatwaves were not triggered as often or as severely during 2021, temperatures hovered just below the heatwave thresholds for much of the year.

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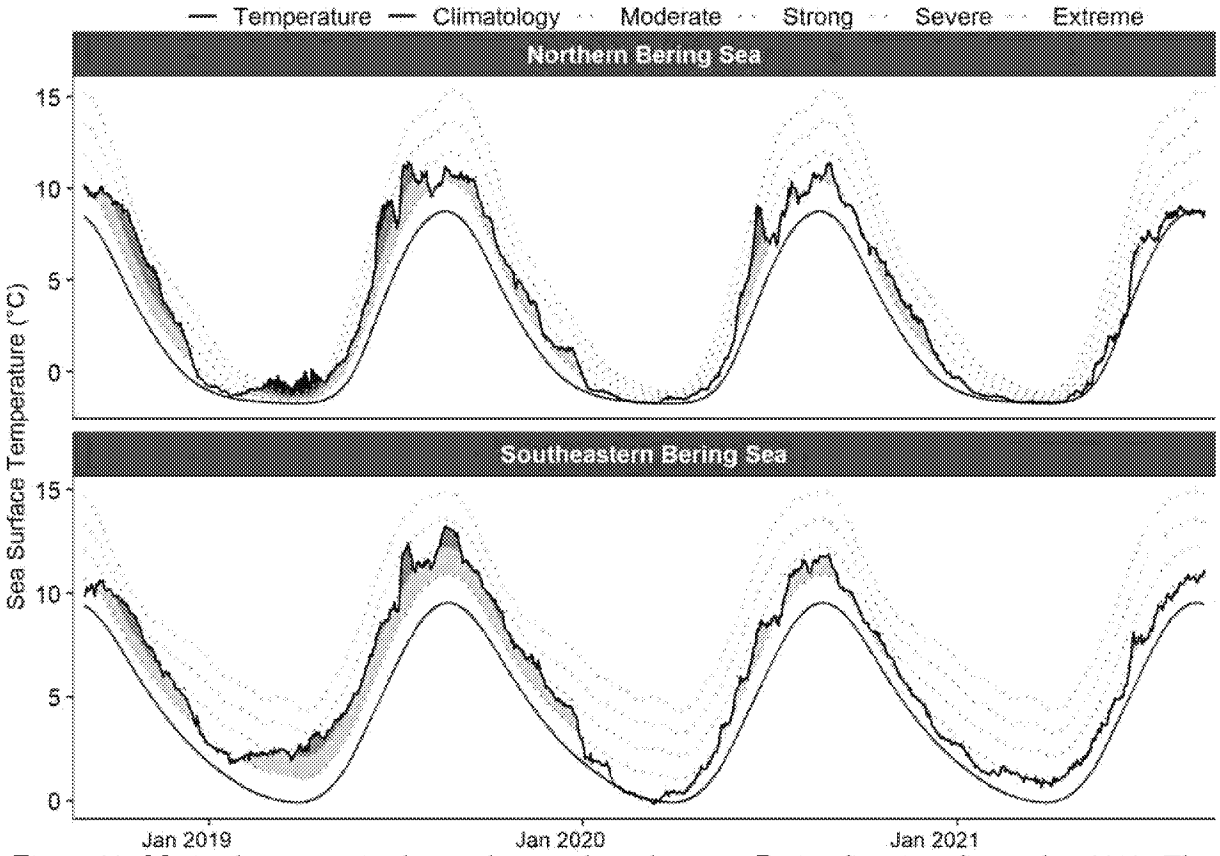

Figure 29: Marine heatwaves in the northern and southeastern Bering Sea since September 2018. The smoothed solid black line represents the baseline average temperature (i.e., climatology) for each day during the 30-yr baseline period (1 Sept 1985–31 Aug 2014). The jagged solid black line is the observed (satellite-derived) sea surface temperature for each day. Dotted lines illustrate thresholds for increasing heatwave intensity categories (moderate, strong, severe, extreme). Colored portions indicate periods during which marine heatwaves occurred, with intensity increasing as colors darken.

Cumulative SST Anomalies

The persistent warmer than average (though typically cooler than heatwave status) conditions still yielded cumulative sea surface temperatures for 2021 that were warmer than average (Figure 30). Such cumulative warming may represent important conditions for the ecology of these systems in that the total thermal exposure for organisms was still higher than historically average conditions. Protracted warming may lead to elevated metabolic rates, higher growth rates, and higher prey demands.

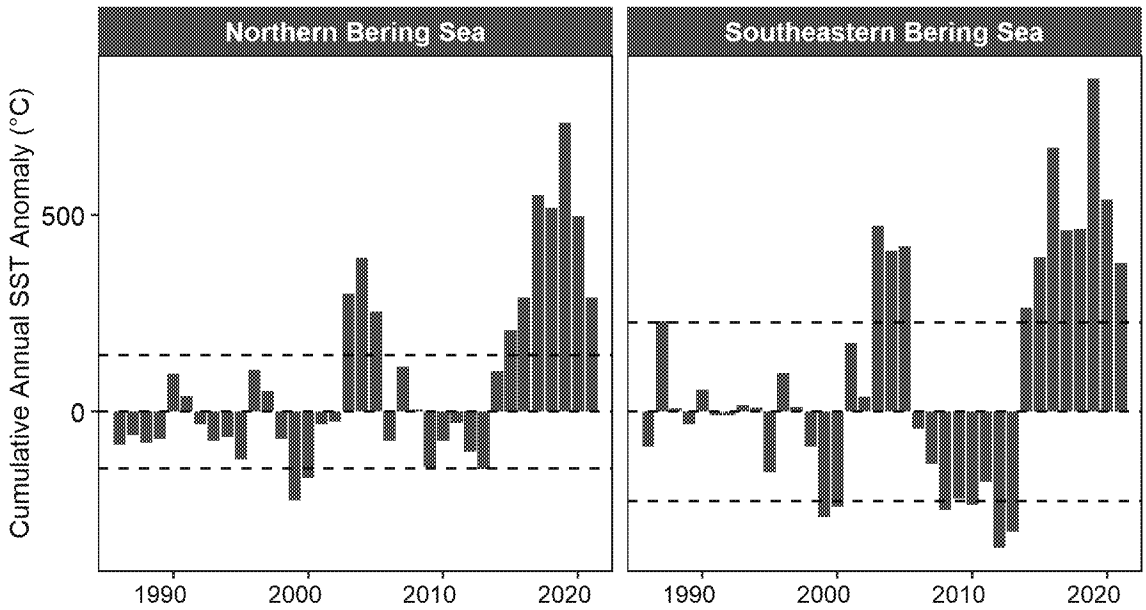

Figure 30: Cumulative annual sea surface temperature anomalies (sum of daily temperatures). Horizontal lines are ±1 SD from the mean during the 30-yr baseline period (1 Sept 1985–31 Aug 2014).

At the seasonal level, patterns of cumulative temperature exposure (degree heating days) demonstrated patterns more consistent with some of the recent warm stanza years than with cooler years of the past (Figure 31). Both the northern and southeastern regions experienced a shift to warmer thermal conditions in 2014.

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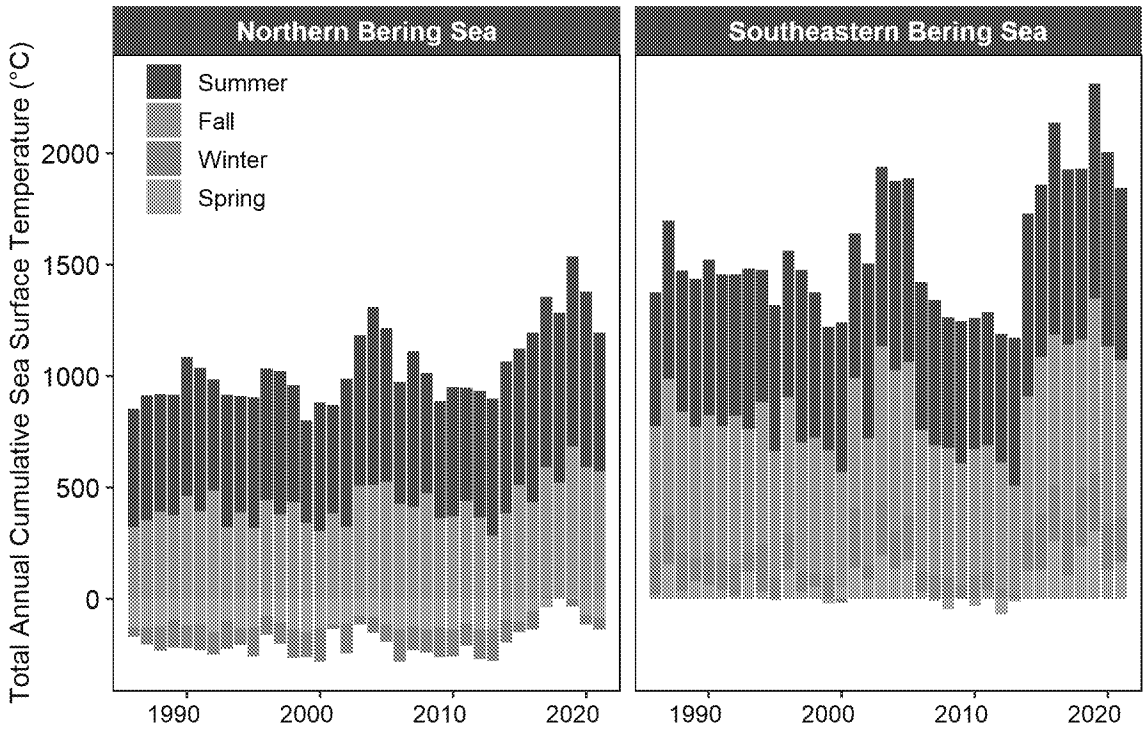

Figure 31: Cumulative sea surface temperatures (sum of daily temperatures) for each year, apportioned by season: summer (Jun–Aug), fall (Sept–Nov), winter (Dec–Feb), and spring (Mar–May). Negative values are the result of sea surface temperatures below zero.

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St. Paul Island Temperature, Salinity, and Chlorophyll-a

Contributed by Seth Danielson, *sldanielson@alaska.edu*, Lauren Divine, *lmdivine@aleut.com*, Elizabeth Dobbins, Aaron Lestenkof, and Tyler Hennon

Community-led monitoring of temperature, salinity, and chlorophyll-a from North Dock on the St. Paul Island breakwater have been made since 2014 using CTD data loggers. Instrumentation used since 2015 also had a sensor for chlorophyll a fluorescence, which provides a measure of phytoplankton concentration. Water depth at the sample site is approximately 8m. Water column profiles are collected nominally weekly (Figure 32) and have been averaged into monthly means (Figure 33).

Trends

Water temperatures collected since 2014 from St. Paul Island indicate that 2016, 2018 (first half), and 2019 showed warmer water temperatures than the 7-year mean for most months while 2017, the latter half of 2018, and 2020 were relatively cool intervals. Although there is moderate variability, temperature in 2021 has remained near the 7-year mean. However, across the North Pacific as a whole, 2014 through 2021 has been appreciably warmer than the long-term average and the anomalies shown here all likely significantly underestimate the actual temperature offset relative to the climatology (e.g., Danielson et al. (2020)).

Salinity, however, shows an increasing trend over the time period. Contributing factors to salinity variability on the Bering Sea shelf include ice melt and advection, river discharge, precipitation, evaporation, inflows from the Gulf of Alaska, and cross-slope exchanges with the basin (Aagaard et al., 2006). Sensor drift has recently been determined to be unlikely, so the increased salinity likely represents a real long-term trend. Though the seasonal variability in water density is driven by changes in both temperature and salinity, the long-term increase in density at St. Paul Island is driven primarily by the increase in salinity (Figure 33).

Chlorophyll-a fluorescence measurements show year-to-year variations in the timing of the spring phytoplankton bloom (Figure 34). In particular, the bloom was not detected until May in 2019 and 2020, but the fluorescence did significantly increase above low winter values in April 2016, 2017, and 2018. The timing of phytoplankton bloom conditions has implications for zooplankton and microzooplankton blooms as well as grazing and growth rates.

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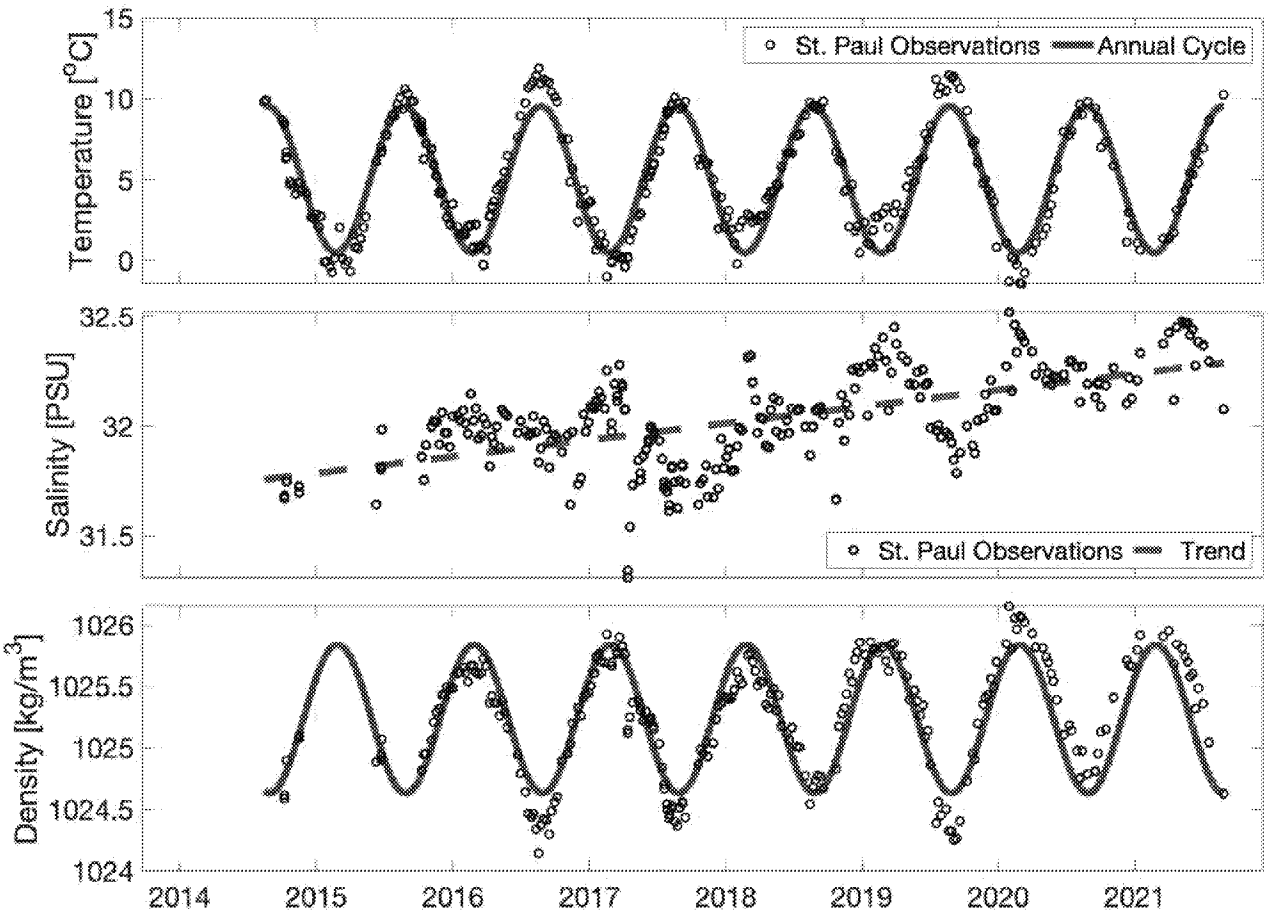

Figure 32: Observations of temperature (top), salinity (middle), and density (bottom) collected at St. Paul Island (black dots). Fitted annual cycles in temperature and density are in magenta and the long-term linear trend in salinity is represented by the dashed green line.

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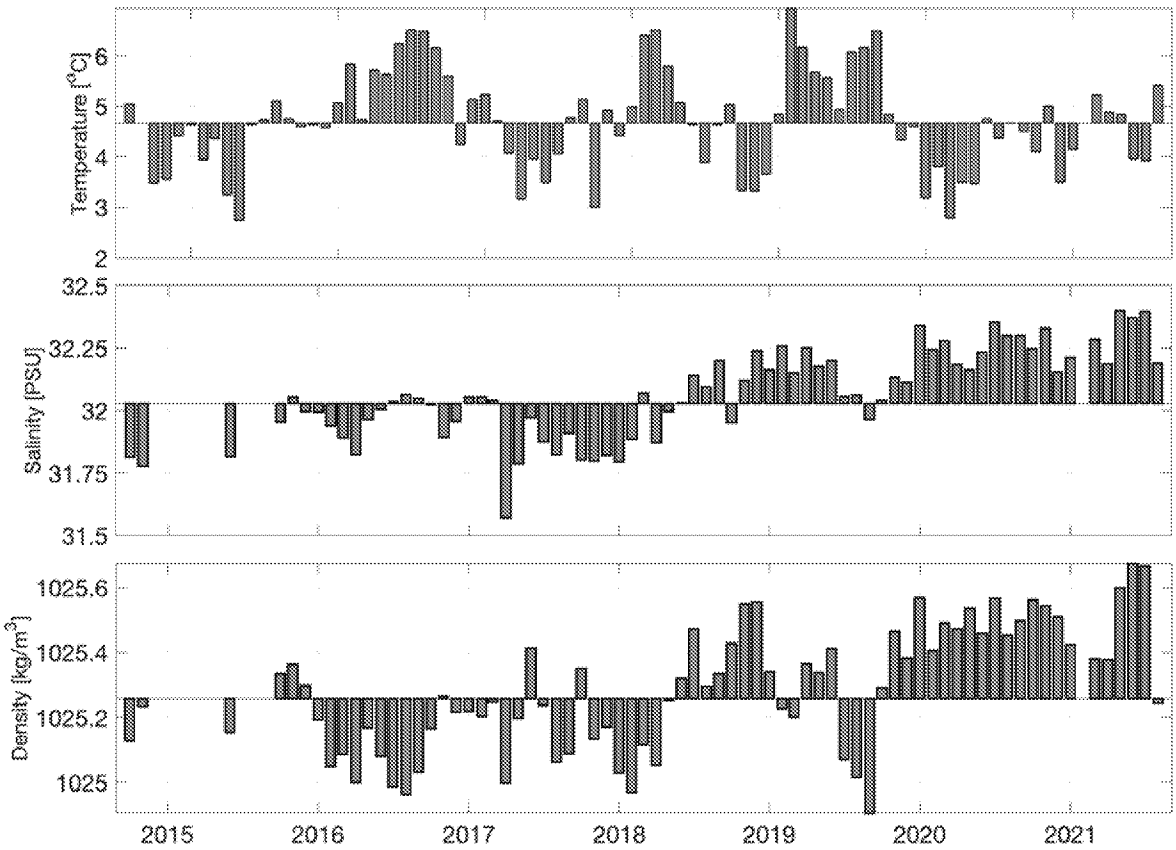

Figure 33: Monthly averages with the seasonal cycle removed for temperature (top), salinity (middle), and density (bottom).

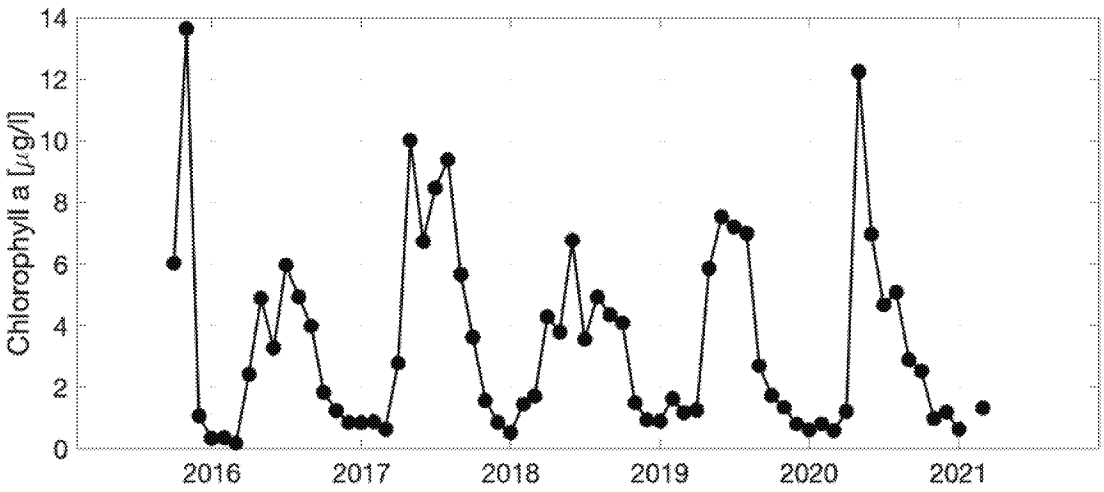

Figure 34: Monthly average of chlorophyll concentrations collected at St. Paul Island through March 2021.

Summer Surface and Bottom Temperatures Over the Bering Sea Shelf
Contributed by Sean Rohan, *sean.rohan@noaa.gov*, and Lewis Barnett, *lewis.barnett@noaa.gov*
In prior years, the mean temperature was calculated as the mean of observed temperatures weighted by stratum area, however this method can be sensitive to missing data. In comparing 10 different interpolation methods with leave-one-out-cross-validation, we found that ordinary kriging with Stein's parameterization of the Matérn semivariogram model produced the lowest prediction error in the majority of years. Therefore, in this and future years, this method will be used to calculate surface and bottom temperatures.

Trends
Mean surface and bottom temperatures were cooler than in the prior survey year (2019) on the shelf (Figure 35). The 2021 mean surface temperature was 7.2°C, which was 2.0°C lower than in 2019 yet 0.5°C higher than the grand mean of the time series (6.7°C). In 2021, the mean bottom temperature in the EBS was 3.3°C, the fourth highest on record after 2019, 2018, and 2016, and 0.9°C above the grand mean of the time series (2.5°C).

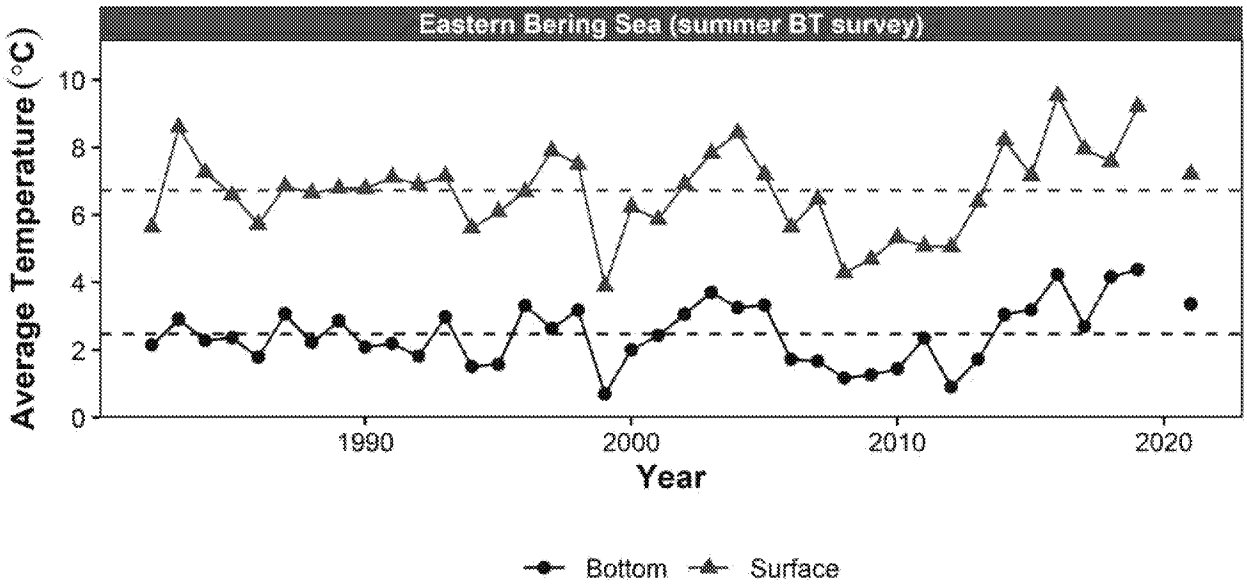

Figure 35: Average summer surface (green triangles) and bottom (blue circles) temperatures (°C) on the eastern Bering Sea (EBS) shelf based on data collected during standardized summer bottom trawl surveys from 1982–2021. Dashed lines represent the time series mean.

Cold Pool Extent Maps and Index Time Series
Contributed by Sean Rohan, *sean.rohan@noaa.gov*, and Lewis Barnett, *lewis.barnett@noaa.gov*
In prior years, the cold pool index was calculated based on the area within the 2°C bottom temperature isotherm derived from an inverse distance weighted interpolation, using a maximum of four observations in the weighting for each prediction. This year, we changed the interpolation method used to estimate this area, as described above for surface and bottom temperatures, to estimate cold pool extent for this and all prior years.

Trends

The cold pool extent has increased since 2018, yet the 2021 extent (58,975 km^2) was the fourth lowest on record and remains more than one standard deviation below the grand mean of the time series (see Figure 1). Estimates of cold pool area from 2018 and 2019 were the smallest on record, followed by 2003, which was only slightly smaller than in 2021. As is typical when the extent is small, the cold pool was restricted to the northern edge of the EBS shelf bottom trawl survey area (Figure 36). In general, the spatial extents of isotherms at all thresholds $\leq$1°C were similar, if slightly greater than prior record lows (Figure 36). The coldest bottom temperatures were restricted to the far northwest corner of the EBS shelf survey area, where temperatures were greater than -1°C, with an extremely small extent of waters $\leq$1°C (14,925 km^2) and $\leq$0°C (4,800 km^2). However, cooler bottom temperatures were observed in the NBS, including a substantial area with bottom temperatures $\leq$-1°C along the U.S.-Russia convention line to the west-southwest of St. Lawrence Island, while extremely warm bottom temperatures were observed on the northern inner shelf from Norton Sound to Nunivak Island (Figure 37). The temperature difference between the inner shelf in the NBS and inner shelf in the EBS is partially due to seasonal thermal heating owing to the NBS inner shelf being the last area sampled by the survey.

Fluctuations in the temperatures at the surface and bottom and the cold pool extent are the result of interannual variability in climatic conditions influencing the formation and retreat of sea ice on the EBS shelf during the prior winter (Stabeno et al., 2012; Stabeno and Bell, 2019). Less sea ice, persisting for less time, results in warmer temperatures and a smaller cold pool extent.

The cold pool has a strong influence on the thermal stratification, and overall, changes in surface and bottom temperature influence the spatial structure of the demersal community (Spencer, 2008; Kotwicki and Lauth, 2013; Thorson et al., 2020), trophic structure of the EBS food web (Mueter and Litzow, 2008; Spencer et al., 2016), and demographic processes of fish populations (Grüss et al., 2021). When the cold pool is small, species with warm water affinity (e.g., Arrowtooth flounder) are distributed more widely over the EBS shelf and expand across the shelf and to the north because there is no thermal barrier to migration. In contrast, the distribution of species with cold water affinity (e.g., Arctic cod, Bering flounder) contracts to the north when the cold pool is small.

While the cold pool area is defined based on the 2°C isotherm, recent studies suggest that a more ecologically relevant temperature for several subarctic fishes and crabs is the 1°C isotherm (Kotwicki and Lauth, 2013) or the 0°C isotherm for Walleye pollock and Pacific cod (Baker, 2021; Eisner et al., 2020). Considering the small extent of bottom temperatures cooler than 0°C and 1°C, it is likely that the bottom temperatures on the EBS shelf did not impose a major thermal barrier to migration for subarctic species in 2021. However, cooler bottom temperatures in the NBS (Figure 37) may have imposed some barrier to migration.

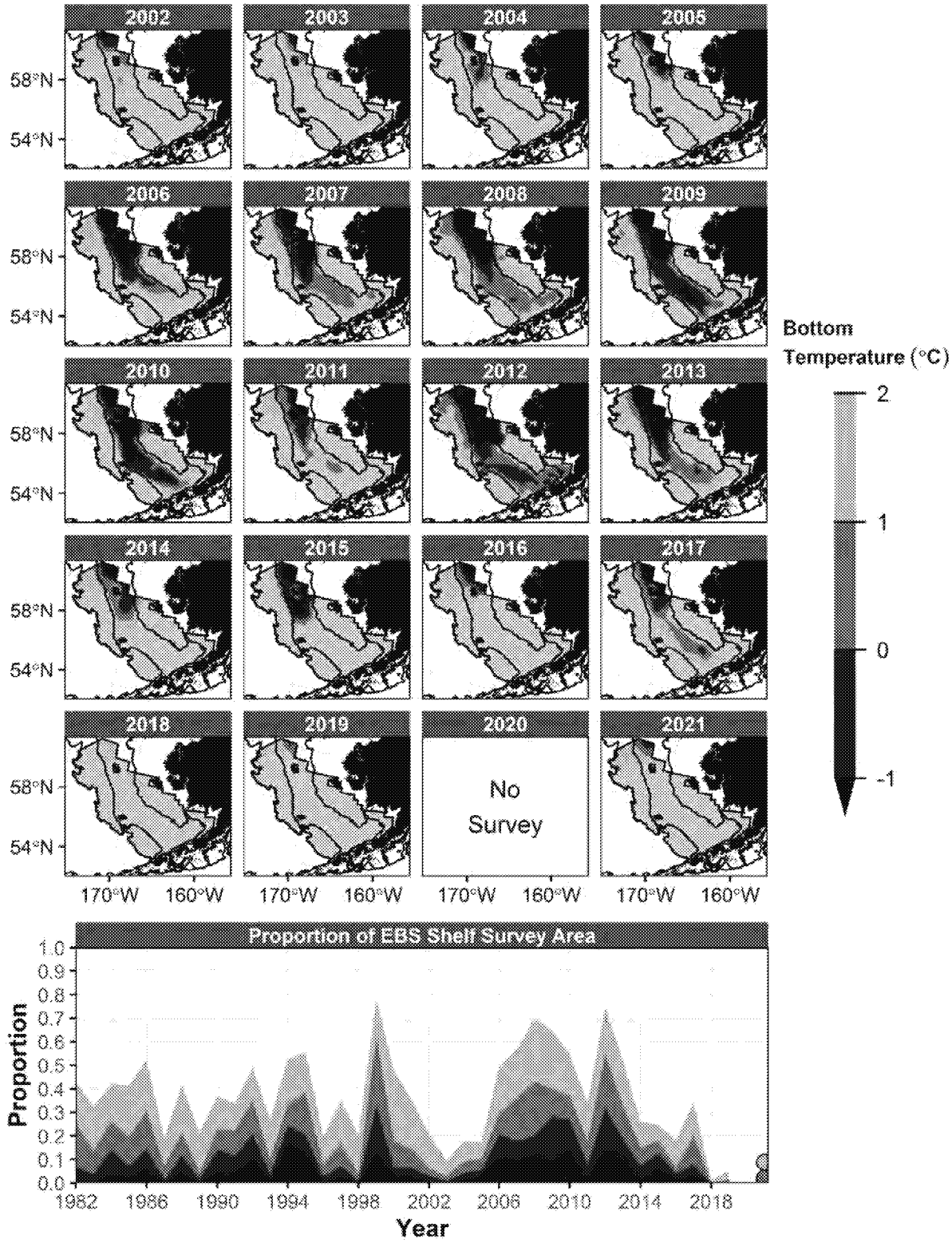

Figure 36: Cold pool extent in the eastern Bering Sea (EBS), as measured using observations from the EBS bottom trawl survey. Upper panels: Maps of cold pool extent in the EBS shelf survey area from 2002–2021. Lower panel: Extent of the cold pool in proportion to the total EBS shelf survey area from 1982–2021. Fill colors denote bottom temperatures ≤2°C, ≤1°C, ≤0°C, and ≤-1°C.

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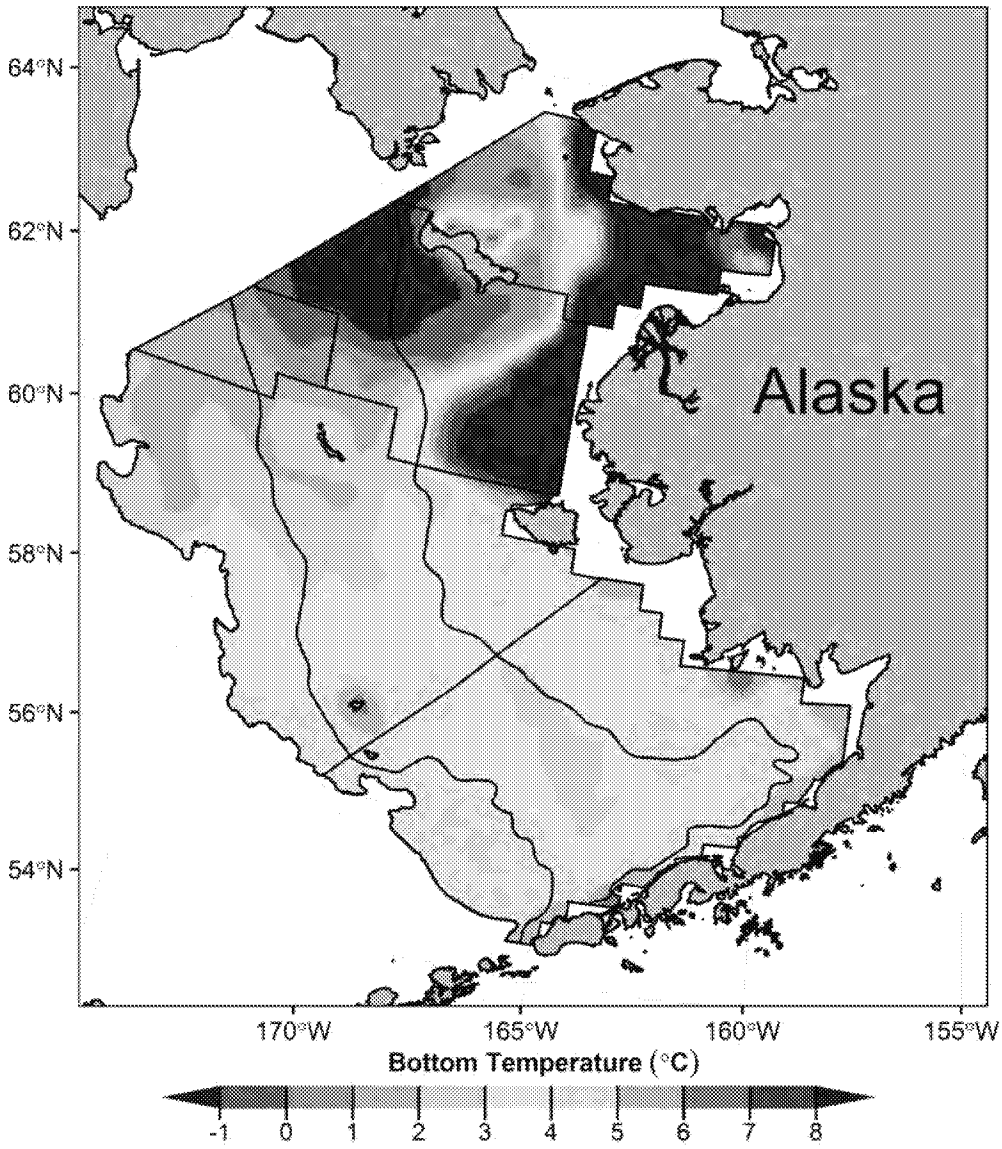

Figure 37: Contour map of bottom temperatures from the 2021 eastern and northern Bering Sea shelf bottom trawl surveys.

Bottom Temperature and Cold Pool Extent from ROMS
Contributed by Kelly Kearney, *kelly.kearney@noaa.gov*
The Bering 10K Regional Ocean Modeling System (ROMS) hindcast simulation was extended to the near-present, using reanalysis-based input forcing. This hindcast simulation now extends from Jan 15, 1970–Aug 18, 2021.

Trends
At 3.30°C, 2021 conditions were warmer than the average simulated southeastern Bering Sea (SEBS) mean bottom temperature between 1970–2021 (2.79°C), following slightly cooler than average conditions in 2020 (2.41°C) (Figure 38). In the summer, much of the SEBS region bottom water was very close to the 2°C threshold used to define the cold pool, with a resulting cold pool index indicating warm conditions (2021: 0.17, 1970–2021 mean: 0.35). As has been the case since 2018, no <0°C water remained in the summer. When compared to previous years, conditions most closely resemble 2004 and 1982 in terms of summer bottom temperature patterns and seasonal evolution of the cold pool indices. These years were all classified as warmer than average, but not extreme, with a spatial pattern showing patches of summer <2°C water in both the northern and southern parts of the southeast middle shelf, some <1°C water in the northern parts of the SEBS region, and no <0°C water.

Bottom Temperatures Along the Shelf Break
Contributed by Kevin Siwicke, *kevin.siwicke@noaa.gov*, and
Tyler Hennon, *tdhennon@alaska.edu*
Since 2005 bottom temperature surveys have been conducted on longline fishing vessels, generally between June and August (Figure 39). Thermistors are mounted to longline equipment, and remain on the bottom for several hours before recovery. Longline surveys are conducted on the Bering shelf break every odd year, and the bottom depths sampled there range between about 250m to 500m.

Trends
Though the period of record is relatively short for the Bering Sea shelf break, the average bottom temperature across all stations during the last four years of surveys (2015–2021) is markedly higher than the prior years (Figure 40). The 2017 summer bottom temperature was particularly high, which may have been a contributing factor leading to extremely low ice extent experienced in 2018. The bottom temperature in 2021 was lower than both 2017 and 2019, though still significantly above the averages from 2009–2013.

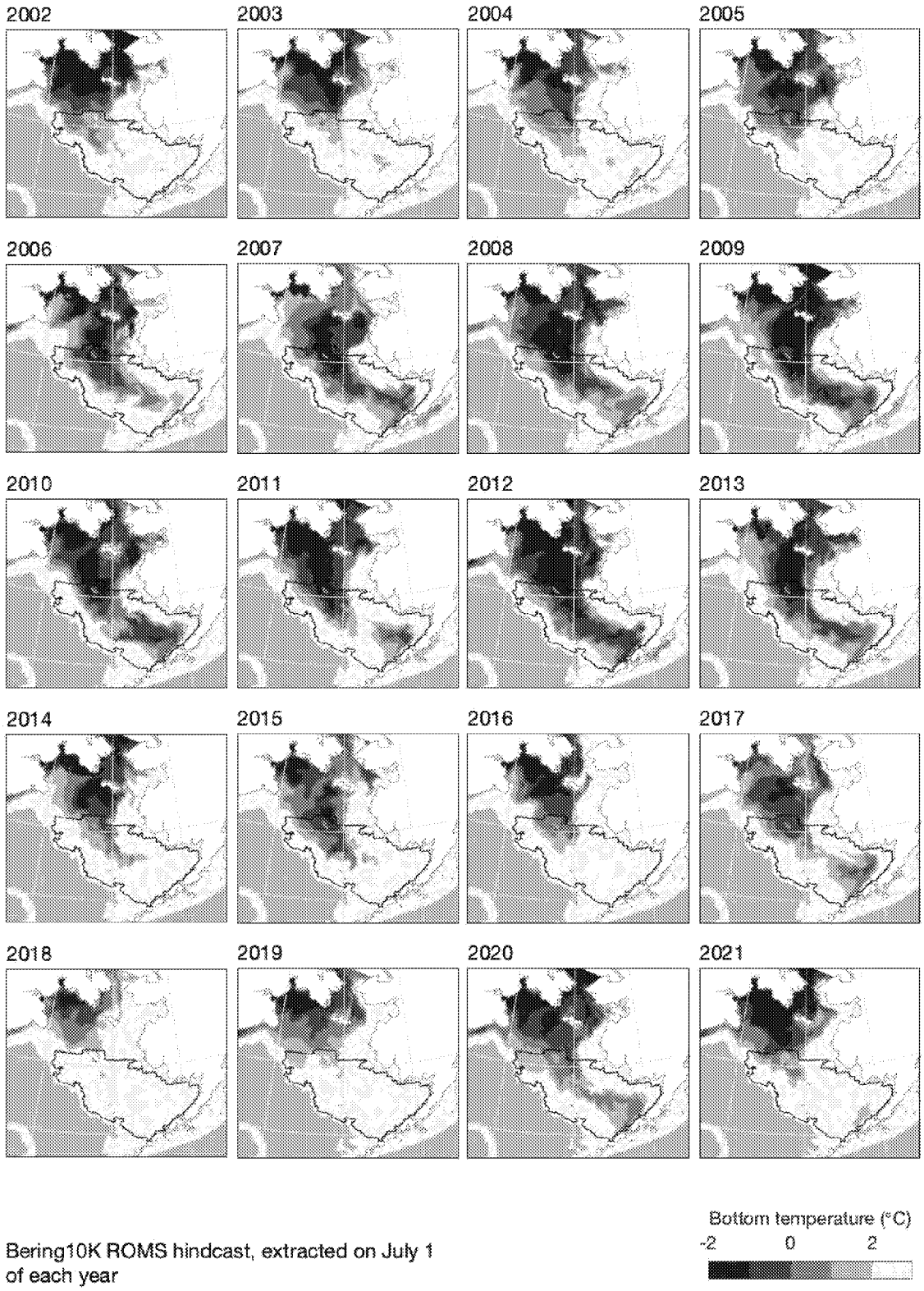

Figure 38: Bering 10K ROMS hindcast of cold pool extent, extracted on July 1 of each year, for the Bering Sea, 2002–2021. The black outline denotes the standard bottom trawl survey grid.

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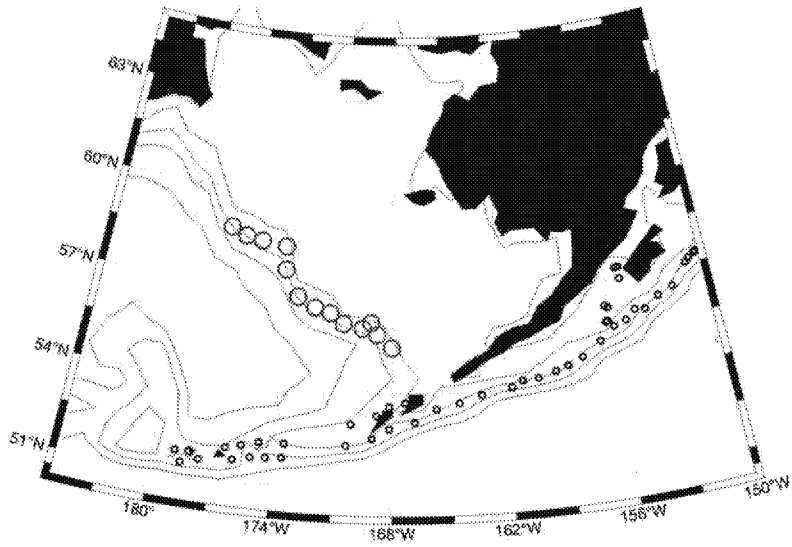

Figure 39: Map of longline survey sites (red circles) on the Bering Sea shelf break, 2009–2021. Black circles show locations of other longline sites across the Aleutian Islands and western Gulf of Alaska.

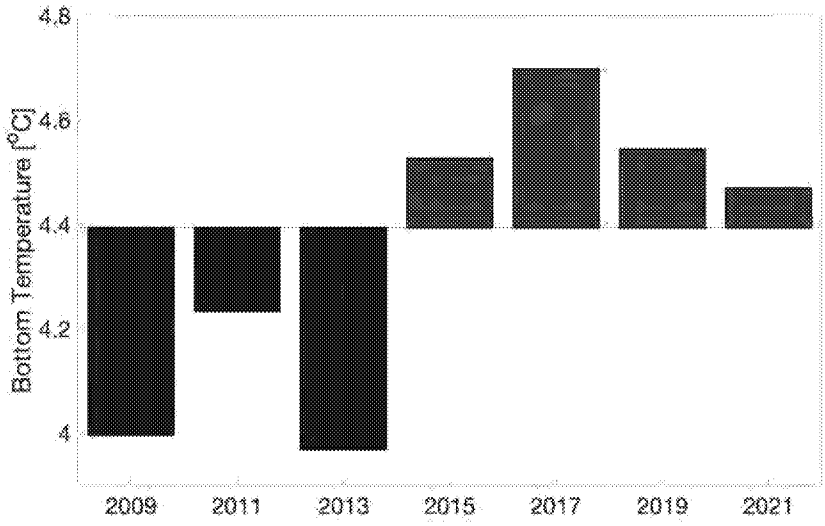

Figure 40: Bottom temperatures averaged across all longline surveys in the Bering Sea (red circles in Figure 39). Red bars indicate bottom temperatures were higher than the period-of-record average, whereas blue indicates they were below average.

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6. Seasonal Projections from the National Multi-Model Ensemble (NMME)

Contributed by Nick Bond, *nicholas.bond@noaa.gov*
Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 41. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME and projections of other variables are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.

The model projections from a year ago are reviewed. In general, the model forecasts from September 2020 for the following fall and winter indicated a continuation of positive SST anomalies across the North Pacific south of 50°N and in the NBS. For the spring of 2021, these forecasts included moderation in the magnitude of the warmer than normal temperatures in the Bering Sea and the development of slightly cooler than normal temperatures in the northern GOA. The model performance as a group was very good for the first period considered (Oct–Dec 2020). In particular, these forecasts showed near-normal temperatures in the vicinity of the Aleutian Islands separating relatively warm SSTs to the south and to the north, as observed. The predictions for the later period (Dec 2020–Feb 2021) were largely correct in a basin-scale sense, specifically relating to La Niña in the tropical Pacific and positive SST anomalies in the mid-latitude North Pacific, particularly in a localized region just east of Japan. From an Alaskan perspective, the models failed to predict the observed development of relatively cold conditions observed along the west coast of Alaska north of Nunivak Island into Norton Sound. The locations and nature of the better and worse model forecasts persisted into the longest time horizon considered (Feb-Apr 2021). The model predictions were quite good for the tropics and mid-latitude North Pacific, but failed with respect to a regional detail in terms of the presence of cool (warm) temperatures for the northern (southern) portion of the EBS shelf.

The NMME forecasts of three-month average SST anomalies indicate a continuation of a large region of relatively warm water in the central and western North Pacific south through the end of the calendar year (Oct-Dec 2021; Figure 41a). Positive anomalies are also predicted for the southeast Bering Sea shelf. Cold anomalies are projected north of Bering Strait, and to a lesser extent, for the GOA. The forecast of cool conditions in the northern waters of Alaska may seem curious given the long-term decline in summer sea ice in the Arctic. The model predictions may in part be attributable to the location of the ice edge during late summer 2021, which is not far displaced from its climatological position for the period of 1981–2010. The models also are indicating relatively high pressure centered south of the Aleutians near the dateline, which results in fewer storms of mid-latitude origin for the northern Bering and Chukchi Seas, and hence fewer incursions of mild, maritime air masses. It will be interesting to see if this scenario actually comes to pass.

The ensemble of model predictions for December 2021 through February 2022 includes anomalously high sea level pressure centered over the western Bering Sea resulting in a decrease in the positive temperature anomalies on the southeast Bering Sea shelf and continued cooling of the GOA (Figure 41b) as compared with climatological norms. These changes are consistent with what has occurred in past La Niña winters; the models as a group are predicting tropical Pacific temperatures commensurate with a moderate La Niña.

The distribution of SST anomalies predicted for February through April of 2022 (Figure 41c) shows

that the trends of the previous 3-month period considered here are liable to be continued. If the models as a group are correct, the late winter and early spring of 2022 will bring near-normal temperatures to most of the Bering Sea and Aleutian Islands, and quite cold temperatures to the central GOA. The models also show a winding down of La Niña in the tropical Pacific. There is a fair amount of spread in the forecasts among the models. More specifically, 2 out of the 6 models forming the NMME are showing that the southeast Bering Sea shelf will remain warmer than normal into spring 2022, and 3 out of the 6 models are emphatic about the cool temperatures in the GOA with the others showing a more muted response. This variability/uncertainty also applies to the sea ice extent over the shelf in the EBS. Most but not all of the models suggest conditions that would result in ice extending south of 60°N perhaps all the way to M2, and as far south as Bristol Bay along the west coast of Alaska.

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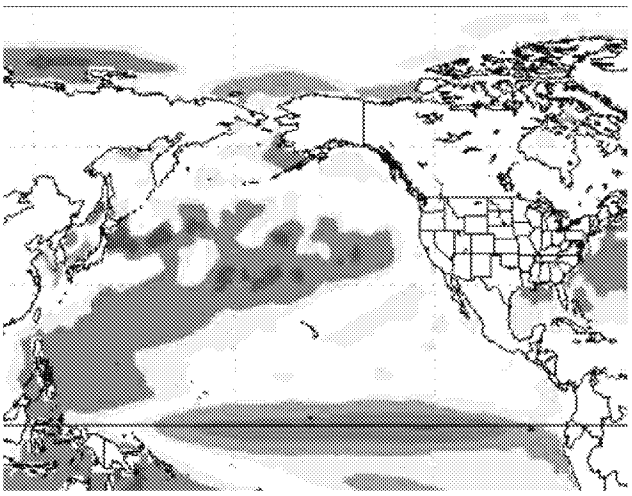
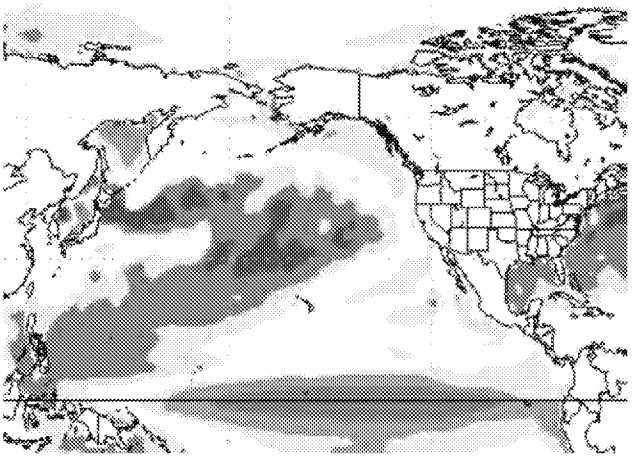
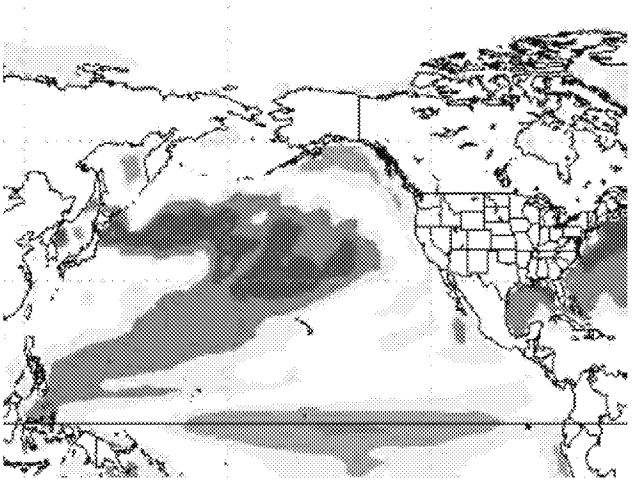


(a) Months Oct–Nov–Dec



(b) Months Dec–Jan–Feb



(c) Months Feb–Mar–Apr

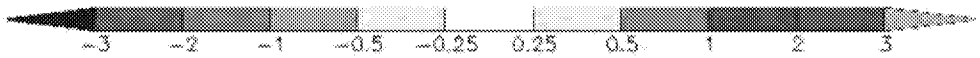


Figure 41: Predicted SST anomalies from the NMME model for Oct–Nov–Dec (1-month lead), Dec–Jan–Feb (3-month lead), and Feb–Mar–Apr (5-month lead) for the 2021–2022 season.

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Habitat

Structural Epifauna - Eastern Bering Sea Shelf

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Last updated: October 2021

Description of indicator: Groups considered to be structural epifauna include: sea whips, corals, anemones, and sponges. Corals are rarely encountered on the eastern Bering Sea shelf so they were not included here. Relative CPUE by weight (kg per hectare) was calculated and plotted for each species group by year for 1982–2021. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (± 1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: Relative catch rates for sea anemones remained similar to estimates from 2016–2019, which were lower than the catch rates during 2010–2015. Sea whip estimates increased from 2019 to a catch rate similar to that observed 1999–2005 and 2013–2016. The catch rate of sponges dropped to the lowest level observed in the time series, but is similar to results observed intermittently during the early years of the time series, 1984–1992. These trends should be viewed with caution, however, because the consistency and quality of their enumeration have varied over the time series (Stevenson and Hoff, 2009; Stevenson et al., 2016). Moreover, the identification of trends is uncertain given the large variability in relative CPUE (Figure 42).

Factors influencing observed trends: Further research in several areas would benefit the interpretation of structural epifauna trends including systematics and taxonomy of Bering Sea shelf invertebrates; survey gear selectivity; and the life history characteristics of the epibenthic organisms captured by the survey trawl.

Implications: Understanding the trends as well as the distribution patterns of structural epifauna is important for modeling habitat to develop spatial management plans for protecting habitat, understanding fishing gear impacts, and predicting responses to future climate change (Rooper et al., 2016); however, more research on the eastern Bering Sea shelf will be needed to determine if there are definitive links.

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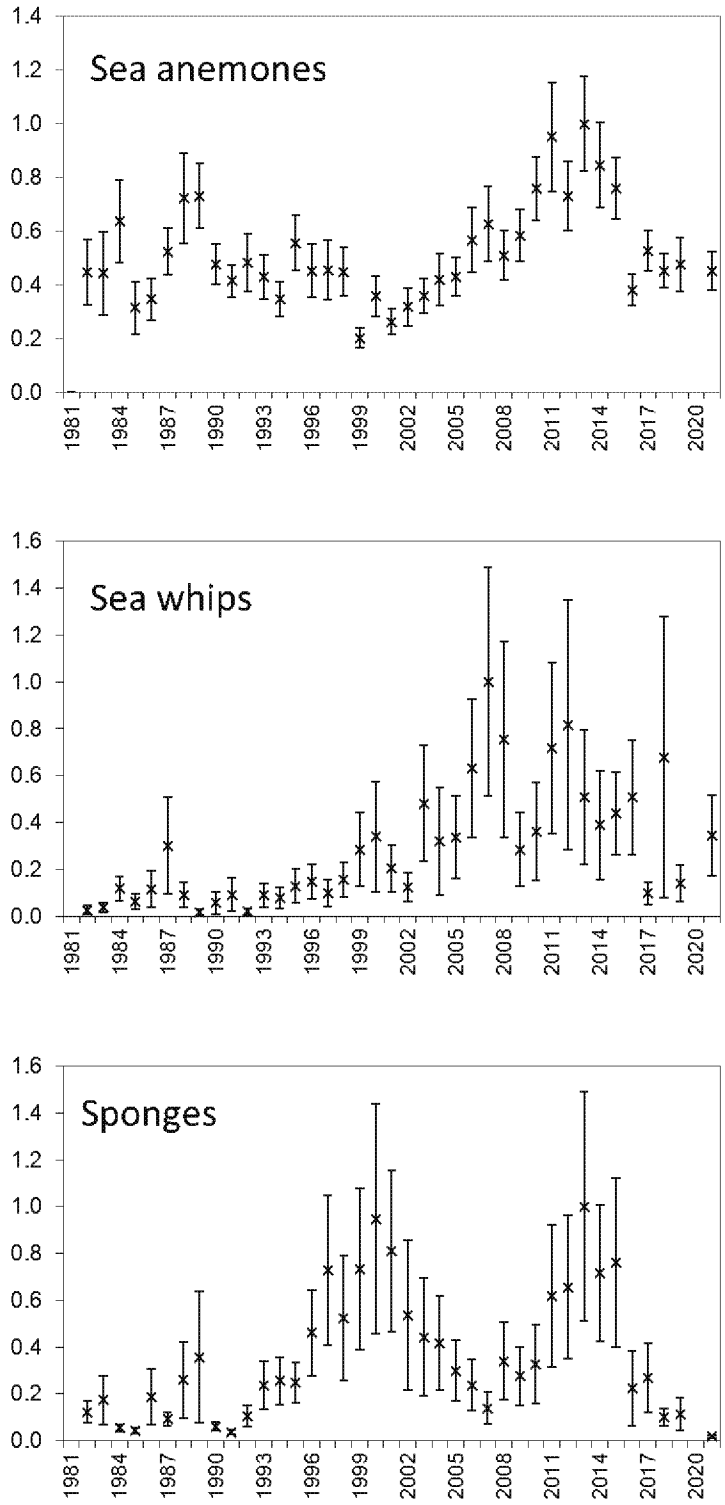

Figure 42: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for benthic epifauna during the May to August time period from 1982–2021.

Primary Production

Spring Satellite Chlorophyll-a Concentrations in the Eastern Bering Sea

Contributed by Jens M. Nielsen[1,2], Lisa Eisner[3], Jordan Watson[3], Jeanette C. Gann[3], Matt W. Callahan[4], Calvin W. Mordy[2,5], Shaun W. Bell[2,5], and Phyllis Stabeno[5]
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[2]Cooperative Institute for Climate, Ocean, and Ecosystem Studies (CICOES), University of Washington, Seattle, WA
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[5]Pacific Marine Environmental Laboratory, NOAA Research, Seattle, WA, USA

Last updated: October 2021

Description of indicator: In subarctic systems, such as the eastern Bering Sea, the timing and magnitude of the spring bloom can have large and long-lasting effects on biological production with subsequent impacts on higher trophic levels including commercial fish stocks (Platt et al., 2003). The fate of the spring bloom (pelagic grazing or sinking to benthos), and it's timing also impact benthic feeders in the Bering Sea (Hunt et al., 2002). Recent climatic changes in the Bering Sea have included reduced sea ice and warming ocean temperatures (Stabeno and Bell, 2019), with consequent changes to the food web (Duffy-Anderson et al., 2019; Hunt et al., 2020). Understanding annual changes in spring phytoplankton biomass and peak timing dynamics are thus important metrics for depicting ecosystem changes. Here, we used ocean color satellite data from 2003–2021 available from the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite at a 4x4 km resolution composites[9] to estimate: 1) average spring (Apr–Jun) chlorophyll-a concentrations (chl-a, an estimate of phytoplankton biomass in the surface layer), and 2) peak timing of the spring open water bloom for major regions in the eastern Bering Sea. In the southeastern Bering Sea, sustained observations at the M2 mooring (56.9°N, -164.1°W) provide good representation of the south middle shelf biophysical conditions. Thus, the long-term chl-a fluorescence mooring measurements were compared to the bloom peak timing estimates calculated from the satellite data.

We focus on the spring period as this is an important time for providing basal resources for zooplankton and thus energy for higher trophic level species. The April–June time-period was chosen as this period consistently includes the pelagic spring bloom peak. We further divided the eastern Bering Sea into 8 distinct regions split between approximately north and south of 60°N and defined by oceanographic fronts and water mass characteristics based on Ortiz et al. (2012) (Figure 43). There are several advantages of satellite data, including high spatial and temporal coverage. However, these products are also limited to measurements within the surface ocean and also have missing data due to ice and cloud cover, particularly in high latitude systems such as the Bering Sea. We used 8-day composite data for the biomass estimates, while 1-day composites were used to assess the spring bloom peak timing.

[9] `coastwatch.pfeg.noaa.gov/erddap/griddap/erdMBchla8day.html`

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Open water spring bloom peak timing was estimated from data binned to 0.5° latitude x 1° longitude spatial grid cells. We then calculated the average and standard deviation of all estimated bloom peaks within a specific region, which allowed for calculation of variability for each of the 8 areas. Grid cells with less than 66% seasonal coverage were excluded.

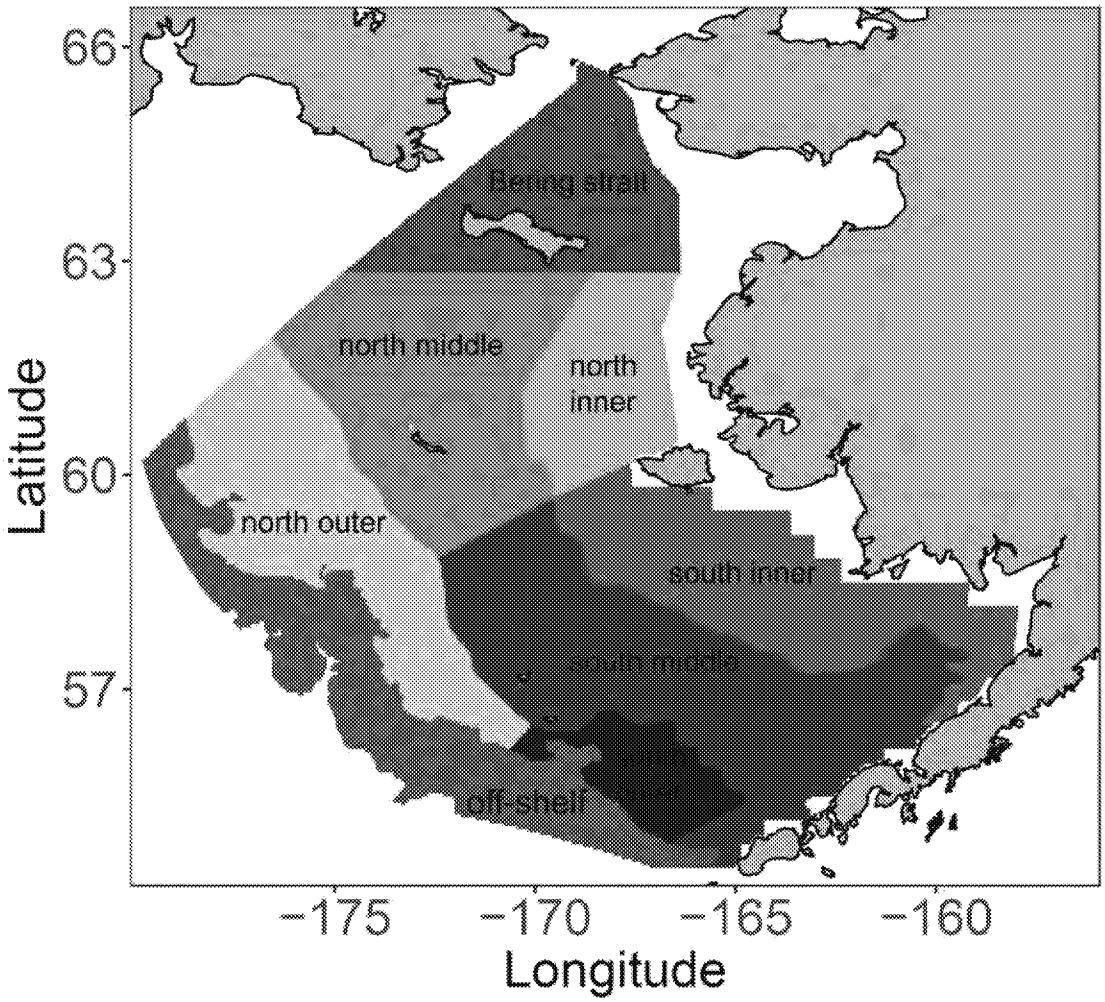

Figure 43: Map of the 8 shelf regions used for satellite chl-a analyses: south inner (purple), south middle (red), south outer (dark blue), off-shelf (dark grey), north inner (orange), north middle (light blue), north outer (yellow), and the Bering Strait (dark green). Off-shelf denotes regions on the shelf break and slope deeper than 200m Ortiz et al. (2012)

.

Status and trends: There was a high degree of interannual variability in satellite chl-a from 2003–2021. Both the south inner (<50m), south middle (50–100m), and south outer shelf (100–180m) had below average values in 2021, similar to values in the period 2016–2019. Values in the north inner and north middle shelf region were close to median. Values along the shelf–break (off-shelf region) were low in 2021, continuing an apparent decreasing trend since 2014 (Figure 44). Data coverage in the southern regions was generally good across all years, however further north, in some years data from April were particularly scarce due to extended ice coverage (Figure 45, blank spaces). Consequently, estimates in spring should be considered with caution during the years when coverage was limited.

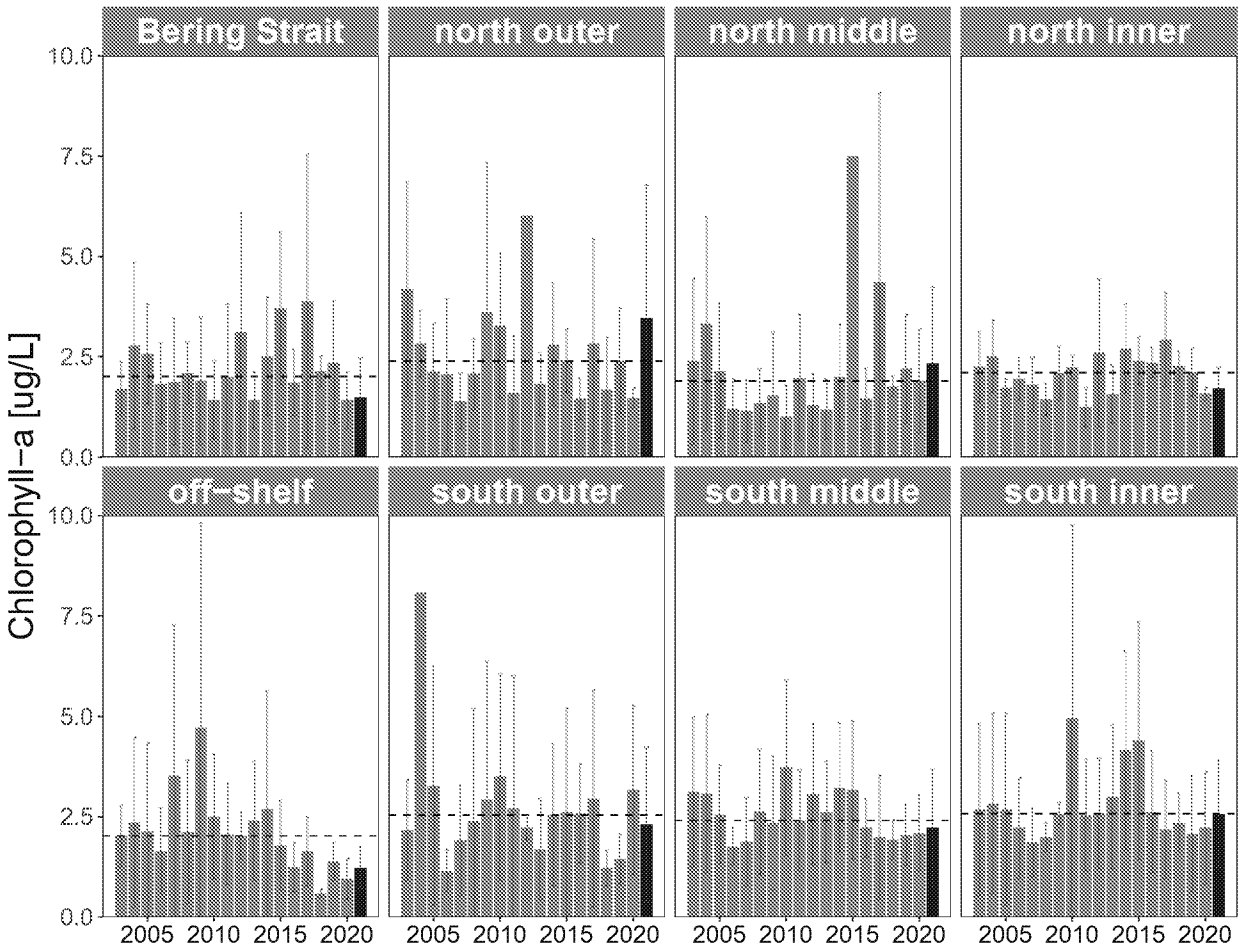

Figure 44: Average and standard deviation (SD) from spring (Apr–Jun) chl-a concentrations for 8 regions in the eastern Bering Sea. Dotted black line denotes the long-term (2003–2021) median for each region. **Note:** For plotting purposes, the minimum error bar is set at 0.01 and the maximum at 9.99. In a few cases, the +standard deviation was >10 (south outer in 2004 was 18.9; north middle in 2015 was 13.8; south outer in 2012 was 11.6).

Preliminary analyses of the pelagic spring bloom peak timing suggest that 2021, which was ice-free, was similar to the long term average in the south inner, south middle, and south outer shelf regions (Figure 46). For the south middle shelf region, peak bloom timing estimated from the satellite data generally concurred well with estimates from the M2 mooring fluorescence data (note: mooring peak timing in 2021 was estimated from the M2 profiling crawler). Exceptions are 2013 and 2016 during which the mooring data showed a much earlier peak than the average peak satellite chl-a timing, though few satellite data was available in that period when the peaks in fluorescence were observed. A second peak in fluorescence was visible in 2013 and 2016 close to the estimates from the satellite peak estimates (data not shown), indicating that some years experience two spring bloom periods. In the off-shelf region, the bloom peak in 2021 was about 1 week earlier than the long-term average but later than 2020, one of the earliest blooms recorded. However, the magnitude of off-shelf spring chll-a concentrations were low overall (Figure 44). Due to lack of consistent data coverage, no bloom satellite peak estimates were done for the northern regions.

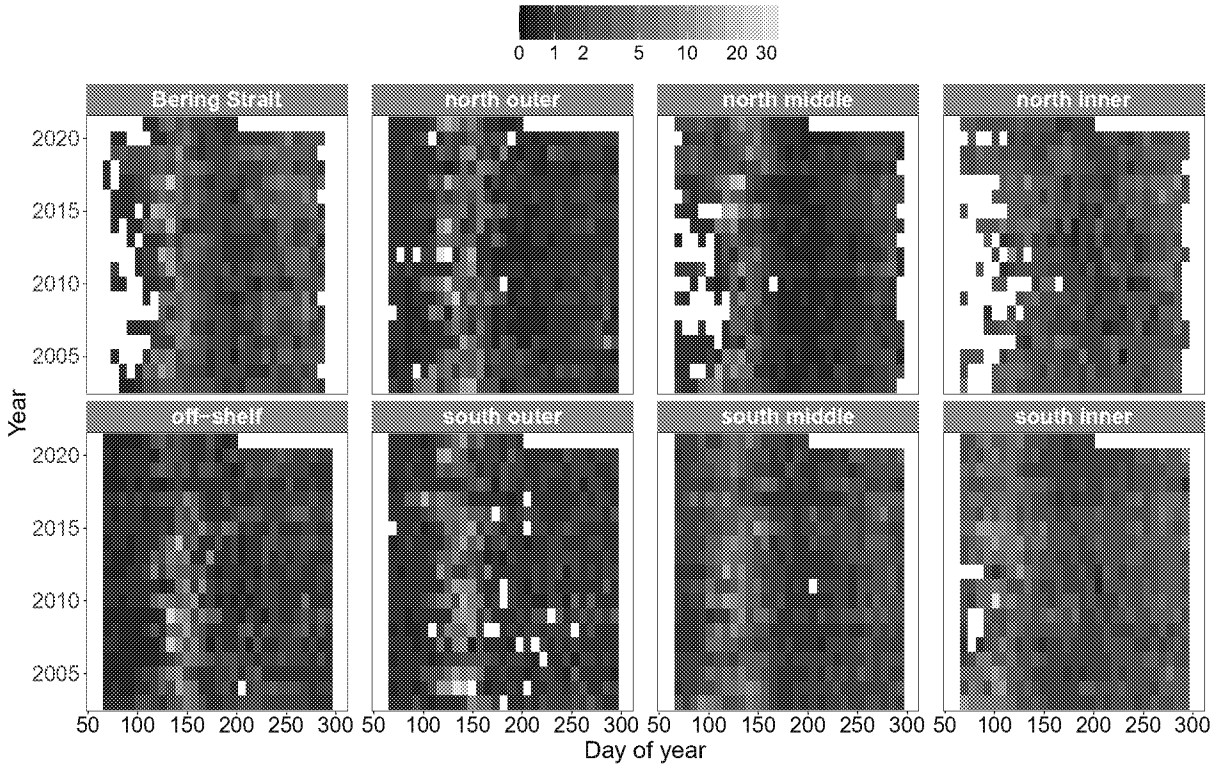

Figure 45: Heatmap of satellite 8-day composite chl-a concentrations for each year and region. Color scale is logged.

Factors influencing observed trends: Previous studies have highlighted the strong coupling between temperature and sea ice dynamics and spring bloom timing. For example, in the southern Bering Sea, ice present after mid-march commonly results in an early and prominent ice-associated bloom, while lack of ice normally results in a delayed open water bloom in mid- to late-May (Hunt et al., 2002, 2011; Sigler et al., 2014). On the southern middle shelf, we observed an earlier spring bloom in the cold years of 2007–2012 (excluding 2009) and in the average years of 2013 and 2017. However, spring bloom timing varied considerably in recent warm years (2018–2021), suggesting that the timing of the bloom was impacted by other factors besides ice. In 2021 bloom timing was average for an open water bloom, which tend to be slightly later (~1–2 weeks) than blooms associated with ice retreat. For open water blooms, variations in springtime winds may influence the setup of stratification (e.g., higher winds can delay stratification, Stabeno et al. (2016)), which in turn affects light availability and the timing of the bloom. Analysis of chl-a biomass, though informative in depicting spring bloom timing, does not directly provide information of primary productivity (growth rates), though biomass levels in spring generally align well with the timing of production peak estimates. Since biomass is a balance between production and losses, lower biomass levels could also indicate enhanced grazing by microzooplankton and mesozooplankton or sinking to the benthos.

Implications: Primary producers provide fundamental energy and nutrients for zooplankton grazers and higher trophic level species. Understanding how climatic perturbations, and particularly the recent warm period, influence phytoplankton dynamics is a critical component in understanding ecosystem dynamics in the Bering Sea. Large, lipid-rich copepods, *Calanus* spp. were in higher

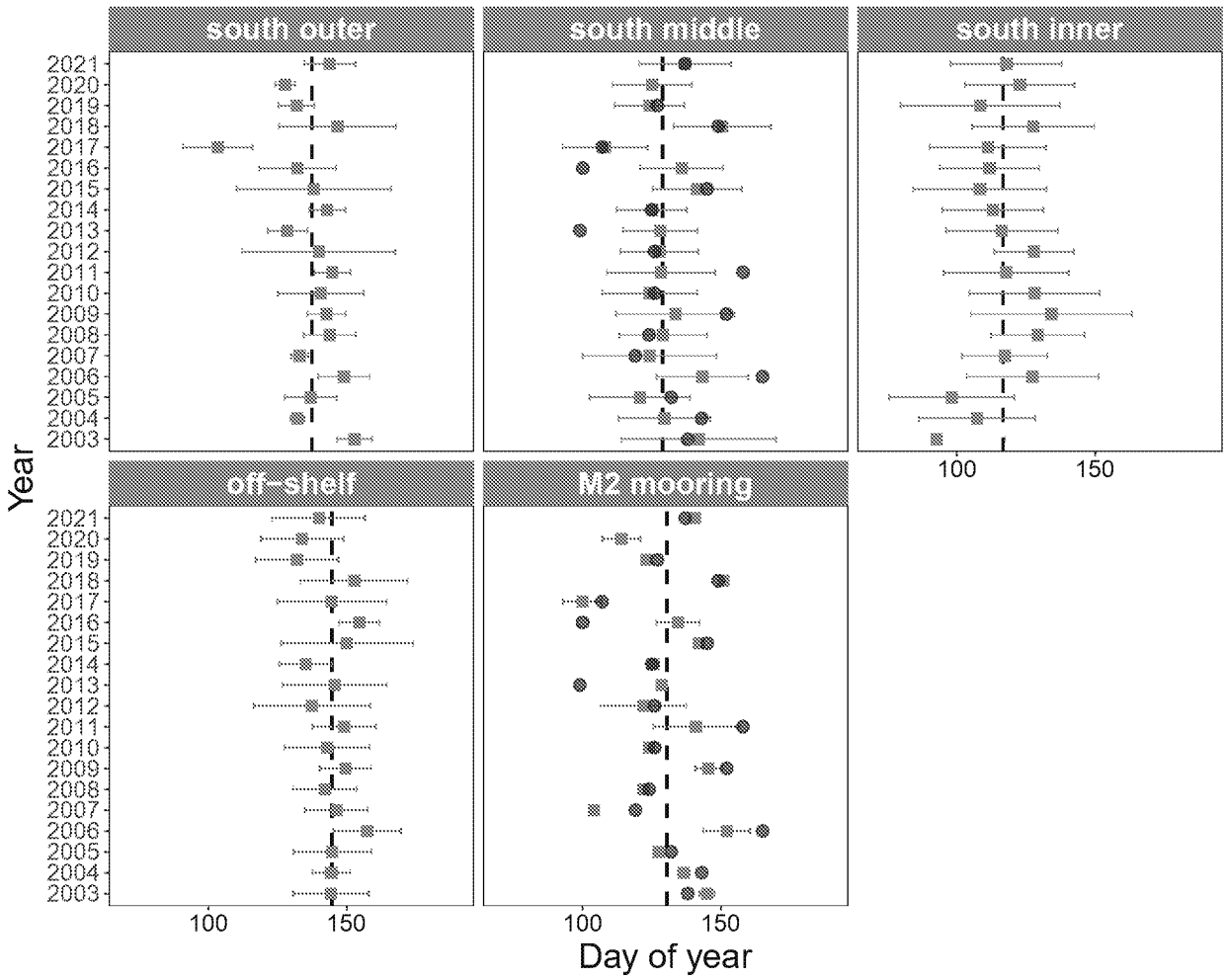

Figure 46: Average and SD of peak spring bloom timing estimated from areas within 4 southern regions in the eastern Bering Sea. Red dots are the M2 fluorescence peak timing estimates, which are compared to both the south middle shelf data and specifically to satellite data near M2 [1° latitude x 1° longitude].

abundance in summer 2017 (see p. 94), a year with an early spring bloom (and average ice cover), which may have offered an early food resource for zooplankton reproduction and survival. Our analyses also showed no significant long-term change in the bloom peak timing among low and high ice years combined. However if warming temperatures during winter and spring accelerate development rates of zooplankton (Coyle and Gibson, 2017) it may also reduce the duration of diapause leading to earlier emergence (Pierson et al., 2013). Thus the timing of the spring bloom has important implications for consumers such as zooplankton, and in turn their predators such as fish larvae. Reduction of sea ice, and thus lack of ice associated phytoplankton blooms also shifts the community composition in favor of pelagic phytoplankton over ice algae; changes that likely have strong impacts on benthic-pelagic energy fluxes (Hunt et al., 2002) and the nutritional composition of basal resources for consumers. The declining trends in chl-a biomass observed along the shelf-break in recent warm years (2016–2021) deserves further investigation. This area includes the "greenbelt", known for high production (Springer et al., 1996), and it will be important to understand the mechanism behind these apparent changes.

Gross Primary Production at the M2 Mooring Site

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[2]Cooperative Institute for Climate, Ocean, and Ecosystem Studies (CICOES), University of Washington, Seattle, WA
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[4]Auke Bay Laboratories, Alaska Fisheries Science Center, NOAA Fisheries

Last updated: October 2021

Description of indicator: The eastern Bering Sea shelf is a highly productive seasonal system with a dominant spring bloom that has long-lasting effects on the biological production of both pelagic and benthic consumers (Springer et al., 1996; Sigler et al., 2016). Here, we categorize seasonal primary production dynamics from 2016 to the present using a high resolution Profiling Crawler (Prawler) attached to a mooring line that collects physical and biological data in the upper 50 meters in combination with other *in situ* data. Specifically, we use dissolved oxygen data to estimate gross primary production (GPP). GPP is the amount of energy (often expressed in carbon units) produced by primary producers (e.g., phytoplankton, ice algae) during a given time (Cassar et al., 2015).

A production indicator using Prawler oxygen measurements was used to better capture the inter-annual dynamics and seasonal of primary production in the eastern Bering Sea. In the southeastern Bering Sea, the long term monitoring buoy "M2" (56.9°N, -164.1°W) provides good representation of the middle Bering Sea shelf biophysical conditions (Stabeno et al., 2001). Starting in 2016, the Prawler continuously collected vertical profiles of physical and biological data, including chlorophyll (chl-a) and dissolved oxygen, in the upper 50 m (data was not available in 2020). From the M2 Prawler we estimated weekly averaged rates of GPP using dissolved oxygen for 2016–2019 and 2021 using a Fourier GPP analysis method (Cox et al., 2015). Currently, GPP estimates are provided as an average estimate based on surface to mixed layer oxygen concentrations. The peak timing of the bloom was estimated as the peak of the 5-day rolling average of the daily GPP estimates. We calculated GPP production estimates for a 2-week period centered around the spring bloom peak, and for the summer period (July–August).

Status and trends: In 2021, the seasonal GPP cycle showed a substantial bloom peak in spring of above >400 mg C m^{-3} day^{-1} (Figure 47). Low production occurs during most of the summer except for smaller increases, commonly induced by increased winds which mix the water column and bring nutrients to the surface. Average GPP in 2021 during the 2-week period around the bloom reached ~350 mg C m^{-3} day^{-1} (Table 2). Those values were similar to values reached during the bloom in 2019 but higher than 2018. The Prawler deployments in 2016 and 2017 only partially covered the bloom and thus those values were not considered. Summer averaged GPP was ~125 mg C m^{-3} day^{-1} which was higher than both 2016 and 2017 but lower than 2018 (141 mg C m^{-3} day^{-1}).

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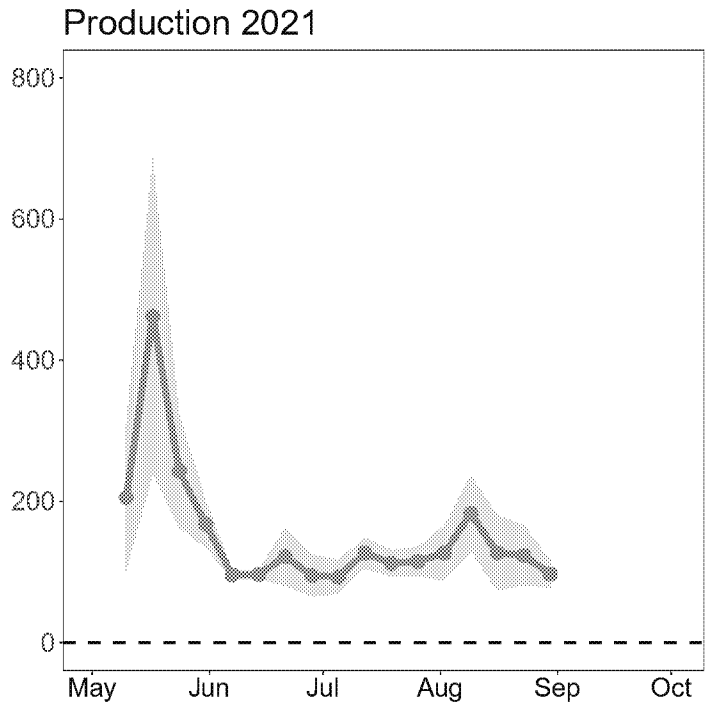

Figure 47: Seasonal cycle of weekly averaged gross primary production in the upper mixed layer from the M2 Prawler in 2021 as determined from dissolved oxygen.

Table 2: M2 Prawler gross primary production (GPP) estimates ± standard deviation (SD) (mg C m^{-3} day^{-1}) during the 14 and 21 days centered around the spring bloom peak, and during mid-summer (July–August). Note that the bloom peak was only partially captured in 2016 and missed entirely by the Prawler in 2017. Data was not available for mid-summer 2019 and all of 2020. Estimates from 2021 are preliminary. The bloom in 2018 was late compared to historical data (see p. 80). Initial gross primary production estimates in O_2 were converted to C units, using a C:O conversion of (106:138).

Year	**Peak bloom timing**	**Bloom GPP** 14 day (centered around peak)		**Mid-summer GPP** July-August	
	day of year	mean	±SD	mean	±SD
2016	129	215.8	61.8	81.1	31.7
2017	107	NA	NA	56.9	14.2
2018	152	302.9	142.6	141.5	53.7
2019	139	322.5	212.7	NA	NA
2020	NA	NA	NA	NA	NA
2021	135	351.2	191	124.8	41.6

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Factors influencing observed trends: The bloom peak timing appears to be average for an ice-free winter in southeastern Bering Sea (see p. 80). The 2021 GPP seasonal dynamics and bloom magnitude may provide good baseline information for average conditions in this region. Previous estimates from the Prawler (2016–2019) were mostly from warm years, except for 2017. However, the year 2017 deserves more attention as this was a highly abnormal year with a very early bloom peak and a subsequent subsurface chl-a max that persisted through the spring and into early summer. Since the Prawler was deployed after the bloom initiation, no GPP spring bloom estimate was possible for the year 2017.

Implications: In 2021, during the 2–3 weeks of the spring bloom peak GPP was >2x the total summer production. Summer production in 2021 appeared to be higher than most previous years (2016, 2017, 2019), but lower than 2018. Nonetheless, production during summer is commonly low, except during wind events that may enhance production during shorter periods (Sambrotto et al., 1986). Reduced production in summer is likely a combination of nutrient limitation and shifts in phytoplankton community composition (Lomas et al., 2020).

Coccolithophores in the Bering Sea

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Last updated: October 2021

Description of indicator: Blooms of coccolithophores, a unicellular calcium carbonate-producing phytoplanktonic organism, are easily observed by satellite ocean color instruments due to their high reflectivity. Coccolithophores produce calcium carbonate plates (coccoliths) that contribute to particulate inorganic carbon (PIC) in the ocean (Matson et al., 2019). Blooms are most commonly observed and cloud cover is typically lower during September than other months allowing for better quantification (Iida et al., 2012). An interannual index of the average area (km^2) covered by coccolithophores during the month of September is calculated with monthly average mapped PIC data (Balch et al., 2005; Gordon et al., 2001) from satellite. The indices are calculated from MODIS-Aqua satellite data (2002–2020) and from the VIIRS-SNPP satellite (2012–2021) provided by NASA Goddard Space Flight Center, Ocean Ecology Laboratory (MODIS-Aqua, 2018) are highly correlated and both are presented here for continuity.

PIC>0.0011 mol/m^3 was used to estimate the location of the influence of coccolithophore blooms. This threshold was derived by Matson et al. (2019). Highly reflective waters in shallow water near the coast can be due to re-suspended diatom frustules rather than coccoliths (Broerse et al., 2003). Thus, the index is calculated from the region south of 60°N and deeper than 30m depth to avoid contamination by shallow regions around St. Matthew and St. Lawrence islands and along the Alaskan coast, as well as sediment associated with the Yukon River. Because blooms are often largely confined to either the middle shelf or the inner shelf (Ladd et al., 2018), two indices are

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calculated, one for the middle shelf (50–100m depth) and one for the inner shelf (30–50m depth).

Note that the methodology for calculating the index has changed since the 2017 contribution. Because the index represents only a monthly estimate of spatial area influenced by coccolithophore blooms (and not more rigorous biomass or other biogeochemical estimates), it was determined that PIC provided the necessary information and is easily available data. Correlation with the previous index is R^2=0.98. In addition, the index calculations were updated in 2021, resulting in some changes to the overall estimates (mean change 13% higher for middle shelf and 26–35% higher for the inner shelf), however, the inteannual patterns from previous years are still present.

Before 1997, coccolithophore blooms in the eastern Bering Sea were rare. A large bloom (primarily *Emiliania huxleyi*) occurred in 1997 (Napp and Hunt, 2001; Stockwell et al., 2001) and for several years thereafter. During the 1997 bloom, the bloom was associated with a die-off of short-tailed shearwaters (*Puffinus tenuirostris*), a seabird commonly seen in these waters (Baduini et al., 2001). It was thought that the bloom may have made it difficult for the shearwaters to see their zooplankton prey from the air (Lovvorn et al., 2001). Since then, coccolithophore blooms in the eastern Bering Sea have become more common. Satellite ocean color data suggest that blooms are only found where water depths are between 20 and 100m. Blooms typically peak in September and interannual variability is related to both very weak and strong stratification (Iida et al., 2012; Ladd et al., 2018).

Status and trends: Annual images (Figure 48) show the spatial and temporal variability of coccolithophore blooms in September. Annual indices are obtained from satellite data by averaging spatially over the inner and middle shelf (Figure 49). Coccolithophore blooms were particularly large during the early part of the record, 1997–2000 (not shown). At the start of the MODIS-Aqua record, the index was low and remained low (<50,000 km^2) through 2006. In 2007, the index rose to almost double that observed in 2006 (~102,000 km^2). A higher index (>50,000 km^2) was observed in 2007, 2009, 2011, 2014, 2016, 2020, and 2021 for the middle shelf and in 2011 and 2014 (>20,000 km^2) for the inner shelf. Commonly for years with high index values (e.g., 2014, 2016, 2020) blooms are also observed in August (data not shown). September 2017 exhibited the lowest index of the record. The bloom index remained below average in 2018 and 2019, but increased, particularly on the middle shelf, in 2020 and was again high in 2021.

Factors influencing observed trends: It has been suggested that the strength of density stratification is the key parameter controlling variability of coccolithophore blooms in the eastern Bering Sea (Iida et al., 2012; Ladd et al., 2018). Stratification influences nutrient supply to the surface layer. Stratification in this region is determined by the relative properties (both temperature and salinity) of two water masses formed in different seasons, the warm surface layer formed in summer and the cold bottom water influenced by ice distributions the previous winter. Thus, the strength of stratification is not solely determined by summer temperatures and warm years can have weak stratification and vice versa (Ladd and Stabeno, 2012).

Implications: Coccolithophore blooms can have important biogeochemical implications. The Bering Sea can be either a source or a sink of atmospheric CO_2, with the magnitude of coccolithophore blooms and the associated calcification playing a role (Iida et al., 2012). In addition, variability in the dominant phytoplankton (diatoms vs. coccolithophores) is likely to influence trophic connections with the smaller coccolithophores resulting in longer trophic chains. Coccolithophores may be a less desirable food source for microzooplankton in this region (Olson and Strom, 2002). As noted previously, the striking milky aquamarine color of the water during a coccolithophore bloom can also reduce foraging success for visual predators.

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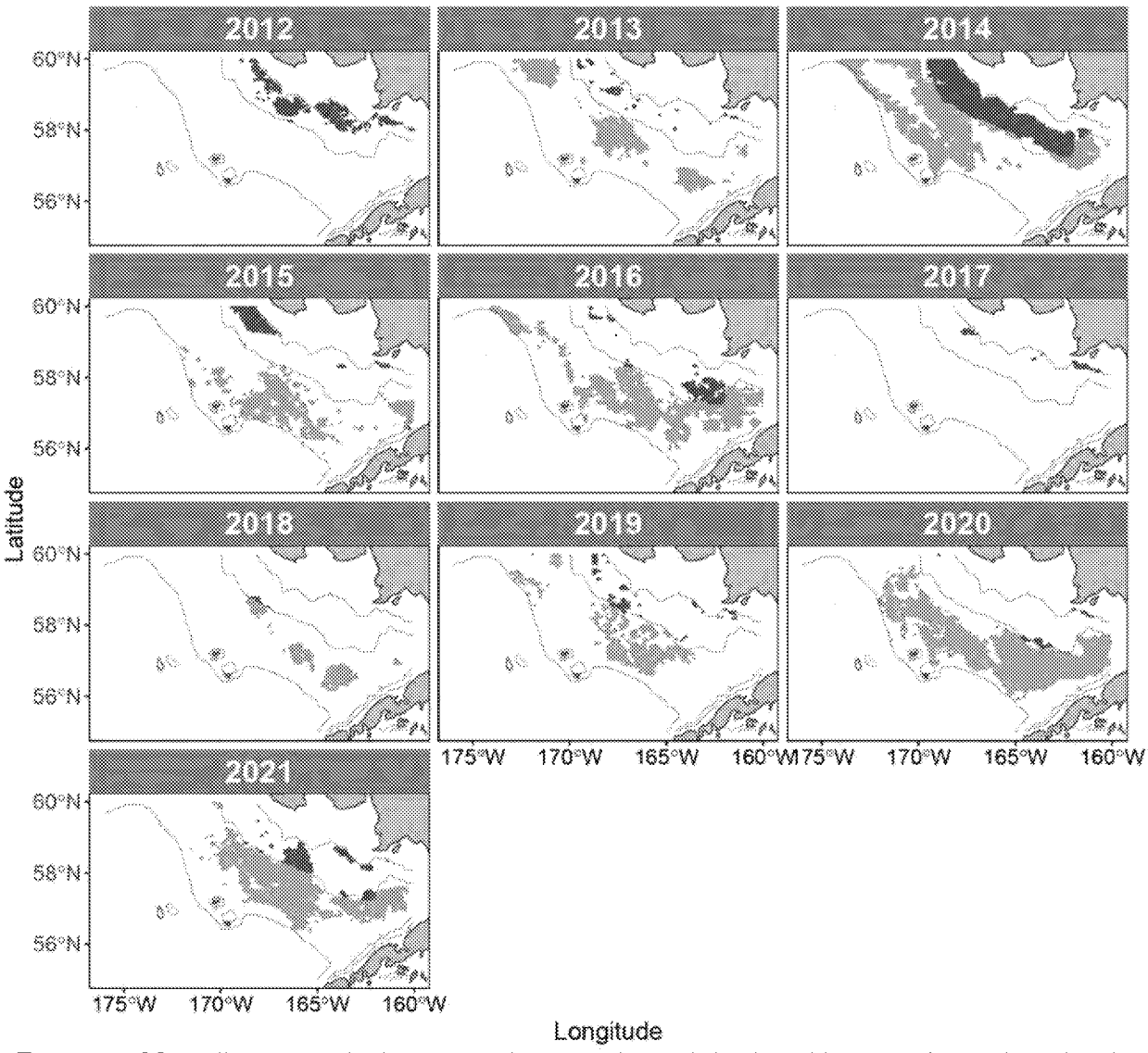

Figure 48: Maps illustrating the location and extent of coccolithophore blooms in September of each year from VIIRS-SNPP data. Color: satellite ocean color pixels exceeding the threshold (PIC>0.0011 mol/m^3) indicating coccolithophore bloom conditions. Blue: inner shelf (30–50 m depth), Green: middle shelf (50–100 m depth). These data are used to calculate the areal index in Figure 49.

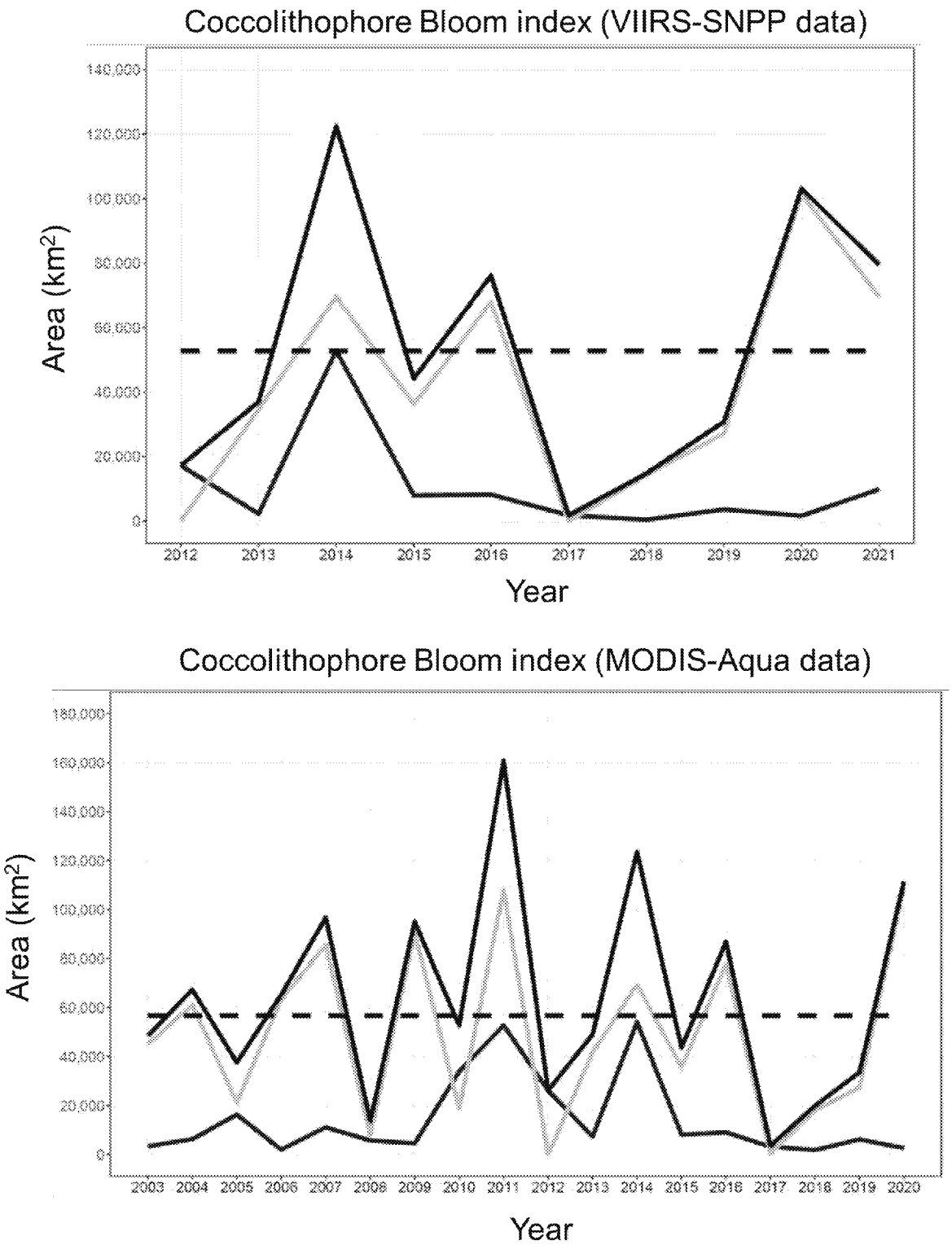

Figure 49: Coccolithophore index for the southeastern Bering Sea shelf (south of 60°N). Top panel shows index calculated from VIIRS-SNPP satellite; Bottom panel shows index calculated from MODIS-Aqua satellite. Blue: average over the inner shelf (30–50 m depth), Green: average over the middle shelf (50–100 m depth), Black: total. The black dotted line is the long-term average. At the time of writing MODIS-Aqua data for 2021 were not yet available.

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Zooplankton

Continuous Plankton Recorder Data from the Eastern Bering Sea

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Description of indicator: Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. Two transects are sampled seasonally, both originating in the Strait of Juan de Fuca, one sampled monthly (~April–September) which terminates in Cook Inlet, the second sampled 3 times per year (in spring, summer, and autumn) which follows a great circle route across the Pacific terminating in Asia. Several indicators are now routinely derived from the CPR data and updated annually.

As well as the regular Pacific CPR sampling, the icebreaker the *Sir Wilfrid Laurier* (SWL) has now sampled a transect through the Bering Strait, and the western Chukchi and Beaufort Seas during the summer months of 2018, 2019, and 2020. The SWL is currently towing a CPR in the same region for 2021, however we do not (at present) have the funds to complete the sample analysis for the year 2021. These Arctic routes have been funded via annual research bursary schemes that have now come to an end; we are therefore looking for long-term funding to continue sampling in these areas in the future, as they provide important information on this transition area.

In this report we highlight this Arctic route that started in 2018 and transects the Bering Strait during the summer months of July through September. We present CPR data from the eastern Bering Sea region (Figure 50) as the following indices: the abundance per sample of large diatoms (the CPR only retains large, hard-shelled phytoplankton so while a large proportion of the community is not sampled, the data are internally consistent and may reveal trends), mean Copepod Community Size (see Richardson et al. (2006) for details but essentially the length of an adult female of each species is used to represent that species and an average length of all copepods sampled calculated) as an indicator of community composition and mesozooplankton biomass (estimated from taxon-specific weights and abundance data). Annual anomaly time series of each index have been calculated using a standard z-score calculation: z-score = $(x - \mu)/\sigma$ where x is the value and μ is the mean, and σ is the standard deviation (Glover et al., 2011). Scores of zero are equal to the mean, positive scores signify values above the mean, and negative scores values below the mean.

Status and trends: Figure 51 shows that the copepod community size and mesozooplankton biomass anomalies for 2020 were negative, where they had been positive in 2019. The mean diatom abundance anomaly was also negative in 2020.

Factors influencing observed trends: As there are only 3 years of consistent data, it is difficult to determine any trend. Analysis of summer CPR data in this region has revealed a general alternating (and opposing) pattern of high and low abundance of diatoms and large copepods in 2018 and 2019. This is a similar finding to the analysis from Batten et al. (2018), which was carried out in the southern Bering Sea and Aleutian Islands, and concluded that this was the result of a

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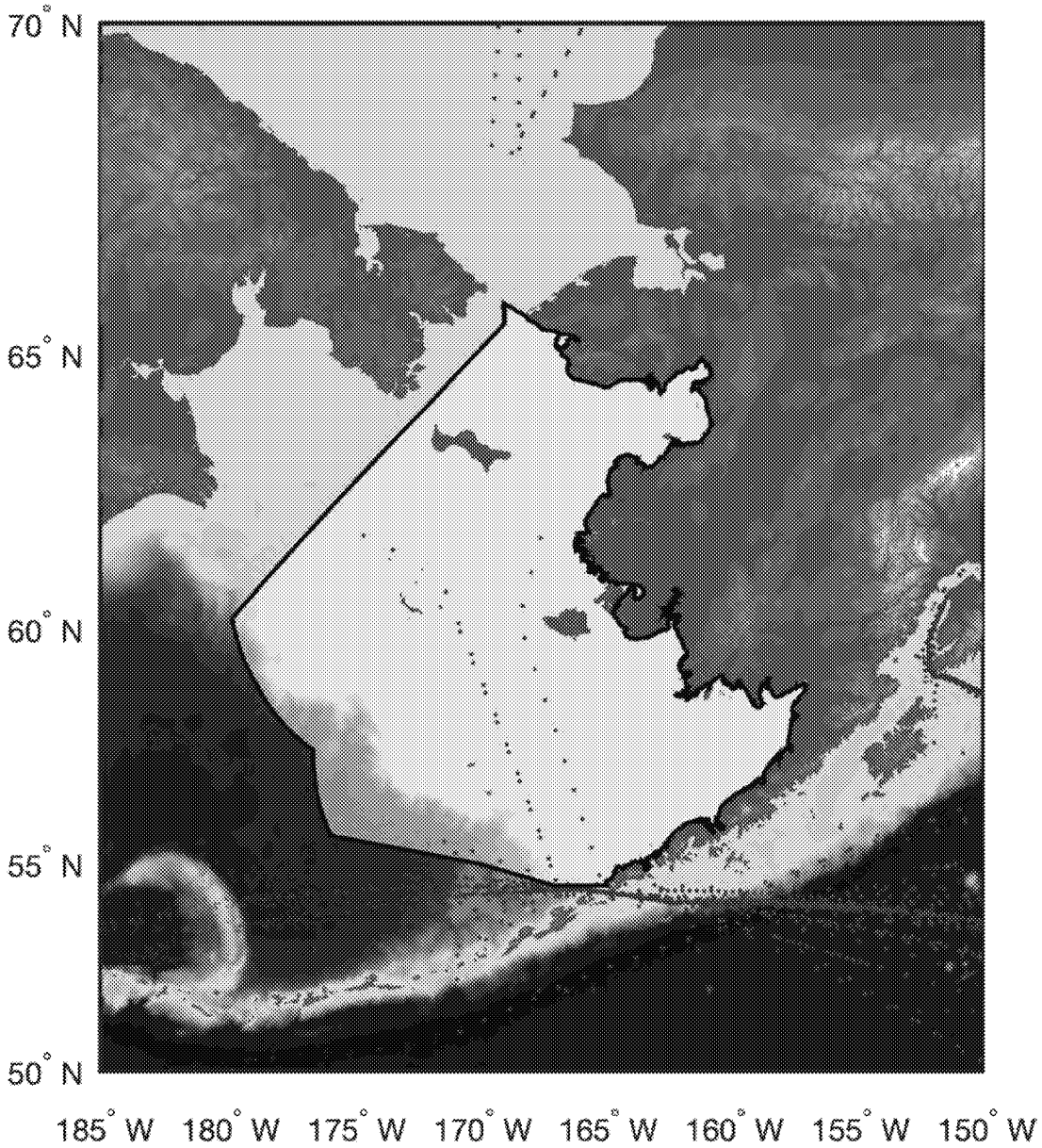

Figure 50: Location of CPR data, the region selected for analysis in this report is highlighted by a yellow rectangle. Red dots indicate actual sample positions and may overlay each other.

trophic cascade caused by maturing pink salmon present in the region. The zooplankton data in Figure 51 consist of more taxa than just large copepods but it is likely that there is some top-down influence of the pink salmon also present in these data.

Implications: This region appears to be subjected to top-down influence by pink salmon as well as bottom-up forcing by ocean climate, which is particularly challenging to interpret. Changes in community composition (e.g., abundance and composition of large diatoms, prey size as indexed by mean copepod community size) may reflect changes in the nutritional quality of the organism to their predators. Changes in abundance or biomass, together with size, influences availability of prey to predators.

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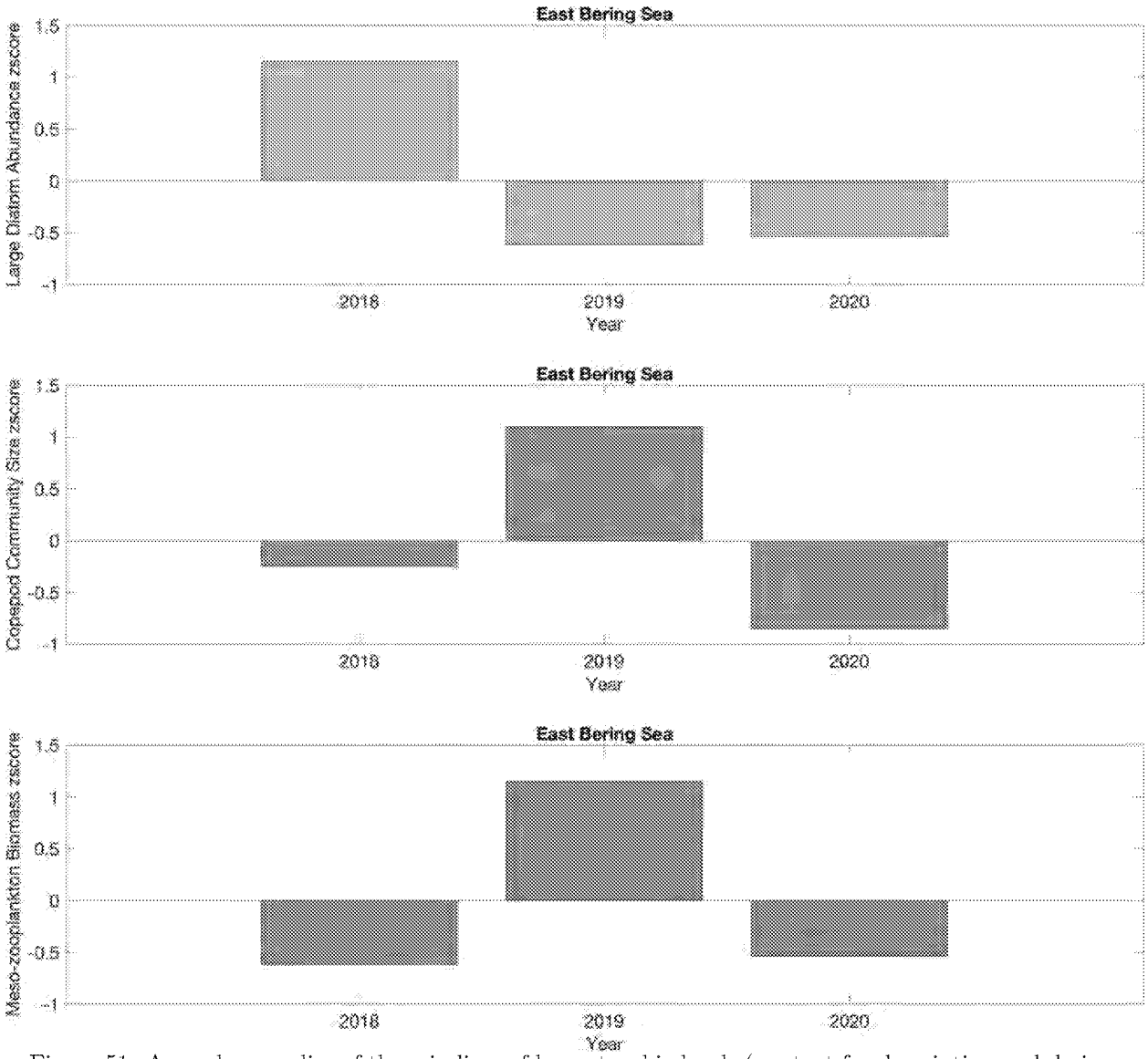

Figure 51: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for the region shown in Figure 2.

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Current and Historical Trends for Zooplankton in the Bering Sea

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Last updated: October 2021

Description of indicator: In 2015, NOAA's Alaska Fisheries Science Center (AFSC) implemented a method for an at-sea Rapid Zooplankton Assessment (RZA) to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20/60 cm oblique bongo tows from 10 m from bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2000). The categories are small copepods ($\leq$2 mm; example species: *Acartia* spp., *Pseudocalanus* spp., and *Oithona* spp.), large copepods (>2 mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids (<15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 μm mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 μm mesh, 60 cm bongo net. Other, rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method.

RZA abundance estimates may not closely match historical estimates of abundance as methods differ between laboratory processing and ship-board RZA, particularly for euphausiids which are difficult to quantify accurately (Hunt et al., 2016). Rather, RZA abundances should be considered estimates of relative abundance trends. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1 year post survey). Here, we show updated long-term time-series for the middle shelf of the southeastern Bering Sea for the spring 70 m isobath survey and northern Bering Sea. The mean abundance of each RZA category was plotted for the southern middle shelf of the Bering Sea (Ortiz et al., 2012) and represent primarily April and May in spring as the months with the greatest sampling frequency. The 2021 survey occurred from 1 May to 20 May. The northern Bering Sea survey represents late summer (August and September) in the inner and middle shelf region. The 2021 NBS survey occurred from 27 August to 20 September. Plots show the historical, archived abundance estimates from laboratory processed samples and on-board RZA estimates.

The total lipid content from RZA samples were performed on the designated zooplankton categories of large copepods and euphausiids, which were collected separately in glass vials from each station, stored frozen, and analyzed at NOAA's Auke Bay Laboratories. Briefly, the measured lipid content was compared to the respective wet-weight for the zooplankton in each vial. Lipid analysis was performed via a rapid colorimetric technique employing a modified version of the sulfo-phospho-vanillin (SPV) assay (Fergusson et al., 2020). This method was proven to be highly accurate for analyzing zooplankton lipids in a recent inter-laboratory cross validation study (Pinger et al., in prep).

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Status and trends:

Southeastern Bering Sea

We did not detect high abundances of large-sized (>2 mm) *Calanus* spp. copepods along the middle shelf (Figure 52a) in spring and estimates were low compared to historical values as well (Figure 53a). Abundances were similar to the last cold year with significant ice coverage that we sampled, 2017. Small copepods (≤2mm) were similar along the 70 m isobath (Figure 52b) and similar to abundances measured in recent years (Figure 53b). Euphausiids (<15 mm) were very low in abundance, particularly in the southern Bering Sea where they were largely absent (Figure 52c). This was also reflected in the time-series, where euphausiid values were near zero (Figure 53c). However, large euphausiids (> 15 mm) were abundant (data not shown). Lipid content in large copepods (*Calanus* spp.) was low overall in spring, with a few stations showing elevated values in the southern portion of the 70 m isobath (Figure 54a). Lipid content in euphausiids was low overall, measuring less than 1% of total wet weight across the 70 m line (Figure 54b).

Northern Bering Sea

In 2021, abundances of large copepods (>2 mm) in the northern Bering Sea were low across the sampling grid, with the exception of some stations in the north (Figure 55a). Average abundances of large copepods estimated by the RZA were higher than 2018 and 2019, but low compared to the colder years of 2011–2013 (Figure 56a). Small copepod (<2 mm) abundances were higher in the northern portion and lower in the southern portion of the sample area (Figure 55b). Numbers of small copepods remained fairly consistent with values measured over the last 7 years (Figure 56b). In contrast, euphausiid abundances were slightly higher in the southern portion of the northern Bering Sea (Figure 55c) with numbers slightly higher compared to recent estimates (Figure 56c). Lipid content in large copepods (>2 mm; *Calanus* spp.) was elevated compared to spring values and highest near the southern, middle shelf portion of the survey (Figure 57a). Lipid content in euphausiids was also higher than that observed during spring with two stations in the northern portion of the sampling grid having the highest percent lipid observed (Figure 57b).

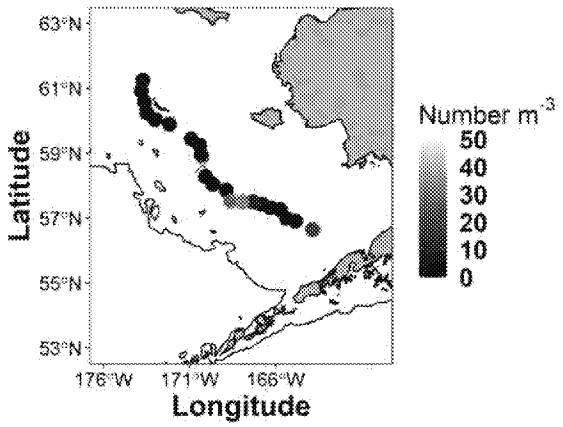
Factors influencing observed trends:

Southeastern Bering Sea

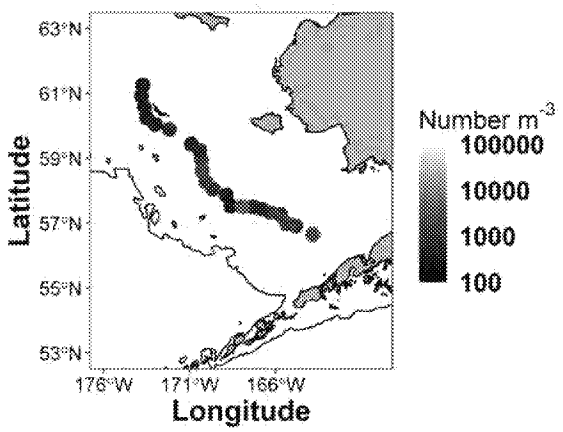
Based on observations made during the spring survey, we began sampling prior to the spring phytoplankton bloom at M2 (see p. 80). Ice had only recently retreated and we were able to approach the ice edge which was approximately 10 nm north of St. Matthew Island. Large copepods (*Calanus* spp.) respond strongly to sea ice dynamics in the Bering Sea (Eisner et al., 2018; Kimmel et al., 2018; Hunt et al., 2020). We noted low numbers of *Calanus* spp. in the larger net; however, we did see evidence of smaller stages of *Calanus* spp. (<2 mm) that were present in the 20 cm net and counted as small copepods. This suggests that *Calanus* spp. individuals were mostly in earlier copepodite stages, thus large copepod abundances were low.

The lower temperatures likely also caused a reduction in small copepod numbers, though not to the same degree as with the larger sized copepods. Small copepods showed little interannual variability in the Bering Sea (Figure 52 and Figure 53). These small, continuously reproducing copepods have growth rates that are more strongly related to temperature than food supply or body size (Hirst and Bunker, 2003). This can be seen in the lower relative abundances during colder years (2009–2012) and the elevated abundances in the more recent warm period (Figure 53).

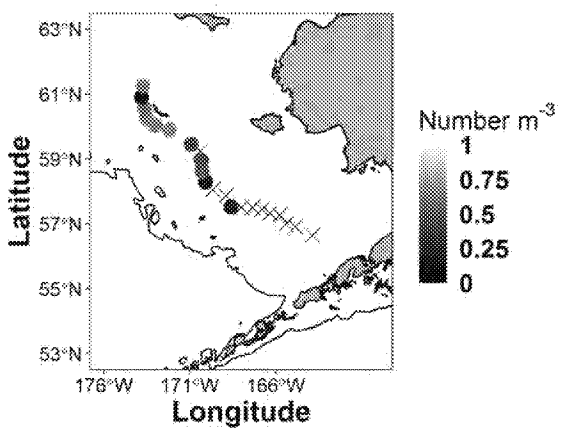
The very low abundances of euphausiids (<15 mm) may also be related to the colder temperatures. Normally, larger sized (>15 mm) euphausiids are in very low abundance in our surveys; however, we found higher abundances of >15 mm euphausiids on average compared to <15 mm euphausiids.



(a) Large copepods (>2 mm)



(b) Small copepods (≤2 mm)



(c) Euphausiids (<15 mm)

Figure 52: Maps show the spring abundance of large copepods (>2 mm), small copepods (≤2 mm), and euphausiid larvae/juveniles (<15 mm) in the southeastern Bering Sea estimated by the rapid zooplankton assessment. Note all maps have a different abundance scales (Number m^3). X indicates a sample with abundance of zero individuals m^3.

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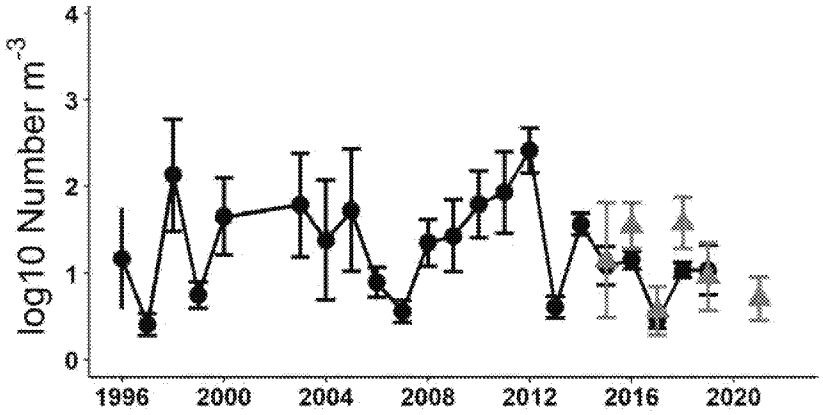
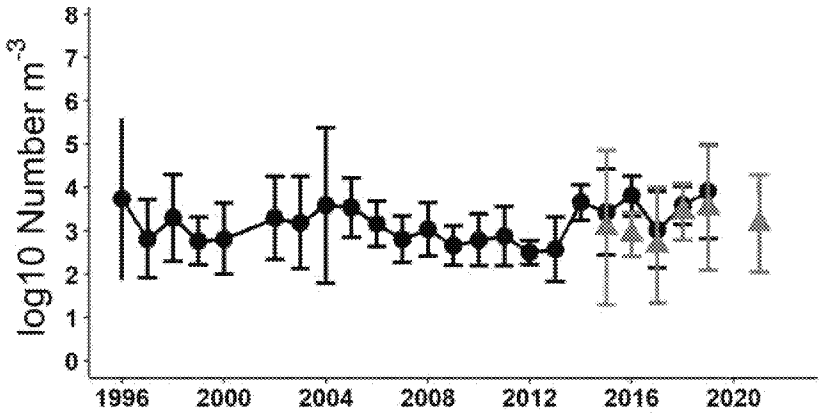
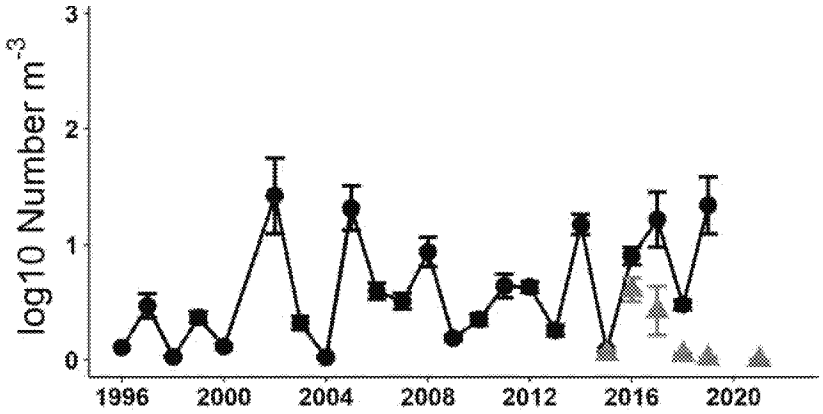


(a) Large copepods (>2 mm)

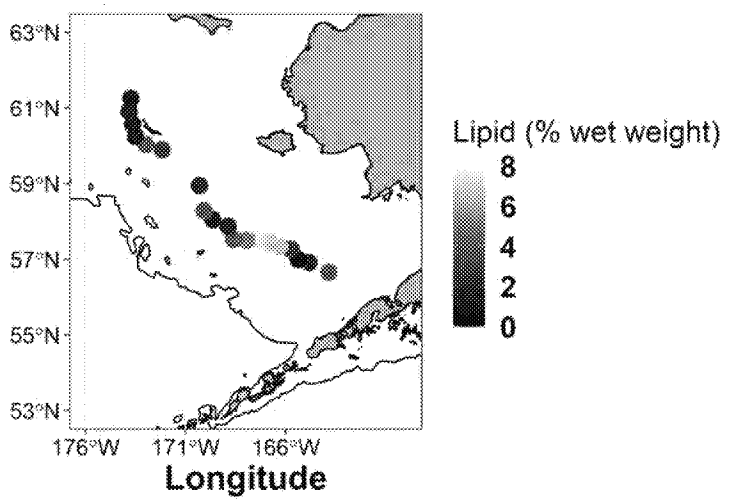


(b) Small copepods (≤2 mm)

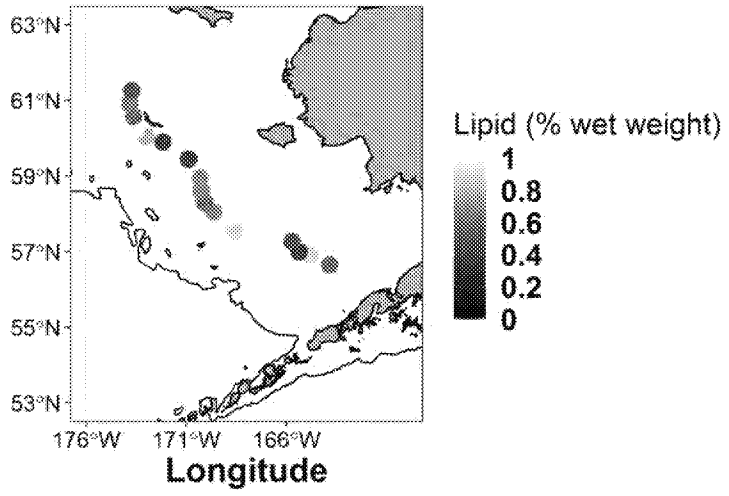


(c) Euphausiids (<15 mm)

Figure 53: Mean abundance of large copepods (>2 mm), small copepods (≤2 mm), and euphausiids (<15 mm) along the 70 m isobath during spring. Black circles represent archived data, blue triangles represent RZA data. Note differences in scale.



(a) Large copepods (>2 mm)



(b) Euphausiids

Figure 54: Lipid content (% wet weight) for large copepods (>2 mm; *Calanus* spp.) and euphausiids (>15 mm) along the 70 m isobath during spring.

Furthermore, it should be noted that the RZA and processed estimates of abundances often differ (Figure 52 and Figure 53). This is expected due to the patchy nature of euphausiid distribution and the difficulty in accurately estimating euphausiid abundances (Hunt et al., 2016).

The lipid content of *Calanus* spp. would be low compared to *Calanus* C5 copepodite stage individuals preparing for diapause, but did indicate that at least, at some locations, *Calanus* spp. was accumulating lipids. This suggests that the *Calanus* spp. population was able to begin lipid accumulation as summer approached. Lipid values in euphausiids were much lower compared to *Calanus* spp. and these large (>15 mm) adults may have not had a chance to accumulate much lipid if caught prior to the spring bloom or not near the ice edge.

Northern Bering Sea

The northern Bering Sea had slightly higher abundances of large copepods compared to the recent low-ice years, though numbers remained low despite some areas with higher abundances in the

northern portion of the survey area. Large copepods such as *Calanus* spp. are relatively less abundant along the inner shelf area sampled in this survey and it appears that *Calanus* spp. only becomes widespread in this region during cold years (Eisner et al., 2018), thus the low numbers along the inner shelf were not surprising.

The neritic zooplankton community primarily consists of small copepods (e.g., *Acartia* spp., *Centropages* spp.) and meroplankton (data not shown) and these numbers appeared similar to those in past surveys. This community remains ubiquitous and present along the inner shelf and is associated with the Alaska Coastal Water (Pinchuk and Eisner, 2017). The peak abundances seen during 2018 appear to have reduced slightly and this is likely related to cooler temperatures.

Euphausiid abundances were low overall and this was not different from the low overall numbers reported in the time-series (Figure 56). Overall, total lipids in both *Calanus* spp. and euphausiids from the northern Bering Sea in summer/fall showed higher values to those observed from the southern survey in the spring. This is consistent with C5 stage *Calanus* spp. accumulating lipid values that are higher later in the year and the greater frequency of occurrence for this species on the inner shelf. In contrast, euphausiids tended to have higher values to the north, albeit with lower sample numbers for euphausiids (Figure 57). These results suggest that euphausiids caught later in the year were able to accumulate a higher proportion of lipids compared to spring.

Implications:

Southeastern Bering Sea

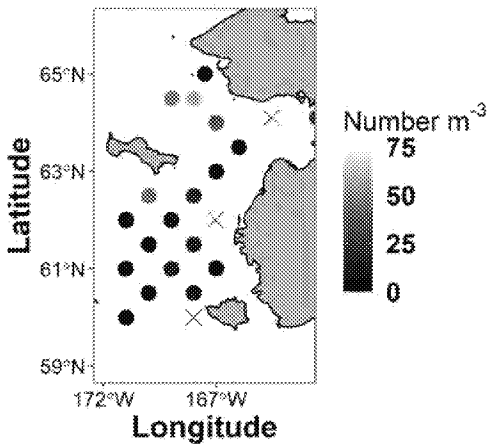
Smaller copepods and their early life history stages form the prey base for larval to early juvenile Walleye pollock, as well as other fish species, during spring (Figure 52 and Figure 53) on the eastern Bering Sea middle shelf. The slight reduction in smaller copepod abundance compared to warmer years was unlikely to impact food availability for larval fish as the observations were within historical ranges (Figure 53). Low abundances of large copepods are less critical in the spring, but very important later in the year (Hunt et al., 2011). Our observations of early life-history stages of *Calanus* spp. suggest that the annual cohort for this species was developing more slowly due to the colder temperatures. This was also reflected in the low lipid values in the spring. This would result in an increase in lipid-rich *Calanus* spp. available to age-0 fish later in the year and this relates to increased overwinter success for pollock (Siddon et al., 2013; Eisner et al., 2020). Observations from the fall survey would have placed this prediction into greater context; however, the survey was canceled.

The low abundances recorded for smaller euphausiids (<15 mm) must be understood in the context of the higher abundances of larger euphausiids (>15 mm) observed (data not shown). Given that the bongo nets are prone to underestimation of larger sized euphausiids, this likely indicated that large euphausiids were active and reproducing along the middle shelf. This observation suggests that euphausiids will persist along the middle shelf later in the year; however, confirming this prediction was difficult due to a lack of a summer acoustic survey in the Bering Sea during 2021. If euphausiids persisted and became abundant along the middle shelf in the fall, they would have represented a significant food source for forage fish (Hunt et al., 2016).

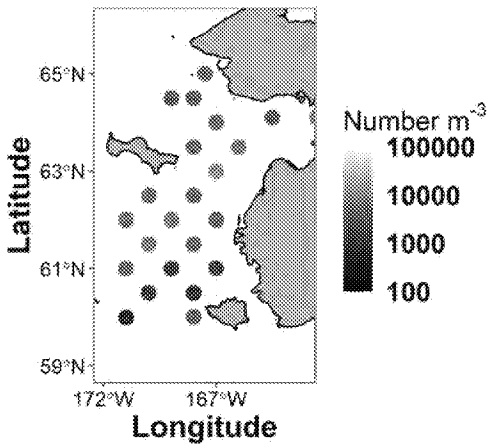
Northern Bering Sea

In the northern Bering Sea, the observed zooplankton abundances remained similar to those observed in recent years, with a slight increase in large copepod and euphausiid numbers. This continues to support the notion that the inner shelf region is an area that is dominated by smaller sized and more diverse plankton community relative to the middle shelf.

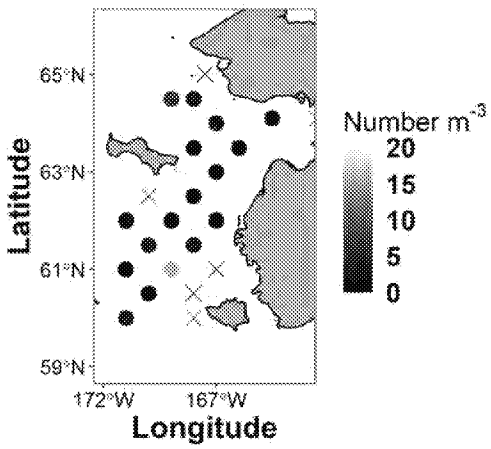
The lipid content of zooplankton from the northern survey, which was later in summer, was significantly higher than in spring, indicating the accumulation of lipids prior to diapause and their value as an energy-rich food source for young-of-year fish. While a direct comparison between the southeastern and northern Bering Sea was not possible for the late summer time-period, the accumulation of lipids in large *Calanus* spp. in the northern Bering Sea suggests the same could have occurred in the southeastern Bering Sea. In a recent paper, less spatial variability in *Calanus* spp. lipid content existed along the 70 m isobath than was expected given the strong difference in north (> 60°N) vs. south temperature observed during 2015 (Tarrant et al., 2021). This suggests that copepods and euphausiids along the middle shelf in 2021 were likely to be storing lipids, if present and available as prey for forage fish.



(a) Large copepods (>2 mm)



(b) Small copepods (≤2 mm)



(c) Euphausiids (<15 mm)

Figure 55: Maps show the summer/fall abundance of large copepods (>2 mm), small copepods (≤2 mm), and euphausiid larvae/juveniles (<15 mm) in the northern Bering Sea estimated by the rapid zooplankton assessment. Note all maps have a different abundance scales (Number m^3). X indicates a sample with abundance of zero individuals m^3.

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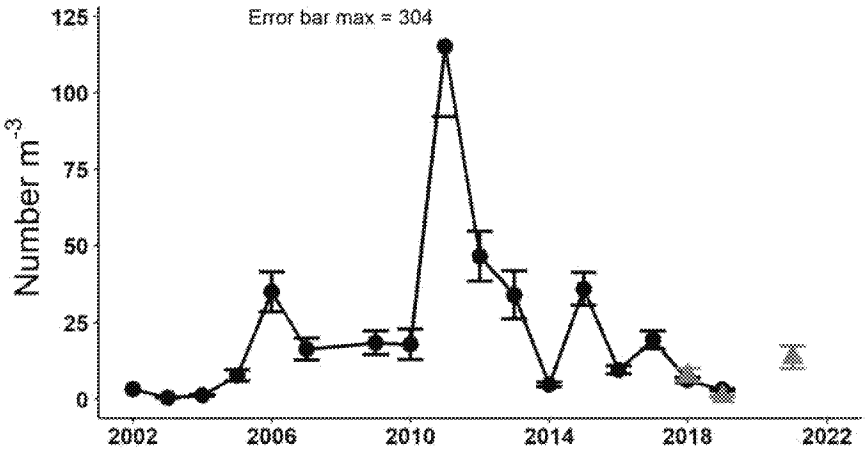
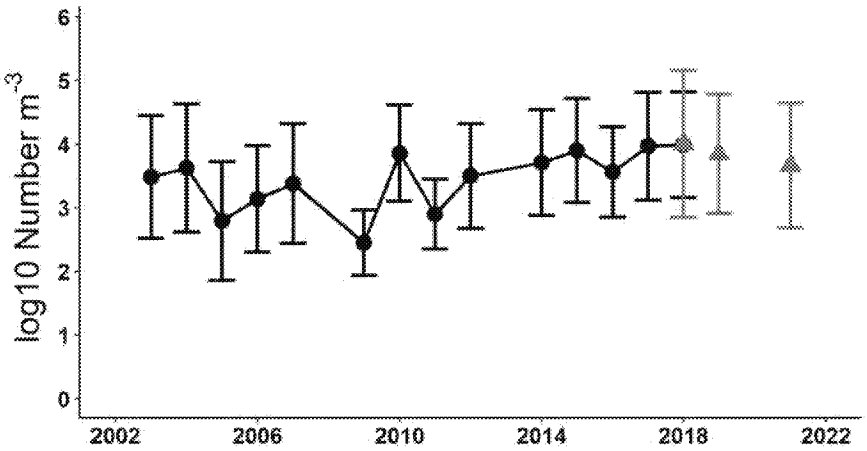
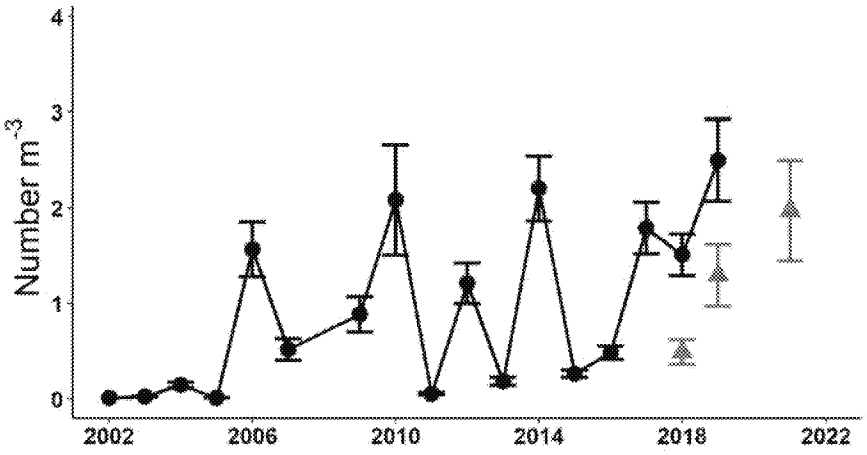


(a) Large copepods (>2 mm)



(b) Small copepods (≤2 mm)



(c) Euphausiids (<15 mm)

Figure 56: Mean abundance of large copepods (>2 mm), small copepods (≤2 mm), and euphausiids (<15 mm) in the NBS during summer/fall. Black circles represent archived data, blue triangles represent RZA data. Note differences in scale.

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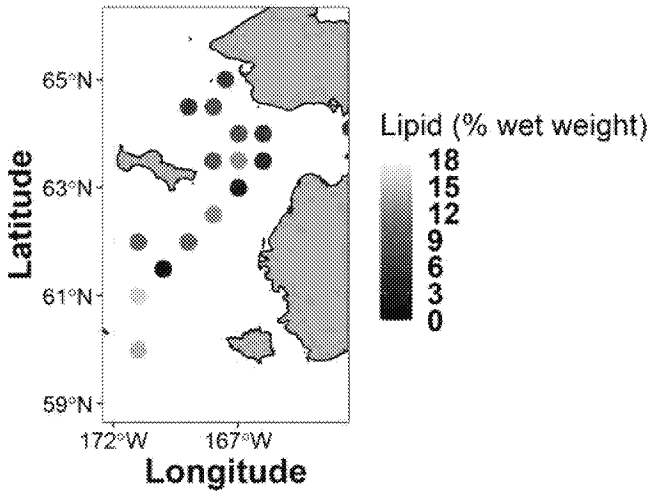
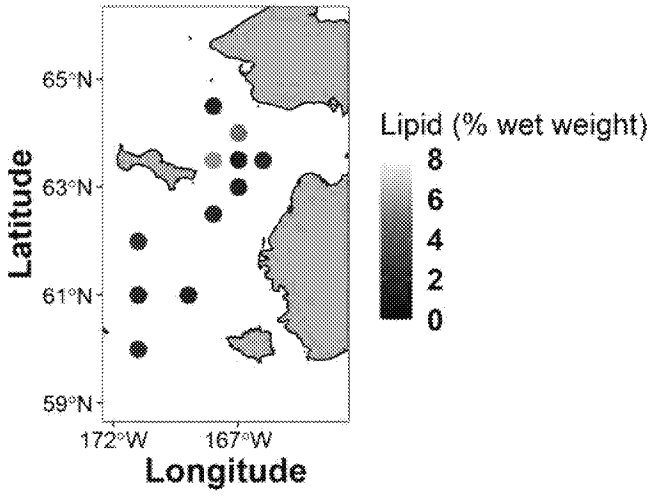


(a) Large copepods (>2 mm)



(b) Euphausiids

Figure 57: Lipid content (% wet weight) for large copepods (>2 mm; *Calanus* spp.) and euphausiids (>15 mm) in the NBS during summer/fall.

Jellyfish

Jellyfishes - Eastern Bering Sea Shelf

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Last updated: October 2021

Description of indicator: The time series for jellyfishes (primarily *Chrysaora melanaster*) relative CPUE by weight (kg per hectare) was updated for 2021 (Figure 58). Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

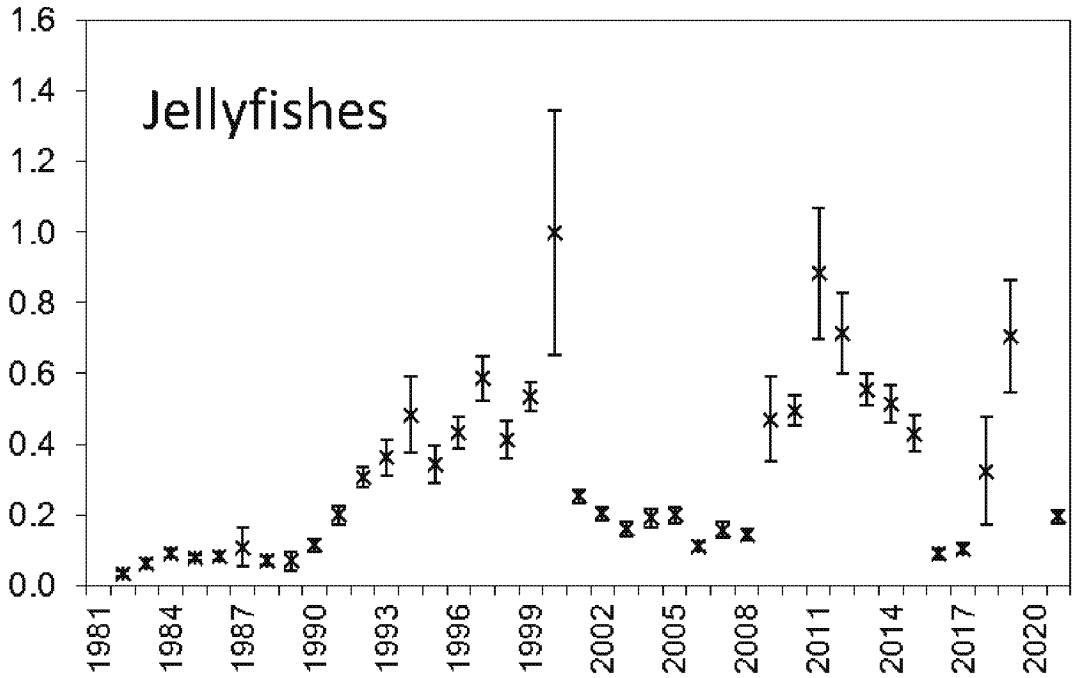

Figure 58: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for jellyfish during the May to August time period from 1982–2021.

Status and trends: The relative CPUE for jellyfishes in 2021 decreased 73% from 2019 survey estimates, similar to the catch rates observed 2001–2008 and 2016–2017. These low CPUE values are also similar to those observed during the first nine years of the time series (1982–1991). There was a period of increasing biomass of jellyfishes throughout the 1990's (Brodeur et al., 1999) followed by a second period of relatively low CPUE's from 2001 to 2008 and then a second period with relatively higher CPUE values from 2009 to 2015.

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Factors influencing observed trends: The fluctuations in jellyfish biomass and their impacts on forage fish, juvenile Walleye pollock (*Gadus chalcogrammus*), and salmon in relation to other biophysical indices were investigated by Cieciel et al. (2009) and Brodeur et al. (2002, 2008). Ice cover, sea-surface temperatures in the spring and summer, and wind mixing all have been shown to influence jellyfish biomass, and affect jellyfish sensitivity to prey availability (Brodeur et al., 2008).

Implications: Jellyfish are pelagic consumers of zooplankton, larval and juvenile fishes, and small forage fishes. A large influx of pelagic consumers such as jellyfish can decrease zooplankton and small fish abundance, which in turn can affect higher trophic levels causing changes to the community structure of the ecosystem.

Ichthyoplankton

There are no updates to Ichthyoplankton indicators in this year's report. See the contribution archive for previous indicators at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`.

Forage Fish

Highlights of the 2021 Bering Sea and Aleutian Islands Forage Report

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Last updated: September 2021

The abundance of forage species (e.g., fishes, squids, euphausiids, and other invertebrates) in the eastern Bering Sea (EBS) is difficult to measure. There are no dedicated surveys for these species, and the existing surveys are limited in their ability to assess forage species due to gear selectivity (e.g., mesh size) or catchability (e.g., vertical distribution).

Nevertheless, these surveys can be used to discern general trends in abundance. The trawl survey-based aggregate forage index (which does not include juvenile pollock or Pacific herring) suggests that forage abundance has declined substantially since 2015 (see Report Card, Figure 1). This is supported by the reduced abundance and frequency of occurrence observed for individual species as described in the 2021 Forage Report. The surface trawl survey in the northern Bering Sea (NBS) indicates a similar decline in capelin and age-0 pollock. Trends in herring abundance are more complicated, with results varying between the EBS bottom trawl survey, the NBS surface trawl survey, and the Togiak District spawner biomass and recruitment indices (see p. 108). The herring data do seem to suggest an increase in herring abundance throughout the Bering Sea in recent years. Temporal patterns of juvenile salmon abundance in the NBS are similarly complex, although the abundance of small salmon, herring, and forage species as a whole were substantially lower in 2021 relative to 2019.

Taken together, the available information suggests that the EBS and NBS are experiencing a decline in the availability of forage species for predators. Because many forage species are sensitive to their

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environment, particularly changes in temperature, it is likely that recent warm years in this region have contributed to this decline. A decline in forage availability may have contributed to other substantial changes in the Bering Sea.

Vertical Distribution of Age-0 Pollock in the Southeastern Bering Sea

Contributed by Adam Spear[1] and Alexander G. Andrews III[2]
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[2]Auke Bay Laboratories
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Last updated: September 2021

Description of indicator: Vertical distribution of age-0 pollock was estimated through the calculation of an abundance-weighted mean depth during two cold years (2011, 2012) and two warm years (2014, 2016). The abundance of age-0 pollock in the southeastern Bering Sea was estimated using acoustic-trawl methods. The process involved assigning trawl-catch data to acoustic-backscatter data that was measured along a transect line. The trawl catch information was manually assigned to backscatter from a single surface, oblique, or midwater-trawl depending on proximity, tow depth, and backscatter characteristics. Scrutinized backscatter was echo-integrated into 0.5 nautical mile (nmi) by 5 m bins, and output as nautical area scattering coefficient, m^2/nmi^2 (NASC). The species-specific compositions from each catch were used to convert NASC to species-specific abundance (individuals/nmi^2) using published measurements of the acoustic properties of these species. Age-0 pollock abundance was summed over each depth bin to calculate the weighted mean depth over the entire survey area. Here, we show yearly abundance-weighted mean depths during the late summer over the southeastern Bering Sea.

Status and trends: Age-0 pollock were deeper in the water column during the cold years of 2011 and 2012, and closer to the surface during the warm years of 2014 in 2016 (Figure 59).

Factors influencing observed trends: Within the years analyzed, 2011 and 2012 represented colder years while 2014 and 2016 represented warmer years in the southeastern Bering Sea. These two oceanographic temperature phases resulted in a change in the vertical distribution of age-0 pollock. Energy densities of age-0 pollock collected in trawls from these surveys showed that pollock collected in cold years had higher energy densities than those collected in warm years, suggesting improved feeding and provisioning conditions at depth in colder thermal conditions. Colder years have greater abundances of larger lipid-rich prey which result in higher dietary percentages of lipid and energy densities of age-0 pollock (Coyle et al., 2011; Heintz et al., 2013; Kimmel et al., 2018). This is partially explained given that larger lipid-rich prey vertically migrate deeper in the water column during the day.

Implications: Vertical distribution shifts may impact predator-prey overlap between age-0 pollock and their lipid-rich prey (e.g., calanoid copepods, euphausiids), resulting in different feeding conditions that ultimately define fish body condition prior to the onset of winter. As the climate warms further, or these warm phases potentially lengthen in time, there may be a compounding problem of poor condition and recruitment, thus significantly reducing the standing stock of pollock.

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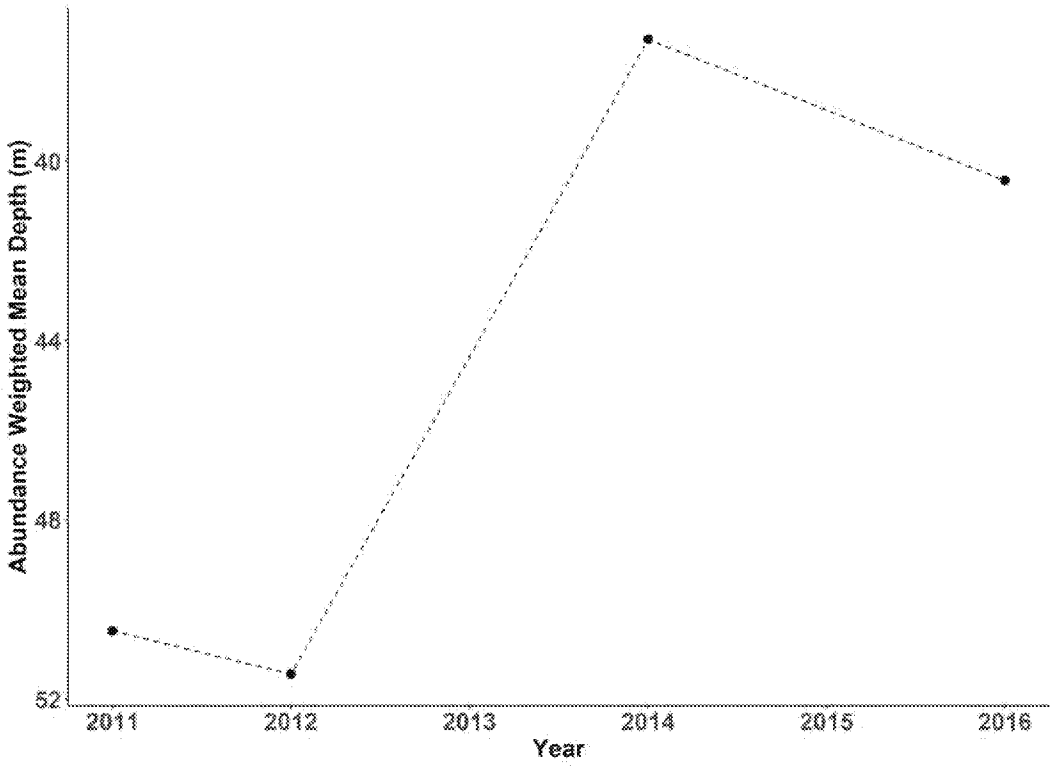

Figure 59: Annual abundance-weighted mean depth of age-0 pollock during late summer in the south-eastern Bering Sea.

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Herring

Togiak Herring Population Trends

Contributed by Greg Buck, Sherri Dressel, Sara Miller, and Caroline Brown
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Last updated: October 2021

Description of indicator: A time-series of catch-at-age model estimates of mature Pacific herring (*Clupea pallasii*) biomass (1980–2020) spawning in the Togiak District of Bristol Bay serves as an index of mature population size. Togiak herring are an important prey species for piscivorous fish, seabirds, and marine mammals, and serve as an important resource for subsistence harvesters and commercial fisheries. The forecast size of the Togiak Bay herring spawning stock is used for the purpose of setting the State of Alaska commercial guideline harvest level for the following year's Togiak spring sac roe fishery and Dutch Harbor bait fishery. The forecasted size of the Togiak Bay herring spawning stock, combined with the size of other eastern Bering Sea (EBS) herring stocks, serves as the basis for setting the annual prohibited species catch (PSC) limit for EBS groundfish fisheries per Amendment 16A of the Bering Sea/Aleutian Islands Groundfish Fishery Management Plan. The annual PSC limit is set at 1% of the annual biomass of mature EBS herring and is apportioned among trawl fishery categories. Attainment of any apportionment may trigger closure of Herring Savings Areas to that fishery. The Togiak Bay herring stock is the largest herring spawning stock in Alaskan waters and is thought to comprise approximately 70% of the EBS herring spawning biomass that occurs along the coastline from Port Heiden/Port Moller to Norton Sound. Due to reduced commercial market demands for herring and State of Alaska budget cuts, Togiak Bay herring is the only mature herring stock in the EBS area that is currently and consistently monitored, surveyed, and assessed for stock size on an annual basis.

The biomass of mature Pacific herring occurring in the Togiak District of Bristol Bay has been tracked through aerial surveys since the late 1970s using methods described by Lebida and Whitmore (1985). Generally, the peak aerial survey biomass estimate occurs while the commercial fishery is open. Typically, the harvest prior to the peak, along with the peak aerial survey biomass and an aerial survey biomass around the time commercial fishery ends, are combined to provide a survey estimate of mature herring biomass. A statistical catch-at-age model is then used to forecast Pacific herring biomass in the Togiak District of Bristol Bay (Funk et al., 1992; Funk and Rowell, 1995). The data used in the model include aerial survey estimates of biomass weighted by a confidence score (confidence depends primarily on visibility conditions, aerial survey coverage, and number of surveys), age composition and weight-at-age information collected from the fishery, and harvest from the purse seine and gillnet fisheries. Recruitment of Togiak herring to the fishery begins around age-4 and fish are believed to be fully recruited into the fishery around age-8.

Status and trends: Mature Togiak herring biomass, as estimated by the model, increased steeply from 1980 to 1983 (Figure 60), due to large age-4 recruitments in 1981 and 1982 (Figure 61). The biomass then declined through the late-1990s and has remained stable since that time. The large annual biomasses estimated by the model during the late 1980s have considerable uncertainty due to the poor aerial survey conditions and confidence scores during that time.

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The 2021 biomass forecast for Togiak was based on aerial survey estimates, annual age composition and weight-at-age data collected from the fishery, and harvest data. The forecast for 2021 (236,742 short tons) was a 25% increase from the model hindcast of 2020 mature biomass (189,375 short tons) is the largest forecast since integrated catch-age models have been used for forecasting (first forecast was made for 1993) and is greater than model hindcasts since 1987 (Figure 60). The increase in the forecast is primarily due to the estimated age-4 recruitment in 2020, which is the highest estimated recruitment since 1982, but is also highly uncertain as the recruit class has only been observed once (2020 data). While the magnitude of the estimated 2020 estimated recruitment is uncertain due to first being observed in 2020 (only one observation of this year class), the high PSC catch in the EBS pollock fishery in 2020 supports the likelihood of a strong increase in young EBS herring (Siddon et al., 2020), as does preliminary Togiak herring data from 2021. The 2020 mature population was estimated to be predominantly age-4 and-6 fish as the population continues to be supported by the 2014 and now also the 2016 year classes (age-4 recruits in 2018 and 2020, Figure 61).

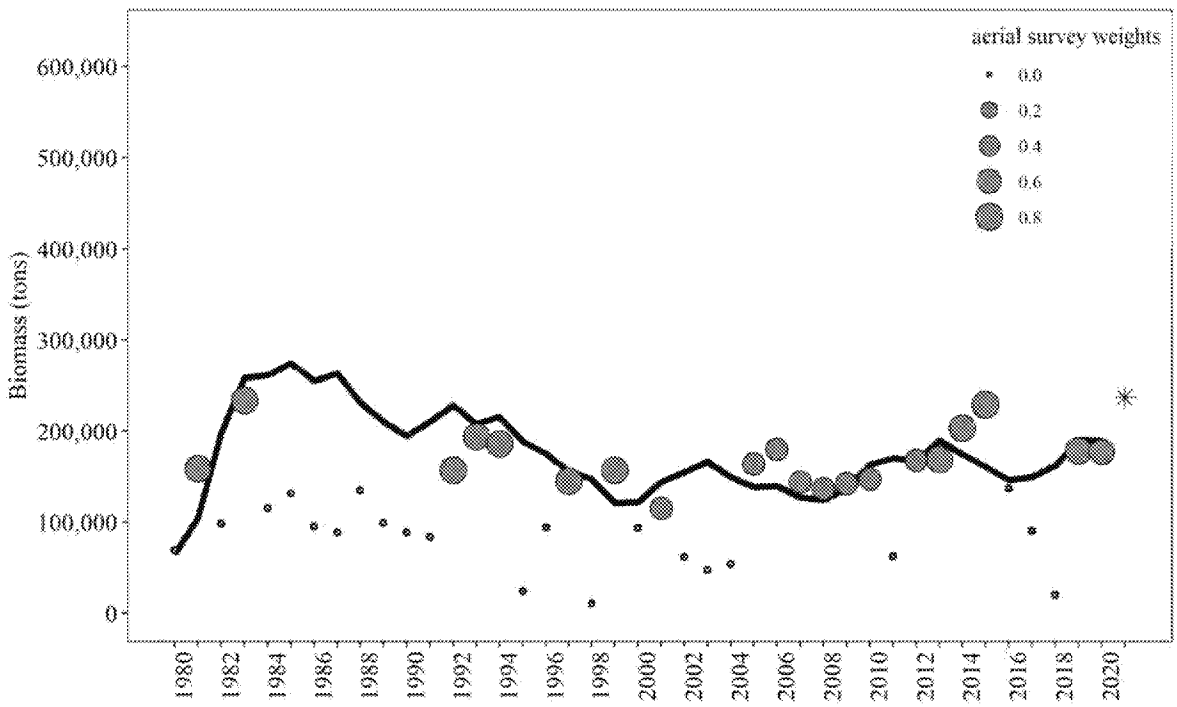

Figure 60: Aerial survey-estimated biomass plus pre-peak catch that were included in the model (grey points), model-estimated mature biomass (black solid line), and model-estimated mature biomass forecast (black asterisk). The size of the grey points reflects the confidence weighting of each aerial survey estimate in the model based on weather, number of surveys, quality of surveys, and timing of surveys relative to the spawn (ranging from 0=no confidence to 1=perfect confidence).

An active commercial sac roe fishery is conducted on this population with gillnet and purse seine gear. A small spawn on kelp quota is allowed but has not been utilized since 2003. The sac roe fishery has harvested an average of 19,081 short tons annually over the last 10 years (2011–2020).

Residents of Togiak have relayed to Alaska Department of Fish & Game staff that they do not participate in the Togiak herring commercial fishery as they once did primarily due to a concern about abundance of herring needed for subsistence uses, as well as competition with commercial

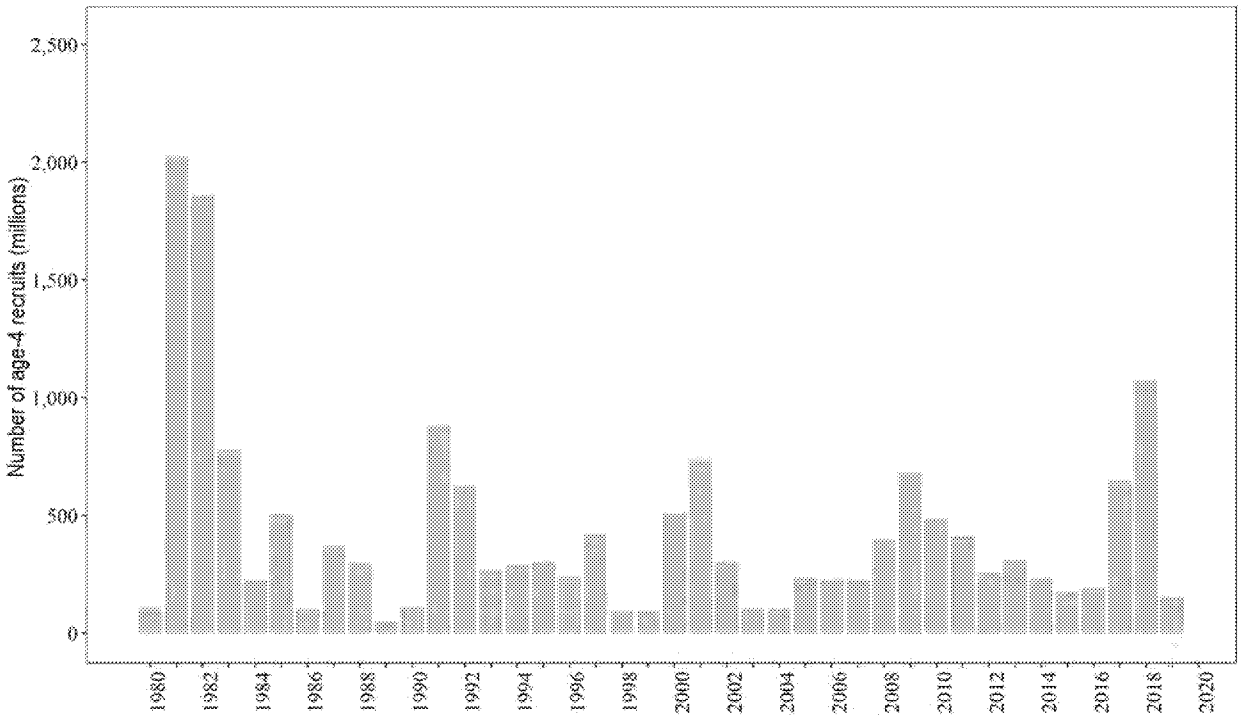

Figure 61: Model estimates of age-4 recruit strength (numbers of age-4 mature and immature fish).

fishers from outside the state. ADF&G has conducted two comprehensive subsistence surveys in Togiak – in 1999 (Coiley-Kenner et al., 2003) and 2008 (Fall et al., 2012), as well as a study designed to address proposals coming before the 2017 Board of Fisheries and a more recent non-salmon fish harvest survey in 2019 (Jones et al., 2021). Harvests of herring and/or herring spawn on kelp were measured in all four years. Harvests of herring declined by 22% between 1999 and 2008 while the harvest of spawn on kelp increased by 146%, from 8 lbs per capita to 20 lbs per capita. During the 2017 study, Togiak households reported harvesting only 3 lbs of spawn on kelp per capita. Many residents expressed concern about the herring stocks in 2008 and in 2017, especially about their ability to harvest spawn on kelp. In 2019, Togiak residents reported harvesting 13.7 lbs of herring roe per capita. Despite lower harvests of herring and herring roe in 2019 than 2008, Togiak respondents noted that the quantity of herring spawn on kelp was improved in 2019 in comparison to resource availability over the previous 10 years. An anecdotal report suggests that the 2020 harvest was also good.

Factors causing observed trends: Togiak herring biomass trends are dependent upon recruitment and are influenced by the environment. Pacific herring recruitment is both highly variable and cyclic with large recruitment events (age-4) occurring roughly every 8–10 years. Biomass trends are greatly influenced by recruitment, with the highest biomasses in 1983–1987 resulting from the largest age-4 recruitments in 1981 and 1982. The substantial recruitment in 2020 suggests the population will increase in 2021 (Figure 60). Williams and Quinn (2000) demonstrate that Pacific herring populations in the North Pacific are closely linked to environmental conditions, particularly water temperature. Tojo et al. (2007) demonstrate how the complex reproductive migration of EBS herring is related to temperature and the retreat of sea ice and how it has changed since the 1980s. Wespestad and Gunderson (1991) suggest that recruitment variation in the EBS relates to the de-

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gree of larval retention in near-coastal nursery areas where temperatures and feeding conditions are optimal for rapid growth. Specifically, they indicate that above average year-classes occur in years with warm sea surface temperatures when the direction of transport is north to northeast (onshore) and wind-driven transport velocity is low, whereas weak year classes occur in years when sea-surface temperature is cold, wind-driven transport is west to northwest (offshore), and wind-driven transport velocity is high. It is possible that the shift to anomalously warm sea surface temperatures from 2014 to 2020 (Watson, 2020) have positively impacted herring recruitment. Continued examination of environmental conditions such as sea surface temperature, air temperature, surface winds, and EBS ice coverage may increase our understanding of the recruitment processes at play in this population.

Elders and Togiak residents have expressed concern that commercial purse seine fishing for sac roe has influenced Togiak herring biomass trends. They describe changes in the density and spatial extent of herring spawn and decreases in herring abundance since approximately the 1990s. However, reports of improved quantity of spawn on kelp in 2019, relative to the last 10 years, is hopeful. As is beginning to be explored for other herring stocks in the North Pacific, closer examination of the spatial distribution of herring spawn and the spatial distribution of commercial fishing effort may increase our understanding of the potential impacts of commercial fishing on herring spawning populations and subsistence harvest.

Implications: Togiak herring are an important prey species for piscivorous fish, seabirds, and marine mammals. Togiak herring are also an important resource for subsistence harvesters, as well as the basis for a directed Togiak commercial herring sac roe fishery and a directed commercial Dutch Harbor bait fishery, as well as being PSC in the EBS groundfish fisheries. The cyclic nature of recruitment into this population has implications for predators and prey of Pacific herring as well as fisheries. The stable trend of this stock since the mid-1990's, despite cyclic recruitment, has allowed for directed commercial fisheries to open and has contributed to approximately stable PSC levels for EBS groundfish fisheries since 1992. Togiak residents express considerable concern about declines in the subsistence fishery since the early 1990s, but subsistence reports from 2019 suggest a positive change. Data in upcoming years will help define the magnitude and impact of the 2020 recruitment on the Togiak herring population and the implications for subsistence harvest, commercial fisheries, and PSC limits in the EBS groundfish fisheries.

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Salmon

Trends in Alaska Commercial Salmon Catch – Bering Sea

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Last updated: September 2021

Description of indicator: This contribution provides commercial catch information for salmon of the Bering Sea. This contribution summarizes data and information available in Alaska Department of Fish & Game (ADF&G) reports (e.g., Brenner et al. (2021)) and on their website[10].

Pacific salmon in Alaska are managed in four regions based on freshwater drainage basins[11]: Southeast/Yakutat, Central (encompassing Prince William Sound, Cook Inlet, and Bristol Bay), Arctic-Yukon-Kuskokwim, and Westward (Kodiak, Chignik, and Alaska peninsula). ADF&G prepares harvest projections for all areas rather than conducting run size forecasts for each salmon run. There are five Pacific salmon species with directed commercial fisheries in Alaska; they are sockeye (*Oncorhynchus nerka*), pink (*O. gorbuscha*), chum (*O. keta*), Chinook (*O. tshawytscha*), and coho (*O. kisutch*) salmon.

Status and trends:
Statewide
Catches from directed fisheries on the five salmon species have fluctuated over recent decades but in total have been generally strong statewide (Figure 62). The commercial harvests from 2020 totaled 118.3 million fish, which was 14.4 million less than the preseason forecast of 132.7 million fish. Preliminary data from ADF&G for 2021 indicates a statewide total commercial harvest of about 222.2 million fish (as of 20 September 2021), which is well above the preseason projection of 190.1 million fish. The 2021 harvest was bolstered by the catch of 151.6 million pinks, primarily from Prince William Sound, and 55.8 million sockeye, primarily from Bristol Bay.

Bering Sea
Salmon harvests in the Bering Sea are numerically dominated by the catch of sockeye in Bristol Bay (Figure 63). The 2020 Bristol Bay sockeye run of 58.3 million is the fourth largest ever, and the harvest of 39.6 million was the fifth highest ever. Escapement goals for sockeye in 2020 were met or exceeded in every drainage in Bristol Bay where escapement was defined. Preliminary data for 2021 from ADF&G indicates that the commercial harvest of Bristol Bay sockeye is strong again, at nearly 42 million fish (for more information on 2021 Bristol Bay sockeye salmon, see p. 115).

Chinook abundance in the Arctic-Yukon-Kuskokwim region has been low since the mid-2000s and remains low. From 2008 to 2020 no commercial periods targeting Chinook were allowed in the Yukon Management Area. Preliminary data for 2021 indicate that Chinook escapement goals will not likely be met for the Yukon Area. In 2020, Chinook did meet the drainage-wide escapement goal for the Kuskokwim Area.

[10] https://www.adfg.alaska.gov/
[11] https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmonareas

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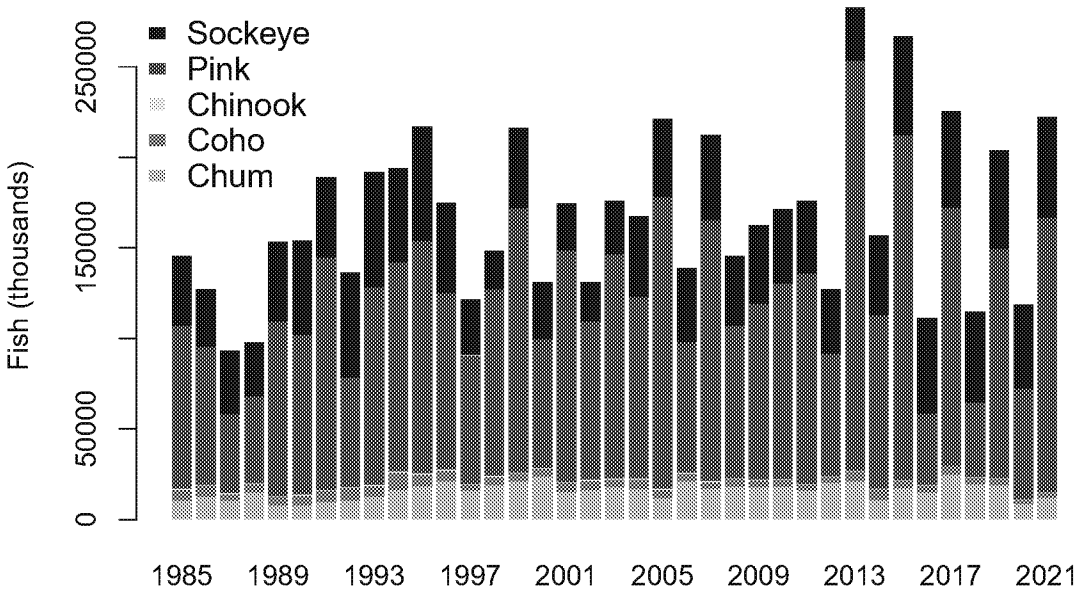

Figure 62: Alaska statewide commercial salmon catches, 2021 values are preliminary. Source: ADF&G; `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data, subsequent analysis, or interpretation.

The 2020 commercial harvest of summer chum in the Yukon Area was the lowest since 2003. There were no commercial harvests for salmon during fall 2020 in the Yukon Management Area due to the low run size for fall chum and coho salmon. According to ADF&G, the 2021 Yukon fall chum run has not met the minimum escapement goal needed to allow commercial harvests[12].

For more information on 2021 Arctic-Yukon-Kuskokwim salmon abundance estimates, see p. 26.

Factors influencing observed trends: Salmon have complex life histories and are subject to stressors in the freshwater and marine environments, as well as anthropogenic pressures. These forces do not affect all species and stocks equally or in the same direction, and resolving what is driving the population dynamics of a particular stock is challenging (Rogers and Schindler, 2011). Interannual variation in statewide total salmon abundance is partly due to the even-year, odd-year cycle in pink salmon, particularly production from the Prince William Sound stock of pink salmon, which typically have larger runs in odd years. Chinook runs have been declining statewide since 2007. Size-dependent mortality during the first year in the marine environment is thought to be a leading contributor to low Chinook run sizes (Beamish and Mahnken, 2001; Graham et al., 2019). Additionally, rising sea temperatures and loss of sea ice may lead to slower growth for juvenile Chinook in the eastern Bering Sea (Yasumiishi et al., 2020).

Salmon are also caught as bycatch in Bering Sea groundfish trawl fisheries, most of which are Chinook and chum. The North Pacific Fishery Management Council has implemented management measures and incentives that have largely been successful at reducing Chinook bycatch in groundfish trawl fisheries since their peak in 2007 (Stram and Ianelli, 2015). However, the bycatch of non-Chinook (i.e., chum) has trended upward since 2012 and in 2021 is at its highest level since 2005[13].

[12] `https://www.adfg.alaska.gov/static/applications/dcfnewsrelease/1335706319.pdf`
[13] `https://www.npfmc.org/wp-content/PDFdocuments/bycatch/BeringSeaSalmonBycatchFlyer.pdf`

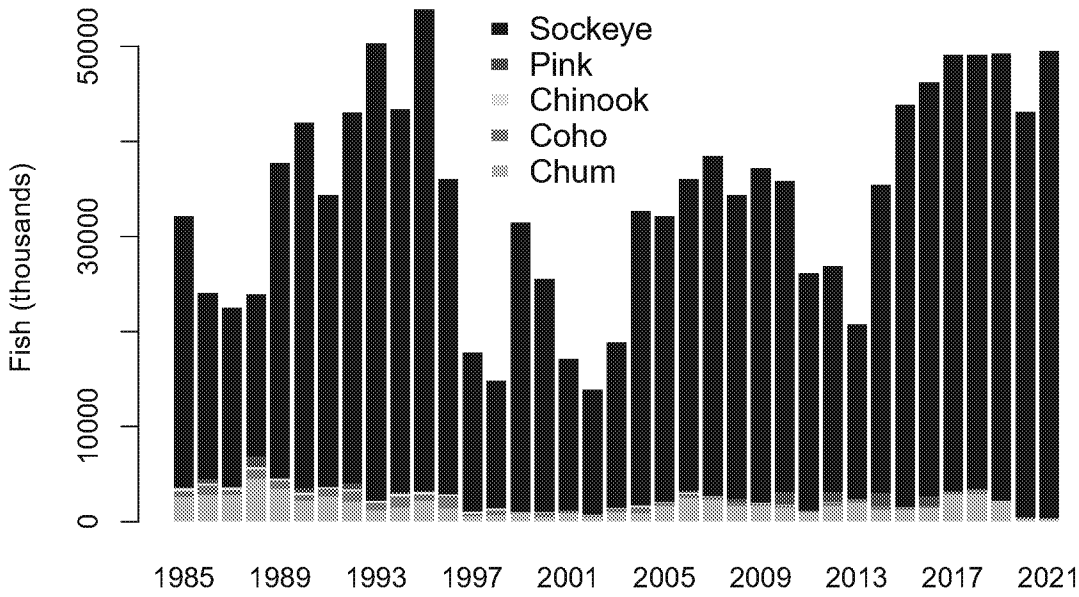

Figure 63: Commercial salmon catches in the eastern Bering Sea, 2021 values are preliminary. Source: ADF&G; `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data, subsequent analysis, or interpretation.

In the Bering Sea, sockeye are the most abundant salmonid, and since the early 2000s they have had consistently strong runs, which have supported large harvests. Bristol Bay sockeye display a variety of life history types. For example, their spawning habitat is highly variable and demonstrates the adaptive and diverse nature of sockeye in this area (Hilborn et al., 2003). Therefore, productivity within these various habitats may be affected differently depending upon varying conditions, such as climate (Mantua et al., 1997), so more diverse sets of populations provide greater overall stability (Schindler et al., 2010). The abundance of Bristol Bay sockeye may also vary over centennial time scales, with brief periods of high abundance separated by extended periods of low abundance (Schindler et al., 2006).

Implications: Salmon have important influences on Alaska marine ecosystems through interactions with marine food webs – as predators on lower trophic levels and as prey for other species such as Steller sea lions. In years of great abundance, salmon may exploit prey resources more efficiently than their competitors. A negative relationship between seabird reproductive success and years of high pink salmon abundance has been demonstrated (Springer and van Vliet, 2014). Directed salmon fisheries are economically important for the state of Alaska. The trend in total statewide salmon catch in recent decades has been for generally strong harvests, despite annual fluctuations.

Measures to reduce salmon bycatch can affect the spatial distribution of groundfish trawl fisheries through area closures and incentives to avoid bycatch. When the aggregate Chinook salmon run size in the Kuskokwim, Unalakleet, and Upper Yukon Rivers is less than 250,000, a lower limit to Chinook bycatch is imposed on the pollock fishery.

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Temporal Trend in the Annual Inshore Run Size of Bristol Bay Sockeye Salmon (*Oncorhynchus nerka*)

Contributed by Curry J. Cunningham[1], Gregory Buck[2], Stacy Vega[2], and Jordan Head[2]
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Last updated: October 2021

Description of indicator: The annual abundance of adult sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay is enumerated by the Alaska Department of Fish and Game (ADF&G). The total inshore run in a given year is the sum of catches in five terminal fishing districts plus the escapement of sockeye to nine major river systems. Total catch is estimated based on the mass of fishery offloads and the average weight of individual sockeye within time and area strata. Escapement is the number of fish successfully avoiding fishery capture and enumerated during upriver migration toward the spawning grounds, or through post-season aerial surveys of the spawning grounds (Elison et al., 2018). Although there have been slight changes in the location and operation of escapement enumeration projects and methods over time, these data provide a consistent index of the inshore return abundance of sockeye to Bristol Bay since 1963.

Status and trends: The 2021 Bristol Bay salmon inshore run of 67.7 million sockeye is the largest on record since 1963 and is 43.5% higher than the recent 10-year average of 47.2 million sockeye, and 99.6% higher than the 1963–2020 average of 33.9 million sockeye (Figure 64). The temporal trend in Bristol Bay sockeye indicates a large increase during the recent 7-year period, with inshore run sizes in 2015–2021 all exceeding 50 million salmon and above recent and long-term averages. The current period of high Bristol Bay sockeye production now exceeds the previous high production stanza that occurred 1989–1995.

Note: *At the time of printing, the 2021 Bristol Bay inshore run size numbers are preliminary and subject to change.*

Factors influencing observed trends: The return abundance of Bristol Bay sockeye is positively correlated with the Pacific Decadal Oscillation (Hare et al., 1999), specifically with Egegik and Ugashik district run sizes increasing after the 1976/1977 regime shift (Figure 65). However, recent research has highlighted that relationships between salmon population dynamics and the PDO may not be as consistent as once thought, and may in fact vary over time (Litzow et al., 2020*a*,*b*). The abundance and growth of Bristol Bay sockeye has also been linked to the abundance of pinks (*Oncorhynchus gorbuscha*) in the North Pacific (Ruggerone and Nielsen, 2004; Ruggerone et al., 2016).

Implications: The high inshore run of Bristol Bay sockeye in 2021 and the preceding 6-year period indicate positive survival conditions for these stocks while in the ocean. Given evidence that the critical period for sockeye survival occurs during the first summer and winter at sea (Beamish and Mahnken, 2001; Farley et al., 2007, 2011) and the predominant age classes observed for Bristol Bay stocks are 1.2, 1.3, 2.2, and 2.3 (European designation: years in freshwater–years in the ocean), the large 2021 Bristol Bay sockeye inshore run suggests these stocks experienced positive conditions at entry into the eastern Bering Sea in the summers of 2018 and 2019, and winters of 2018–2019 and 2019–2020.

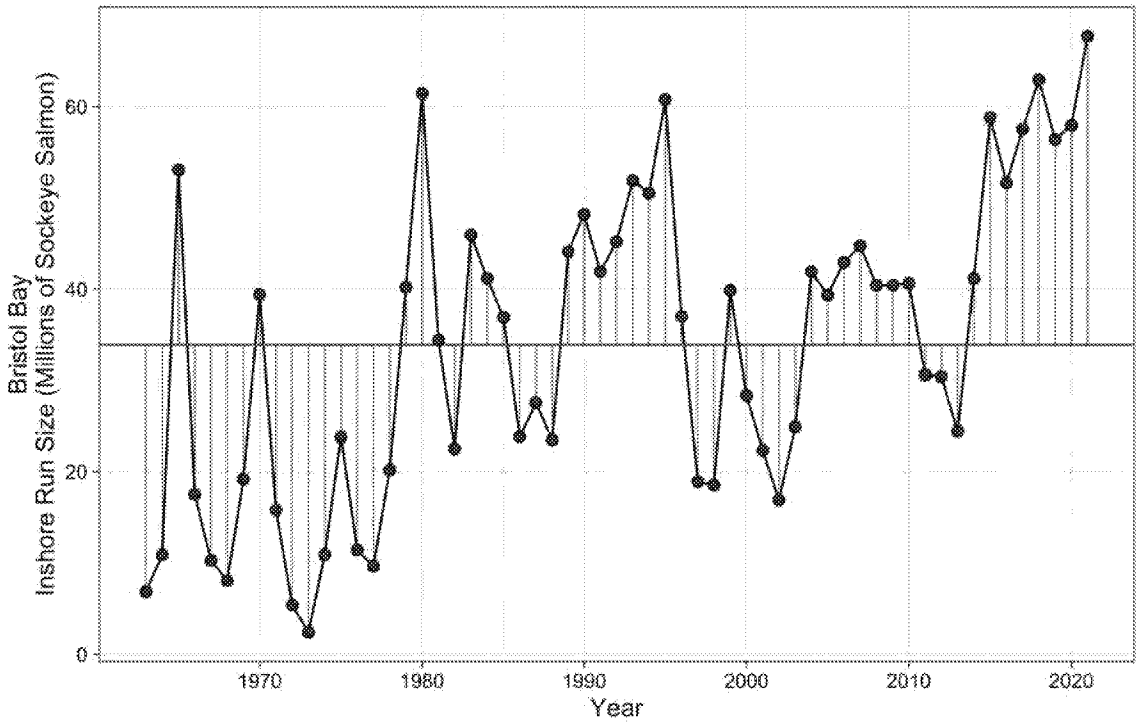

Figure 64: Annual Bristol Bay sockeye salmon inshore run size 1963–2021. Red line is the time series average of 33.9 million sockeye.

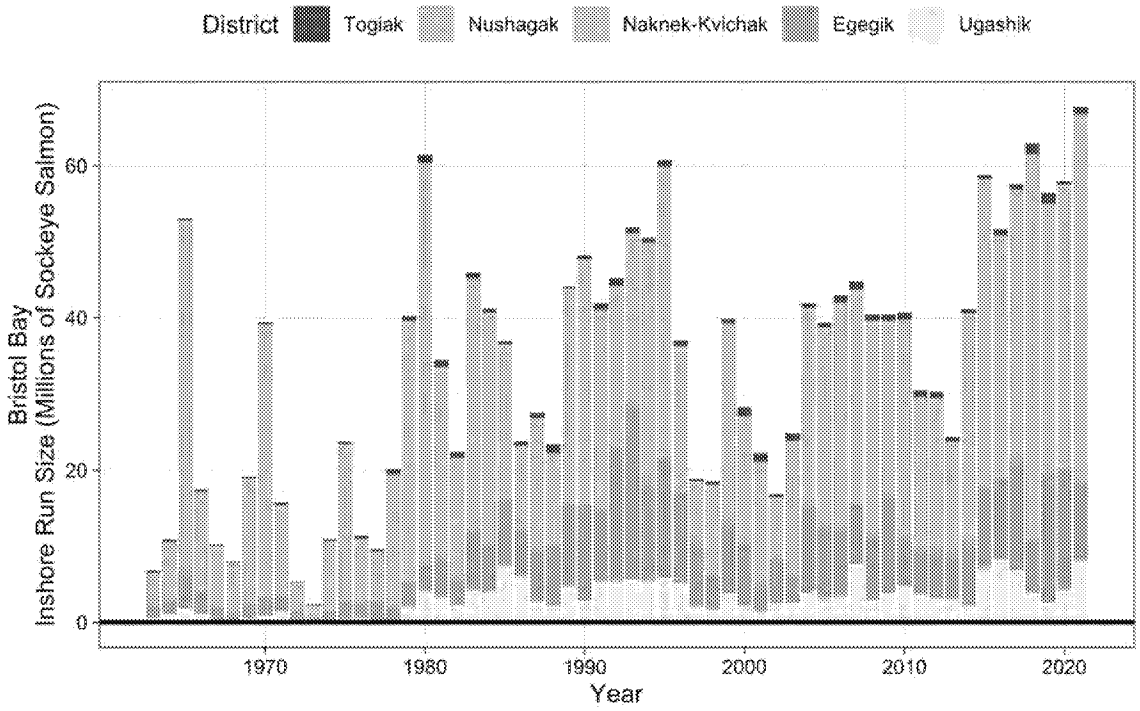

Figure 65: Annual Bristol Bay sockeye salmon inshore run size 1963–2021 by commercial fishing district.

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Northern Bering Sea Juvenile Chinook Salmon Abundance Index

Contributed by Jim Murphy[1], Sabrina Garcia[2], Andrew Dimond[1], Jamal Moss[1], Elizabeth Lee[2], and Kathrine Howard[2]
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Last updated: October 2021

Description of indicator: A mixed-stock juvenile (first year at sea) Chinook salmon (*Oncorhynchus tshawytscha*) abundance index is estimated from surface trawl catch and effort data in the northern Bering Sea (NBS). The NBS surface trawl and ecosystem survey was initiated by NOAA's Alaska Fisheries Science Center (AFSC) in 2002 as part of the Bering-Aleutian Salmon International Survey (BASIS), and has continued to support research objectives on the marine ecology of salmon and to improve our understanding of how the NBS ecosystem is changing in response to warming climate and loss of Arctic sea ice.

This index is based on late summer (September) surface trawl catch-per-unit-effort (CPUE) data expanded to the survey area and adjusted for mixed layer depth (MLD). Stock-specific abundance of Chinook salmon has been used to provide insight into the survival of Yukon River Chinook salmon (Murphy et al., 2017; Howard et al., 2020; Murphy et al., 2021) and has become a key part of their pre-season assessment (JTC, 2021). Stock-specific abundance indices will be available once stock compositions have been estimated for the survey. This mixed-stock index follows a similar pattern to the stock-specific indices as stock compositions have tended to be relatively stable over time (with the exception of 2019) (Murphy et al., 2021). The mixed-stock abundance index for juvenile Chinook salmon in the northern Bering Sea ranged from 1.4 million to 5.6 million juveniles with an average of 3.0 million, 2003–2019 (Figure 66).

Status and trends: The mixed-stock abundance of juvenile Chinook salmon in the northern Bering Sea was below average in 2021 and has been below average since 2017. Juvenile abundance has steadily declined from its latest peak in 2013.

Factors influencing observed trends: Early life-history (freshwater and early marine) survival of Yukon River Chinook salmon is the primary factor influencing juvenile abundance in the northern Bering Sea. On average, 87% of the juvenile Chinook salmon in the northern Bering Sea are from the Yukon River (Howard et al., 2019; Murphy et al., 2021). Although spawning abundance varies from year to year, juvenile abundance is most closely related to juvenile survival or the number of juveniles-per-spawner.

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Implications: The abundance of juvenile Chinook salmon in the NBS is significantly correlated with adult returns (Murphy et al., 2017; Howard et al., 2019, 2020; Murphy et al., 2021). Below average juvenile abundance is expected to contribute to below average adult returns three to four years in the future (juveniles typically remain at sea for three to four years before returning to freshwater to spawn). Below average returns will result in subsistence fishery restrictions in the NBS (Yukon River and Norton Sound Chinook salmon) and contribute to reduced Chinook salmon bycatch caps in the eastern Bering Sea pollock fisheries. Yukon River and Norton Sound (Unalakleet River) Chinook salmon are two of the three stock groups used to define abundance-based bycatch caps in the eastern Bering Sea pollock fishery.

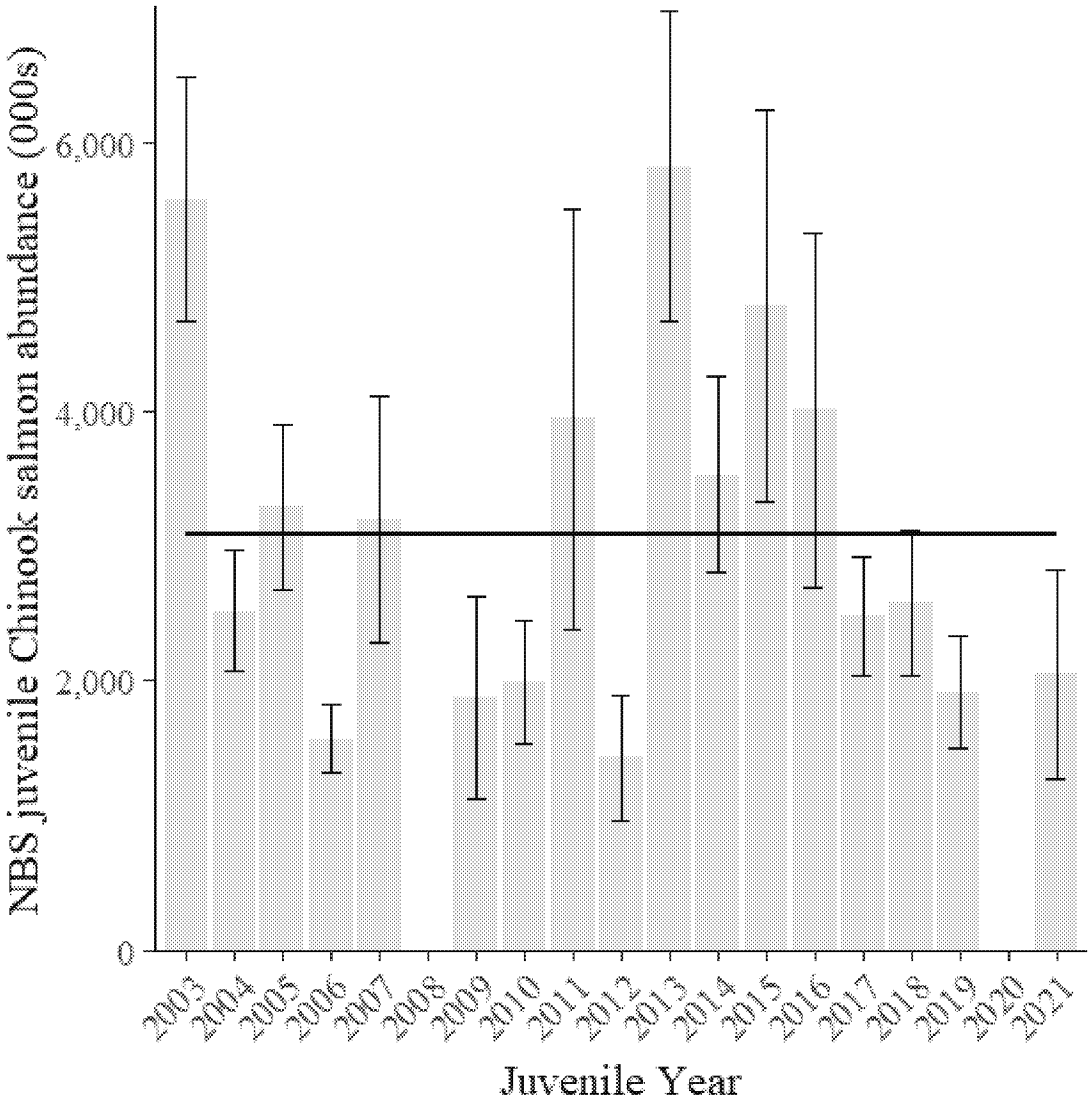

Figure 66: Juvenile Chinook salmon abundance estimates in the northern Bering Sea, 2003–2021. Error bars are one standard deviation above and below juvenile abundance estimates.

Juvenile Pink Salmon Abundance in the Northeastern Bering Sea

Contributed by Ed Farley[1], Jim Murphy[1], Kathrine Howard[2], and Sabrina Garcia[2]
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[2]Alaska Department of Fish & Game, Anchorage, Alaska
Contact: ed.farley@noaa.gov
Last updated: October 2021

Description of indicator: A relative index of abundance of juvenile (first year at sea) pink salmon (*Oncorhynchus gorbuscha*) was constructed from late-summer (typically September) surface trawl and oceanographic surveys in the northeastern Bering Sea (NBS). The index is based on trawl catch-per-unit-effort data (log) and mixed layer depth, and has ranged from 0.9 to 5.4 with an overall average of 3.0 from 2003 to 2021 (no surveys in 2008 and 2020) (Figure 67). The juvenile index is significantly correlated with an index of pink salmon returns to Yukon and Norton Sound rivers and provides an informative tool to forecast adult returns to these regions (Figure 68). The preliminary index for 2021 is 0.9, which forecasts an adult return of approximately 500,000 pink salmon to these regions during 2022.

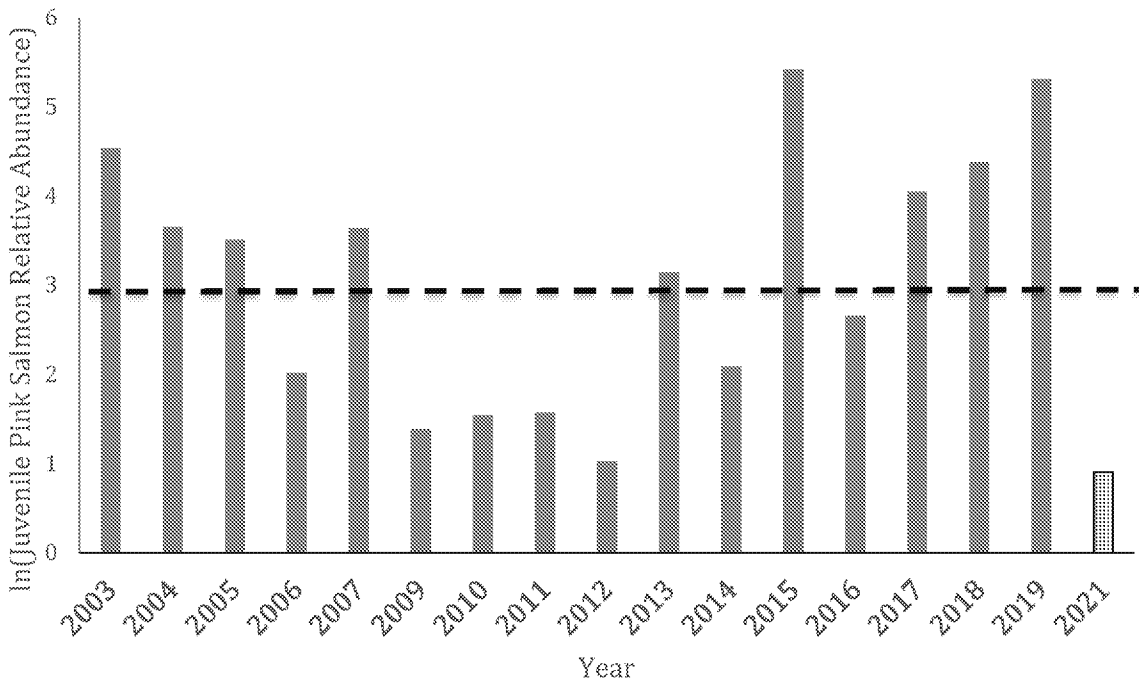

Figure 67: Juvenile pink salmon relative abundance index for the northeastern Bering Sea, 2003–2021. Dashed line indicates the average relative abundance index from 2003 to 2021. The dashed bar is the preliminary juvenile pink salmon relative abundance index for 2021. No surveys were conducted in 2008 or 2020.

Figure 1. Juvenile Pink salmon relative abundance index for the northeastern Bering Sea, 2003 to 2021. Dashed line indicates the average relative abundance index from 2003 to 2021. The dashed bar is the preliminary juvenile Pink salmon relative abundance index for 2021. No survey was conducted during 2008 or 2020.

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Status and trends: The juvenile pink salmon index has varied over time, and was generally higher in warmer years (2003–2005; 2015–2019), but decreased dramatically during 2021.

Factors influencing observed trends: The NBS is experiencing significant warming and extremes in seasonal ice extent and thickness that may benefit pelagic production during summer months and improve the growth and survival of local pink salmon stocks in early marine life history stages. It is unclear at this time why juvenile pink salmon relative abundance declined abruptly during the 2021 NBS survey.

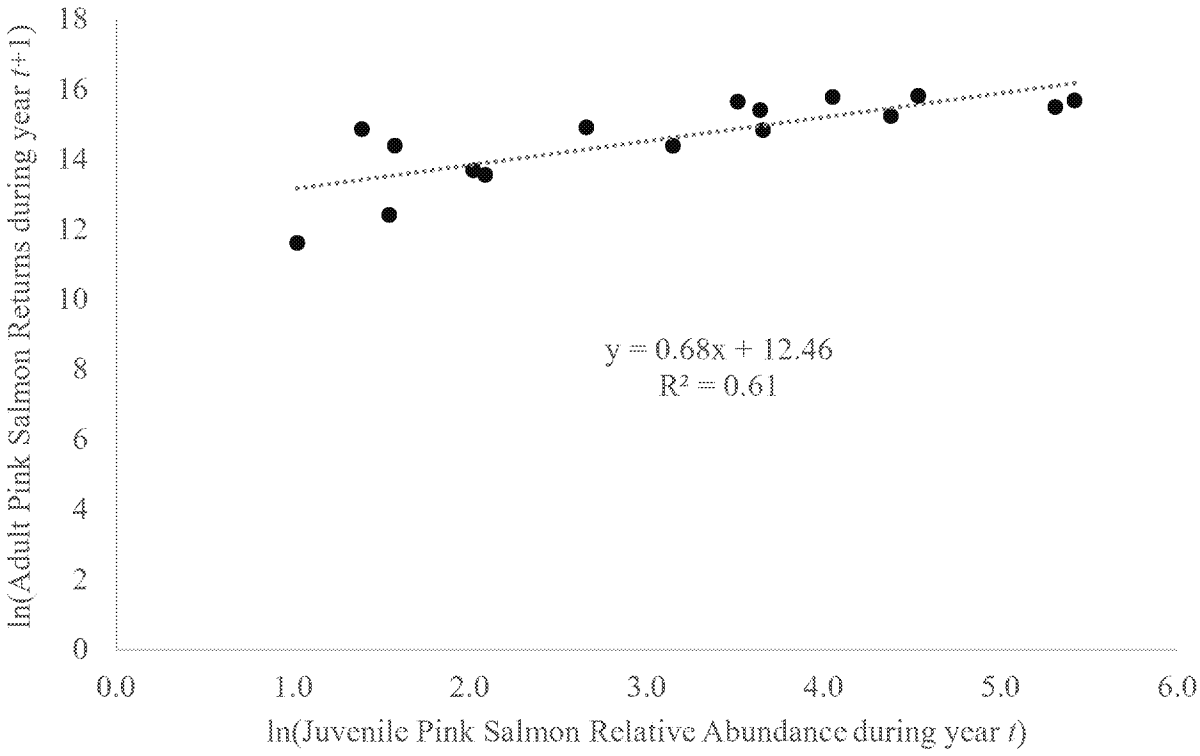

Figure 68: The relationship between juvenile pink salmon relative abundance index (2003–2019) and the index of pink salmon returns (2004–2020) to Yukon and Norton Sound rivers the following year.

Figure 2. The relationship between juvenile Pink salmon relative abundance index (2003 to 2019) and the index of Pink salmon returns (2004 to 2020) to Yukon and Norton Sound rivers the following year.

Implications: In general, pink salmon appear to be taking advantage of warming freshwater and marine environments of the NBS and may portend further changes in the NBS region as a result of ongoing warming. Higher pink salmon production in the NBS region may be linked to the northward movement of salmon into the Arctic as pink salmon seek other areas to colonize. However, there is still high variability in numbers of juvenile pink salmon, even during warm years, as indicated by their dramatic decline during fall 2021.

Juvenile Abundance Index for Yukon River Fall Chum Salmon

Contributed by Sabrina Garcia[1], Christine Kondzela[2], Jim Murphy[2], and Kathrine Howard[1]
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[2]Auke Bay Laboratories, Alaska Fisheries Science Center, NOAA
Contact: sabrina.garcia@alaska.gov
Last updated: October 2021

Description of indicator: Stock-specific abundance indices of juvenile (first year at sea) chum salmon (*Oncorhynchus keta*) in the eastern Bering Sea are estimated for the Upper Yukon River stock group, which is comprised of stocks in both the U.S. and Canada (hereafter, fall chum salmon). These abundance indices are available for all years from 2003 to 2021 (except 2008 and 2020). Given that the abundance indices for juvenile chum salmon are in the early phases of model development, caution should be exercised when interpreting results as they are subject to change as the model is refined over time.

Abundance indices are based on surface trawl catch-per-unit-effort (CPUE, #/km^2) from surveys operating between 58°N and 63°N and east of 172.5°W. These boundaries were chosen as they encompass the area of the eastern Bering Sea where genetic analyses indicate fall chum salmon in their first year at sea are encountered in high proportions. Annual CPUEs were then expanded by the proportion of fall chum salmon to generate an annual stock-specific CPUE for the eastern Bering Sea. The 2021 abundance index was generated using the average genetic stock proportion from 2015–2019 and will change once stock compositions from 2021 become available. From 2003–2021, the index of abundance for the fall chum salmon stock group ranged from a low of 14 in 2006 to a high of 169 in 2019, with an average CPUE of 50 (Figure 69).

Fall chum salmon caught as juveniles in eastern Bering Sea surveys are assumed to be age-1 (one winter spent in the gravel before migrating to the sea). Therefore, the stocks of juvenile fall chum salmon encountered will primarily return as adults to the Yukon River three years later as age-4 and four years later as age-5. Between juvenile years 2003–2015 (brood years 2002–2014), the relationship between the juvenile fall chum salmon index in the eastern Bering Sea and the adult returns from those juveniles showed a strong, positive trend. However, the addition of the most recently completed brood year (2015 brood year, 2016 juvenile year) does not follow this trend (Figure 70).

Status and trends: While the 2016 juvenile fall chum salmon index was above average, the adult returns from that juvenile year were lower than expected based on the juvenile to adult relationship (Figure 70). Juvenile fall chum salmon caught in 2016 predominantly returned to the Yukon River as age-4 in 2019 and age-5 in 2020. The other juvenile years that would have predominantly contributed to the poor adult run abundances in 2020 and 2021 were the 2017 juvenile cohort (returning as age-4 in 2020 and age-5 in 2021) and the 2018 juvenile cohort (returning as age-4 in 2021 and age-5 in 2022). While the 2017 juvenile fall chum salmon abundance index in the eastern Bering Sea was below average, the index has been above average since 2018 (Figure 70). Although the above-average juvenile abundance indices in 2018, 2019, and 2021 suggest improved adult run sizes over the next few years, uncertainty in the juvenile to adult relationship precludes our ability to reliably forecast future run sizes. Additional years of adult return data are needed to see how future years affect the juvenile to adult relationship.

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and ecosystem survey cruise report, 2019. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-423, 124 p.

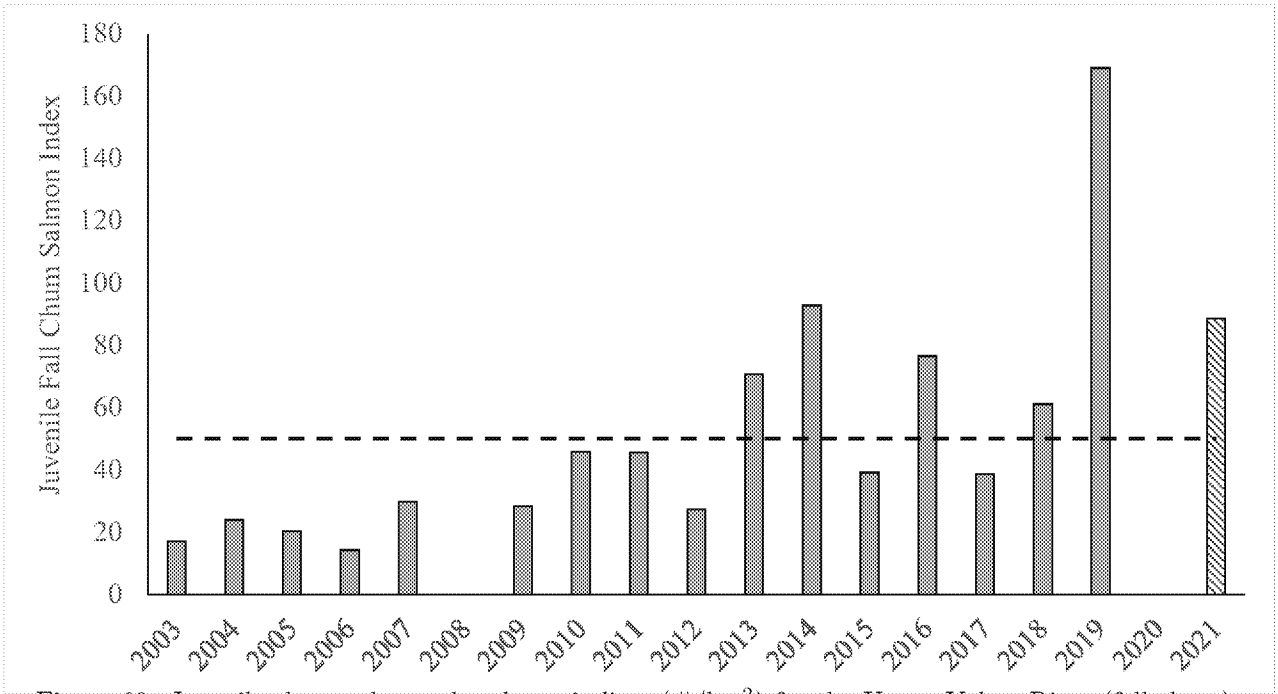

Figure 69: Juvenile chum salmon abundance indices (#/km^2) for the Upper Yukon River (fall chum) stock group, 2003–2021. No surveys occurred in 2008 and 2020. The 2021 abundance index was generated using the average genetic stock proportion from 2015–2019 and will change once stock compositions from 2021 become available. Dashed line indicates the average juvenile chum salmon index across years 2003–2019.

Figure 1: Juvenile chum salmon abundance indices (#/km^2) for the Upper Yukon River (fall chum) stock group, 2003 to 2021. No surveys occurred in 2008 and 2020. The 2021 abundance index was generated using the average genetic stock proportion from 2015 to 2019 and will change once stock compositions from 2021 become available. Dashed line indicates the average juvenile chum salmon index across years 2003–2019.

Factors influencing observed trends: The strong, positive relationship between the juvenile abundance index and adult returns from juvenile years 2003–2015 (brood years 2002–2014) suggests that the strength of adult returns is determined sometime before the end of the first summer in the ocean. However, the weakening of this relationship with the addition of the 2016 juvenile year (2015 brood year) suggests that changes in later-stage marine mortality in recent years may be disproportionately affecting the productivity of fall chum salmon returns. Whether the current trend will continue in recent years is unknown and additional years of adult return data are needed.

Implications: A primary objective of estimating a juvenile fall chum salmon abundance index is to determine if a reliable adult forecasting tool can be developed for fall chum salmon, similar to the forecasting tool created for Yukon River Chinook salmon (Murphy et al., 2017; Howard et al., 2020; Murphy et al., 2021). Chum salmon mortality following the first summer in the ocean must be relatively stable before juvenile abundance can be used to reliably forecast future adult returns. While preliminary model results were promising, fluctuations in marine mortality, likely driven by rapid changes in the marine environment, may complicate the development of an accurate tool to predict adult returns. Future iterations of model development may require environmental covariates (e.g., sea surface temperature) to account for natural mortality that occurs during later life-history stages.

Fall chum salmon from the Yukon River are an important subsistence resource and are increasingly important when Chinook salmon runs are low, especially for the people of the Upper Yukon River. The ability to predict changes in productivity for this stock group would be beneficial to fishery managers and stakeholders in the region and would allow them to plan for anticipated run sizes up

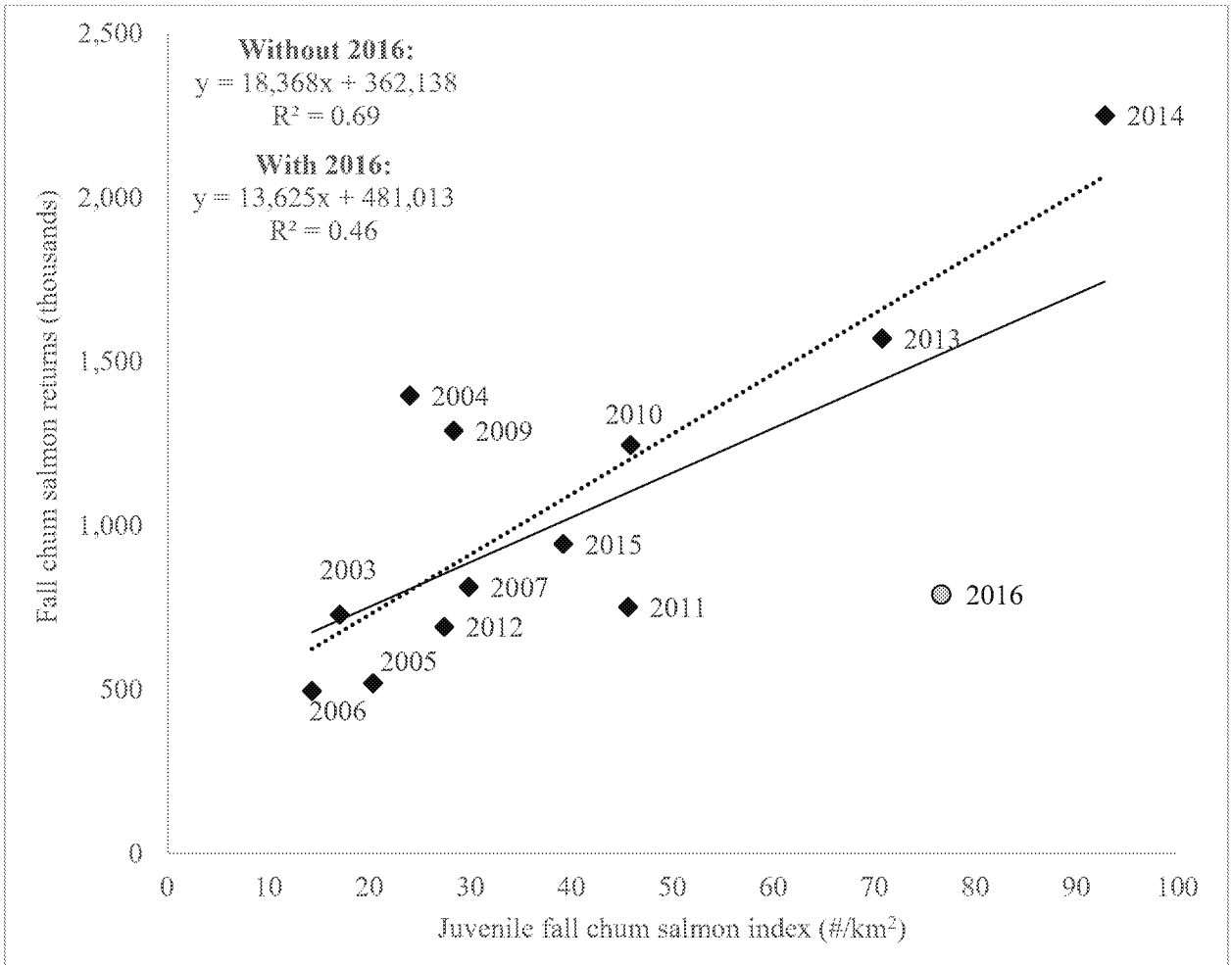

Figure 70: Relationships between juvenile abundance and adult abundance for Upper Yukon River (fall chum salmon) for juvenile years 2003–2016. Adult abundance is the number of returning adults and only includes years where all juveniles from a cohort have returned to the Yukon River. The dashed regression line excludes juvenile year 2016 and the solid black line includes all years. Labels indicate juvenile year (juvenile year is equal to brood year + 1).

Figure 2. Relationships between juvenile abundance and adult abundance for Upper Yukon River (fall chum salmon) for juvenile years 2003–2016. Adult abundance is the number of returning adults and only includes years where all juveniles from a cohort have returned to the Yukon River. The dashed regression line excludes juvenile year 2016 and the solid black line includes all years. Labels indicate juvenile year (juvenile year is equal to brood year + 1).

to three years in the future. More work is needed to refine the juvenile model, such as determining a core area that is consistently sampled year to year. Similarly, continued marine research on juvenile salmon is necessary to understand how rapid changes to the marine environment affect chum salmon population dynamics.

Groundfish

Eastern and Northern Bering Sea Groundfish Condition

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Last updated: October 2021

Description of indicator: Length-weight residuals represent how heavy a fish is per unit body length and are an indicator of somatic growth variability (Brodeur et al., 2004). Therefore, length-weight residuals can be considered indicators of prey availability, growth, general health, and habitat condition (Blackwell et al., 2000; Froese, 2006). Positive length-weight residuals indicate better condition (i.e., heavier per unit length) and negative residuals indicate poorer condition (i.e., lighter per unit length) (Froese, 2006). Fish condition calculated in this way reflects realized outcomes of intrinsic and extrinsic processes that affect fish growth, which can have implications for biological productivity through direct effects on growth and indirect effects on demographic processes such as reproduction and mortality (Rodgveller, 2019; Barbeaux et al., 2020).

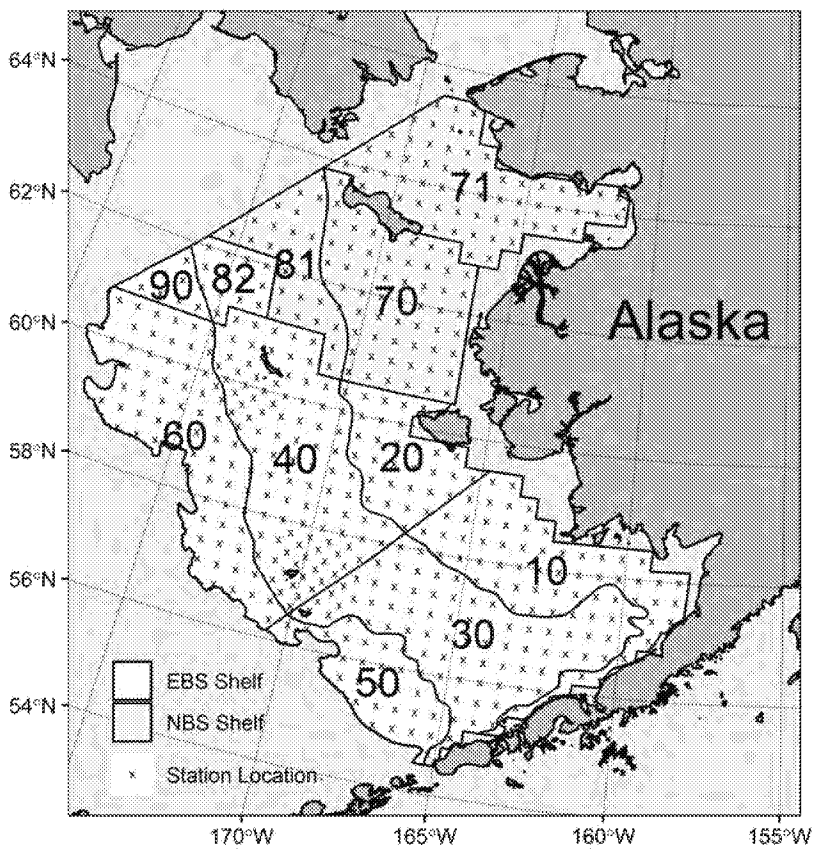

Figure 71: NOAA Alaska Fisheries Science Center summer bottom trawl survey strata (10–90) and station locations (x) on the eastern Bering Sea (EBS) shelf and in the northern Bering Sea (NBS).

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The groundfish morphometric condition indicator is calculated from paired fork lengths (mm) and weights (g) of individual fishes that were collected during bottom trawl surveys of the eastern Bering Sea (EBS) shelf and northern Bering Sea (NBS) which were conducted by the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (AFSC/RACE) Groundfish Assessment Program (GAP). Fish condition analyses were applied to Walleye pollock (*Gadus chalcogrammus*), Pacific cod (*G. macrocephalus*), Arrowtooth flounder (*Atheresthes stomias*), Yellowfin sole (*Limanda aspera*), Flathead sole (*Hippoglossoides elassodon*), Northern rock sole (*Lepidopsetta polyxystra*), and Alaska plaice (*Pleuronectes quadrituberculatus*) collected in bottom trawls at standard survey stations (Figure 71). For these analyses and results, survey strata 31 and 32 were combined as stratum 30; strata 41, 42, and 43 were combined as stratum 40; and strata 61 and 62 were combined as stratum 60. Northwest survey strata 82 and 90 were excluded from these analyses.

To calculate indicators, length-weight relationships were estimated from linear regression models based on a log-transformation of the exponential growth relationship, $W = aL^b$, where W is weight (g) and L is fork length (mm) for all areas for the period 1997–2021 (EBS: 1997–2021, NBS: 2010, 2017–2019, 2021). A unique slope (b) was estimated for each survey stratum to account for spatial-temporal variation in growth and bottom trawl survey sampling. Length-weight relationships for 100–250 mm fork length pollock (corresponding with ages 1–2 years) were calculated separately from adult pollock (> 250 mm).

Residuals for individual fish were obtained by subtracting observed weights from bias-corrected weights-at-length that were estimated from regression models. For the EBS shelf, individual length-weight residuals were averaged for each stratum and weighted based on the proportion to total biomass in each stratum from area-swept expansion of bottom trawl survey catch per unit effort (CPUE; i.e., design-based stratum biomass estimates). Variation in fish condition was evaluated by comparing average length-weight residuals among years. Analysis for the NBS was conducted separately from the EBS because of the shorter time series and the NBS was treated as a single stratum. To minimize the influence of unrepresentative samples on indicator calculations, combinations of species, stratum, and year with sample size <10 were used to fit length-weight regressions but were excluded from calculating length-weight residuals for both the EBS and NBS.

Methodological Changes: Length-weight data from corner stations were included in analyses. This change was made because length-weight samples from corner stations are collected within stratum boundaries following regular sampling protocols.

Status and trends: Fish condition, based on length-weight residuals, has varied over time for all species examined (Figures 72 and 73). In 2019, an upward trend in condition was observed for most species relative to 2017–2018 with positive weighted length-weight residuals relative to historical averages for large pollock (>250 mm), Northern rock sole, Yellowfin sole, Arrowtooth flounder, and Alaska plaice. In 2021, mean weighted length-weight residuals in the EBS were negative for large pollock (>250 mm) and Arrowtooth flounder (Figure 72). Mean weighted length-weight residuals were negative for Pacific cod, Northern rock sole, Alaska plaice, and Flathead sole, although 95% confidence intervals for these species included the historical mean. Weighted length-weight residuals were near the historical averages for small pollock (100–250 mm) and Yellowfin sole (Figure 72).

In 2021, negative length-weight residuals were observed for large pollock (>250 mm), Pacific cod, Yellowfin sole, and Alaska plaice in the NBS (Figure 73). The only species with a positive length-weight residual in the NBS in 2021 was small pollock (100–250 mm) (Figure 73).

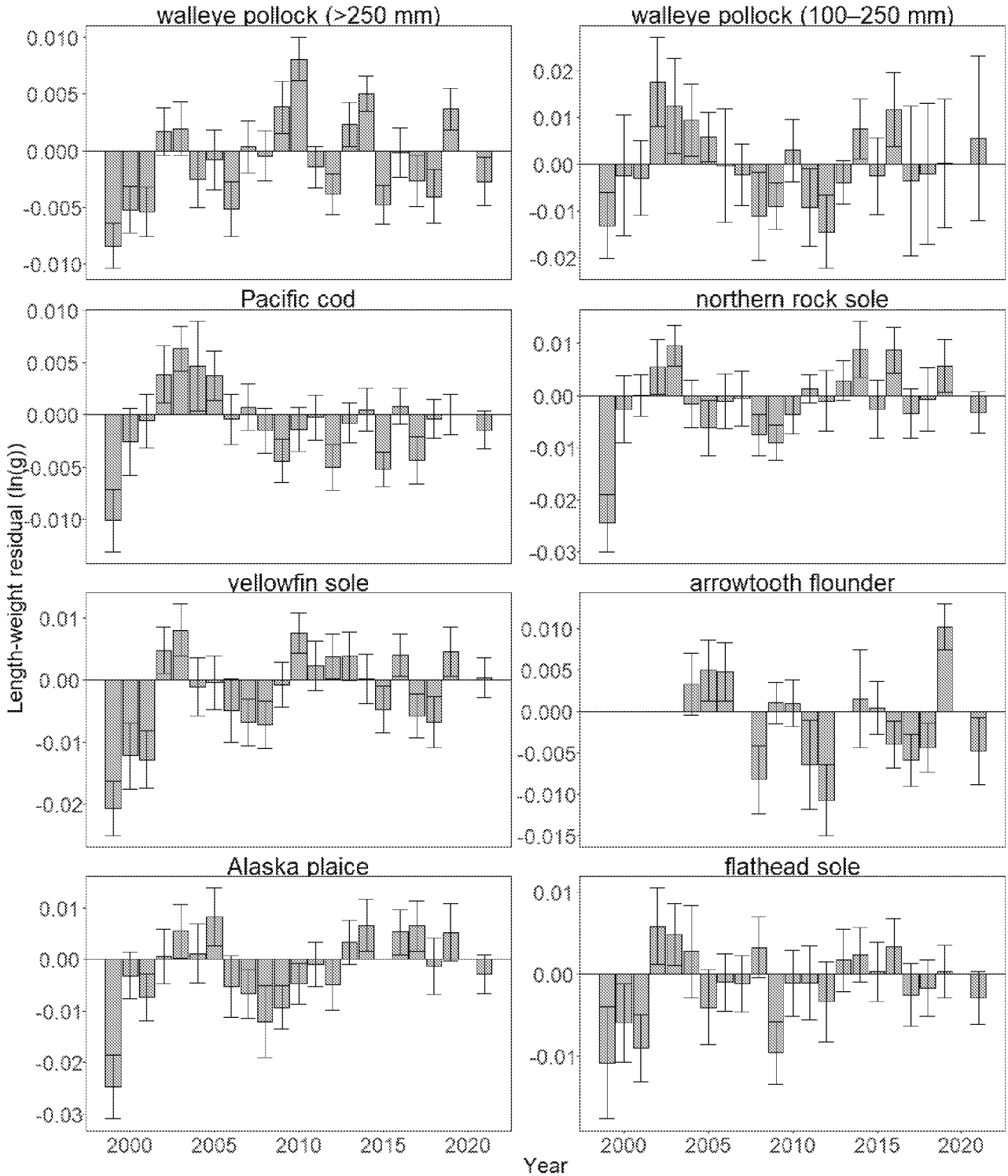

Figure 72: Weighted length-weight residuals for seven groundfish species and age 1–2 Walleye pollock (100–250 mm) collected during AFSC/RACE GAP standard summer bottom trawl surveys of the eastern Bering Sea shelf, 1999–2021. Filled bars denote weighted length-weight residuals using this year's indicator calculation. Error bars denote two standard errors.

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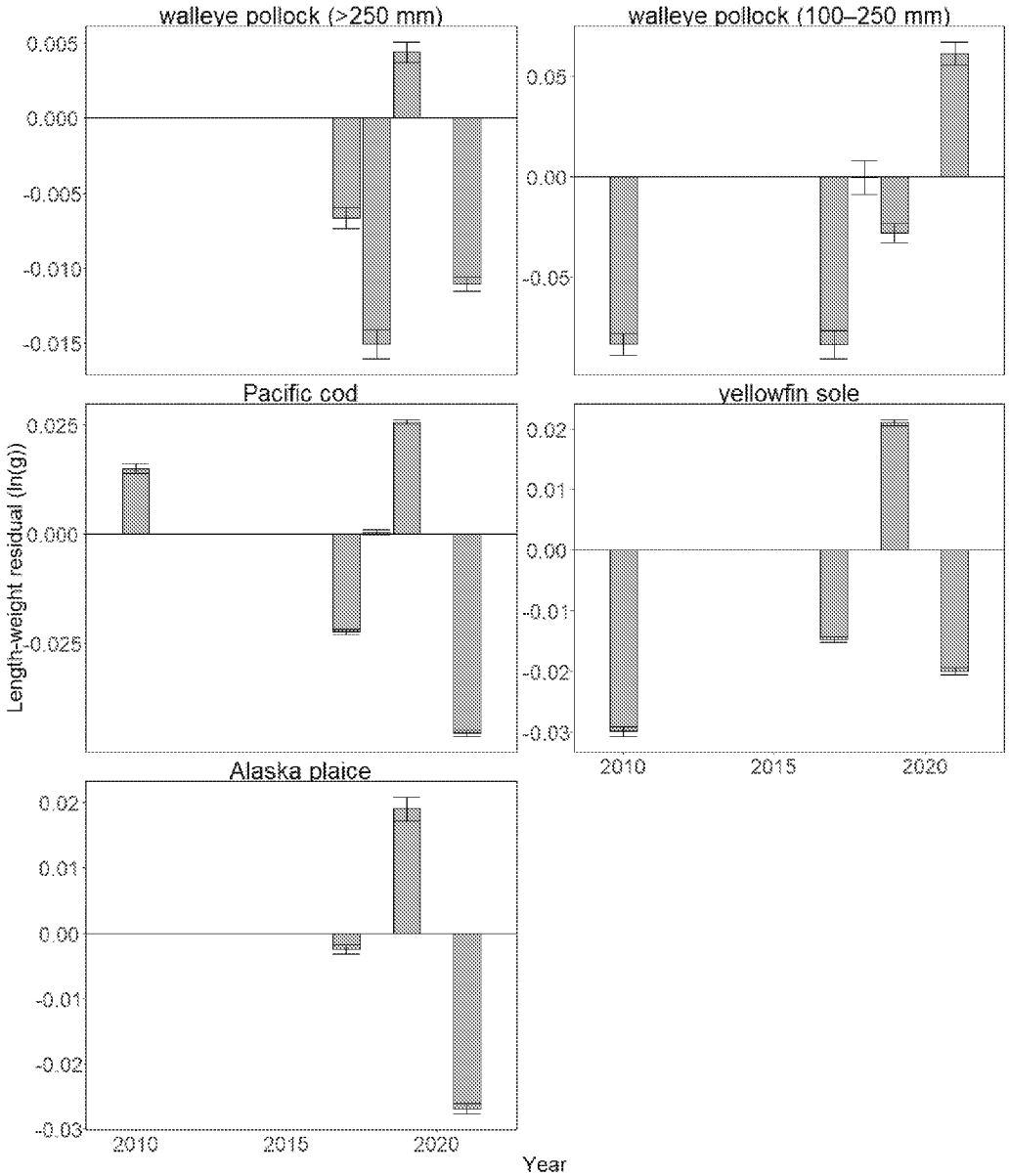

Figure 73: Length-weight residuals for groundfish species and age 1–2 Walleye pollock (100–250 mm) collected during AFSC/RACE GAP summer bottom trawl surveys of the northern Bering Sea, 2010 and 2017–2021. Error bars denote two standard errors.

In 2021, similar to 2010–2019, Pacific cod condition was generally negative on the middle and outer northern shelf and outer southern shelf (strata 40, 50, and 60); however, condition was also negative on the inner southern shelf and inner northern shelf (strata 10, 20 and 30), indicating a decline in condition on these strata since 2019 (Figure 74). Large pollock (>250 mm) condition was primarily negative on all strata in 2021, which is consistent with the observed condition on the inner shelf since 2015. In 2021, small pollock (100–250 mm) condition was generally positive, and consistent with observed condition on the inner shelf since 2014. In 2021, negative condition was observed in all EBS strata for Northern rock sole, Alaska plaice, Flathead sole, and Arrowtooth flounder. The remaining species, Yellowfin sole, had positive residuals on the outer shelf (stratum 40) (Figure 74).

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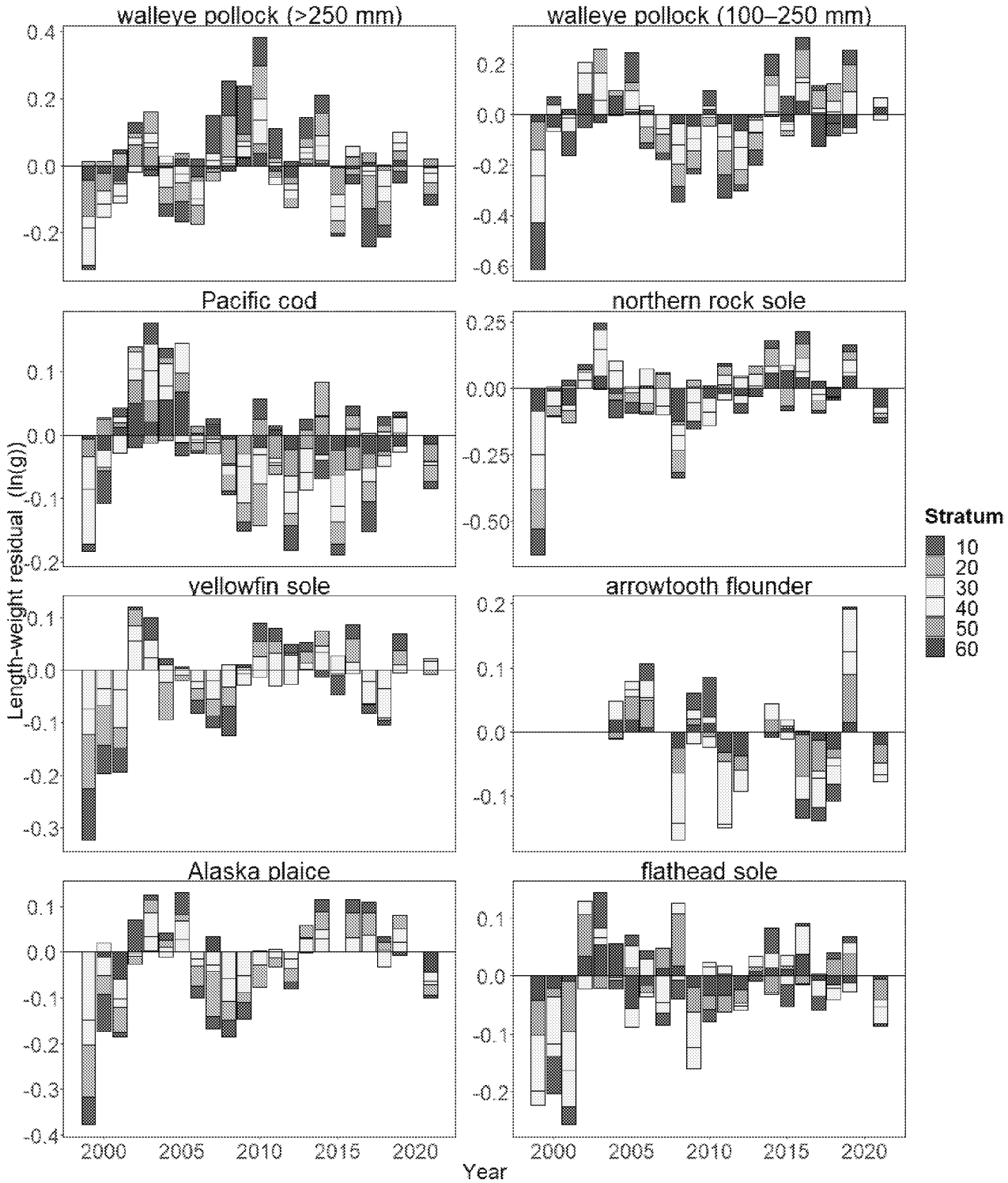

Figure 74: Length-weight residuals by survey stratum (10–60) for seven eastern Bering Sea shelf groundfish species and age 1–2 Walleye pollock (100–250 mm) sampled in the AFSC/RACE GAP standard summer bottom trawl survey, 1999–2021. Length-weight residuals are not weighted by stratum biomass.

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Factors influencing observed trends: Several factors may influence the observed temporal and spatial patterns in fish condition in the EBS and NBS. Water temperature could explain some of the spatial and temporal variability in length-weight residuals. Historically, particularly cold years tend to correspond with negative condition, while particularly warm years tend to correspond with positive condition. For example, water temperatures during the 1999 survey were particularly cold in the Bering Sea and this corresponded to a year of negative condition for all groundfish for which data exist. In addition, spatial temporal factor analyses suggest the morphometric condition of age-7 pollock is strongly correlated with cold pool extent in the EBS (Grüss et al., 2021). In recent years, continuing warm temperatures across the Bering Sea shelf since the record low seasonal sea ice extent in 2017–2018 and historical cold pool area minimum in 2018 (Stabeno and Bell, 2019) may have influenced the positive trend in fish condition from 2016 to 2019. Although warmer conditions also occurred in 2021, with the fourth smallest cold pool area and fifth warmest mean bottom temperature in the 39-year survey time series, the majority of species had negative or neutral conditions in 2021.

Although warmer temperatures may increase growth rates if there is adequate prey to offset temperature-dependent increases in metabolic demand, growth rates may also decline if prey resources are not adequate to offset temperature-dependent increases in metabolic demand. For example, elevated temperatures during the 2014–2016 marine heatwave in the Gulf of Alaska led to lower growth rates of Pacific cod and lower condition because prey resources were not sufficient to make up for increased metabolic demand (Barbeaux et al., 2020). The influence of temperature on growth rates depends on the physiology of predator species, prey availability, and the adaptive capacity of predators to respond to environmental change through migration, changes in behavior, and acclimatization. Thus, the factors underpinning the negative or neutral condition remain unclear.

Other factors that could affect length-weight residuals include survey timing, stomach fullness, fish movement patterns, sex, and environmental conditions (Froese, 2006). The starting date of annual length-weight data collections has varied from late May to early June and ended in late July-early August in the EBS, and mid-August in the NBS. Although we account for some of this variation by using stratum-specific regression coefficients, variation in condition could relate to the timing of collection within survey strata. Survey timing can be further compounded by seasonal fluctuations in reproductive condition with the buildup and depletion of energy stores (Wuenschel et al., 2019). Another consideration is that fish weights sampled at sea are typically inclusive of stomach content weight so gut fullness may influence the length-weight residuals. Since feeding conditions likely change over space and time, how much the fish ate at its last meal and the proportion of its total body weight attributable to the gut weight could be an important factor influencing the length-weight residuals. We can also expect some fish to exhibit seasonal or ontogenetic movement patterns during the survey months. Although the condition indicator characterizes spatial and temporal variation of length-weight residuals for important fish species in the EBS and NBS, they do not inform the mechanisms or processes behind the observed patterns.

Implications: Fish morphometric condition can be considered an indicator of ecosystem productivity with implications for fish survival, maturity, and reproduction. For example, in Prince William Sound, the pre-winter condition of herring may determine their overwinter survival (Paul and Paul, 1999), differences in feeding conditions have been linked to differences in morphometric condition of pink salmon in Prince William Sound (Boldt and Haldorson, 2004), variation in morphometric condition has been linked to variation in maturity of sablefish (Rodgveller, 2019),

and lower morphometric condition of Pacific cod was associated with higher mortality and lower growth rates during the 2014–2016 marine heat wave in the Gulf of Alaska (Barbeaux et al., 2020). Thus, the condition of EBS and NBS groundfishes may provide insight into ecosystem productivity as well as fish survival, demographic status, and population health. However, survivorship is likely affected by many factors not examined here. We also must consider that, in these analyses, fish condition was computed for all sizes of fishes combined, except in the case of pollock. Examining condition of early juvenile stage fishes not yet recruited to the fishery, or the condition of adult fishes separately, could provide greater insight into the value of length-weight residuals as an indicator of individual health or survivorship (Froese, 2006), particularly since juvenile and adult pollock exhibited opposite trends in condition in both the EBS and NBS this year.

The negative trend in fish condition observed during the 2021 AFSC/RACE GAP EBS and NBS bottom trawl surveys (i.e., increasingly negative length-weight residuals) could be related to concurrent trends in other ecosystem components and needs to be examined further. Furthermore, this denotes a shift in a general positive trend in fish condition in the previous two to three survey years. Trends such as prolonged warmer water temperatures following the marine heat wave of 2014–2016 (Bond et al., 2015) and reduced sea ice and cold pool area extent in the eastern Bering Sea (Stabeno and Bell, 2019) may affect fish condition in ways that have yet to be determined. As we continue to add years of length-weight data and expand our knowledge of relationships between condition, growth, production, survival, and the ecosystem, these data may increase our understanding of the health of fish populations in the EBS and NBS.

Research priorities: Due to programmatic constraints, we did not transition the groundfish condition indicator to use a spatio-temporal model with spatial random effects (VAST) in 2021. For next year's ESR, we aim to transition to VAST, which should allow more precise biomass expansion, improve estimates of uncertainty, and better account for spatial-temporal variation in length-weight samples from bottom trawl surveys. Revised indicators will be presented alongside a retrospective analysis to compare the current condition indicator to a VAST-based condition indicator in 2022. Furthermore, there is an ongoing Essential Fish Habitat project within the AFSC Groundfish Assessment Program to validate the morphometric condition indicator in Pacific cod and pollock using a physiological metric. Finally, the Condition Congress Steering Committee provided four recommendations for the future of fish condition research at AFSC: inter-calibration of existing condition indices, development of projects to link physiological measurements of condition to demographic outcomes, management-directed research, and standardizing formulation and description of metrics (Hurst et al., 2021). Future research priorities should consider this guidance.

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Patterns in Foraging and Energetics of Walleye pollock, Pacific cod, Arrowtooth flounder, and Pacific halibut

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Last updated: October 2021

Description of indicator: We report trends in metabolic demand from an adult bioenergetics model for groundfish in SEBS (Ciannelli et al., 1998; Holsman et al., 2019; Holsman and Aydin, 2015) and patterns in diet composition from the NOAA Fisheries Alaska Fisheries Science Center's Food Habits database of fish diets collected during summer bottom trawl surveys in the eastern Bering Sea (EBS). This work is part of an in prep manuscript and the authors request that the images and data reported herein not be duplicated or shared outside of this reprot until the publication is complete in 2022. Bioenergetics-based indices were calculated for individual predator stomach samples using bioenergetic models. Samples were averaged by 5-cm predator bins across stations within a strata and then extrapolated to the population level using annual proportional biomass for each bin in each strata based on bottom trawl surveys (see Ciannelli et al. (1998); Holsman et al. (2019); Holsman and Aydin (2015), and Livingston et al. (2017) for more information).

Bioenergetic diet indices collectively indicate changes in foraging and growing conditions; relative foraging rate (RFR) reflects the ratio of observed food consumption (specific consumption rate; C_ggd) to a theoretical temperature and size-specific maximum consumption rate from laboratory feeding experiments. Declines in this index can reflect decreases in prey availability or prey switching to more energetically valuable prey. Therefore we also present mean diet energy density (mnEDJ_g) which reflects the average energetic density of prey in stomachs sampled from across the EBS in a given year. Less favorable foraging patterns would be reflected in declines in RFR when mnEDJ_g remains the same or also declines in a given year. Metabolic demand (R_ggd) generally increases with temperature and indicates the basal energetic requirements of the fish. Finally, scope for growth (G_ggd) integrates metabolic demand, prey energy, and relative consumption rates to indicate how changes in temperature and foraging collectively influence (potential) growth.

Status and trends: We observe directional trends in consumption and potential growth that reflect climate driven changes to metabolic demand and trophic interactions and which indicate declining conditions for groundfish in the southeastern Bering Sea (SEBS) in recent years. All five indices suggest continued poor conditions for Walleye pollock (*Gadus chalcogrammus*; hereafter "pollock") and Pacific cod (*Gadus macrocephalus*) in recent years relative to historical rates (1982–2010).

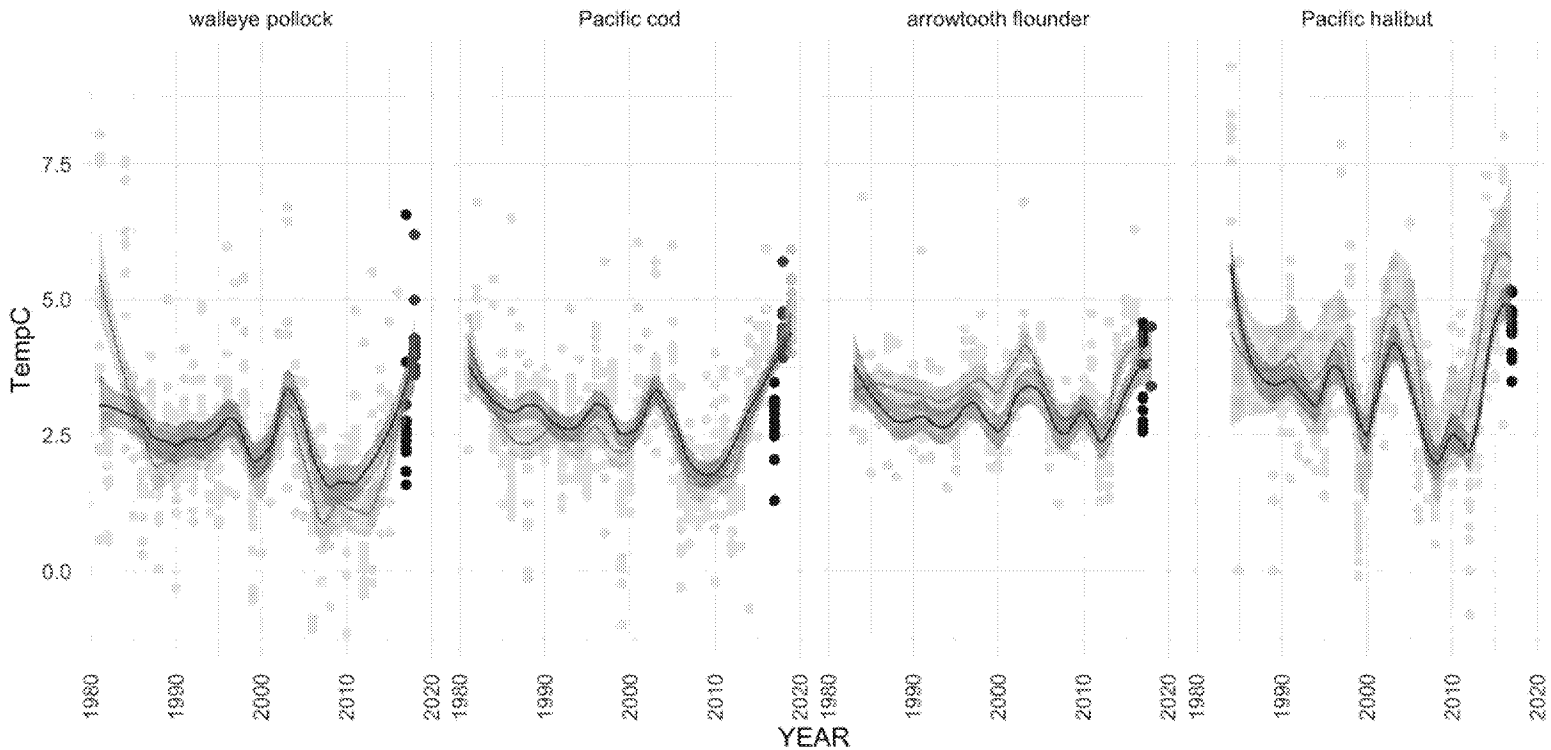

Figure 75: Average thermal experience (TempC) for 5-cm size bins of groundfish species in SEBS (light blue dots), with 2016 (dark blue), 2017 (dark teal), and 2018 (bright green) highlighted for reference. The spline represents a loess smoother for juvenile (orange) and adult (teal) fish. Data is based on biomass-weighted bottom temperature for samples collected during NOAA AFSC summer bottom trawl surveys.

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Thermal experience (biomass weighted bottom temperature) of all four groundfish species in the SEBS has increased in recent years (Figure 75), with Pacific cod recent thermal experience the highest in the 30+ year time series. Relative energetic demand of pollock, Pacific cod, and Pacific halibut (*Hippoglossus stenolepis*; hereafter "halibut") reflect climate-driven changes to metabolic demand with marked increases in metabolic demand since 2005–2010 ("R_ggd" for respiration). Accordingly, metabolic demand for (juvenile and adult) pollock and Pacific cod continues to increase relative to historical (1982–2010) rates with 2015–2019 rates approximately 64%, 5%, and 7% higher than historical values for pollock, Pacific cod, and halibut (respectively).

Meanwhile relative foraging rates for juvenile pollock and Pacific cod declined markedly in recent years (2015–2019) relative to historical rates (1982–2010) by -41% and -18%, respectively (Figure 76).

The mean energetic value of sampled diets dropped in 2000 (pollock) and 2005 (Pacific cod) relative to previous years and has generally remained lower than 1982–2000 values. Mean energetic density of prey for pollock and Pacific cod is approximately -5% lower than prior to 2000. The integrated outcome of these changes is an overall decline in scope for growth for both pollock and juvenile Pacific cod in recent years, especially for juvenile Pacific cod, where (2015–2019) juvenile Pacific cod scope for growth remains well below the long-term average (1982–2010; Figure 77).

Factors influencing observed trends: Metabolic demands for ectothermic fish like pollock, Pacific cod, Arrowtooth flounder, and halibut are largely a function of thermal experience and body size and tend to increase exponentially with increasing temperatures. Fish can minimize metabolic costs through behaviors, such as movement to thermally optimal temperatures, or can increase consumption of food energy to meet increasing metabolic demands. The latter requires sufficient access to abundant or high energy prey resources.

Implications: For pollock and Pacific cod in the EBS, during recent anomalously warm years, metabolic demands were elevated while foraging rates and scope for growth were reduced (Figures 75 and 76). This pattern was most pronounced for juvenile and adult pollock, and juvenile Pacific cod (Figure 77). This has important implications; in order to offset metabolic demands these fish would have had to (1) consume more food or more energetically rich food, (2) access energetic reserves leading to net body mass loss, or (3) move to more energetically favorable foraging grounds. There are a few lines of evidence to support all three of these potential responses to climate-driven changes in the EBS, including observations of large numbers of Pacific cod in the northern Bering Sea surveys in 2017–2021.

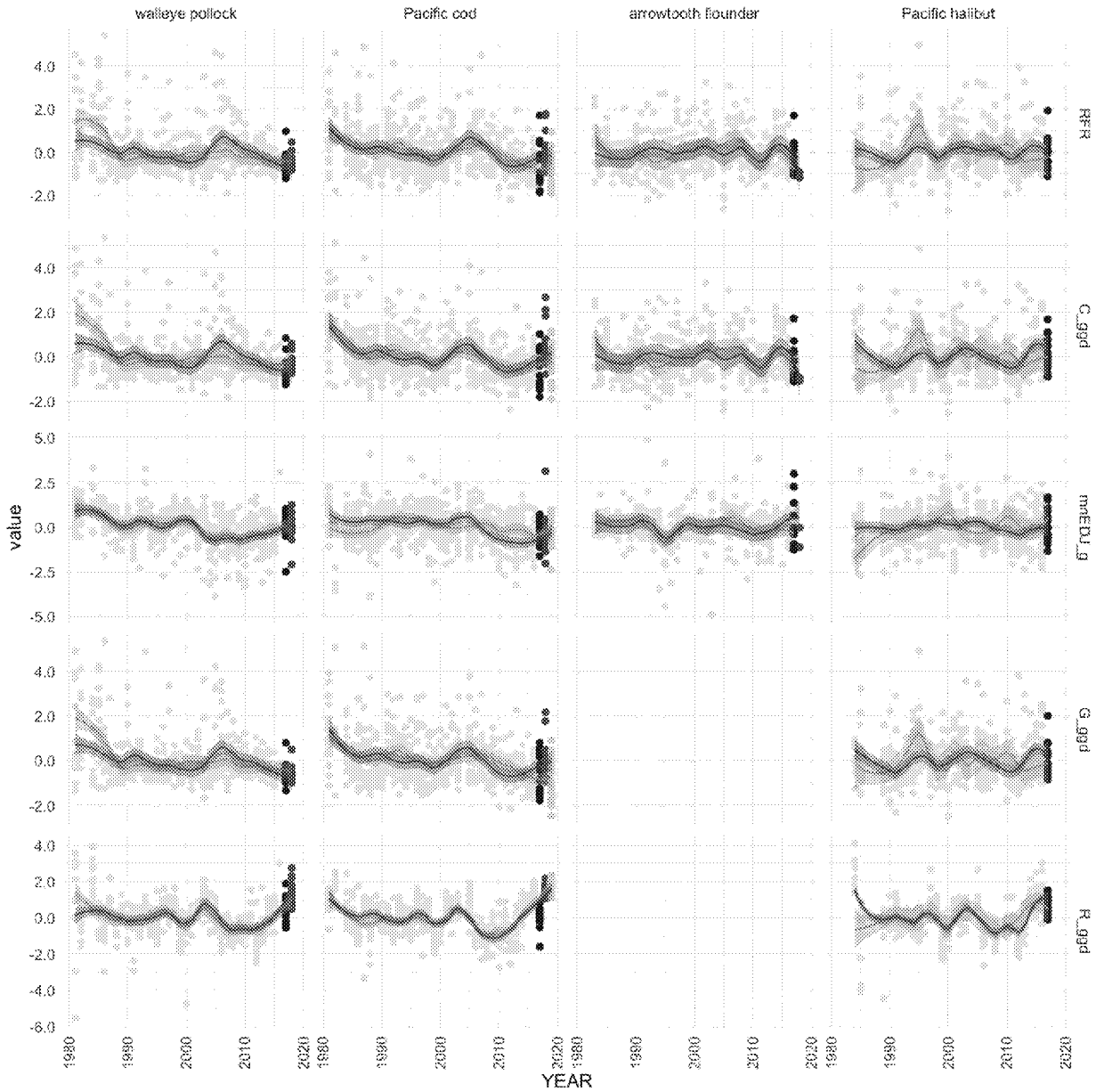

Figure 76: Normalized (i.e., Z-score scaled) bioenergetic diet indices for groundfish species over time including relative foraging rate (RFR), specific consumption rate (C_ggd), mean diet energy density (mnEDJ_g), scope for growth (G_ggd), and metabolic demand (R_ggd). Mean values for each year and bin are shown as light blue dots, while 2016 (dark blue), 2017 (dark teal), and 2018 (bright green) are highlighted for reference. The spline represents a loess smoother for juvenile (orange) and adult (teal) fish. Data is based on biomass-weighted indices for samples collected during NOAA AFSC summer bottom trawl surveys.

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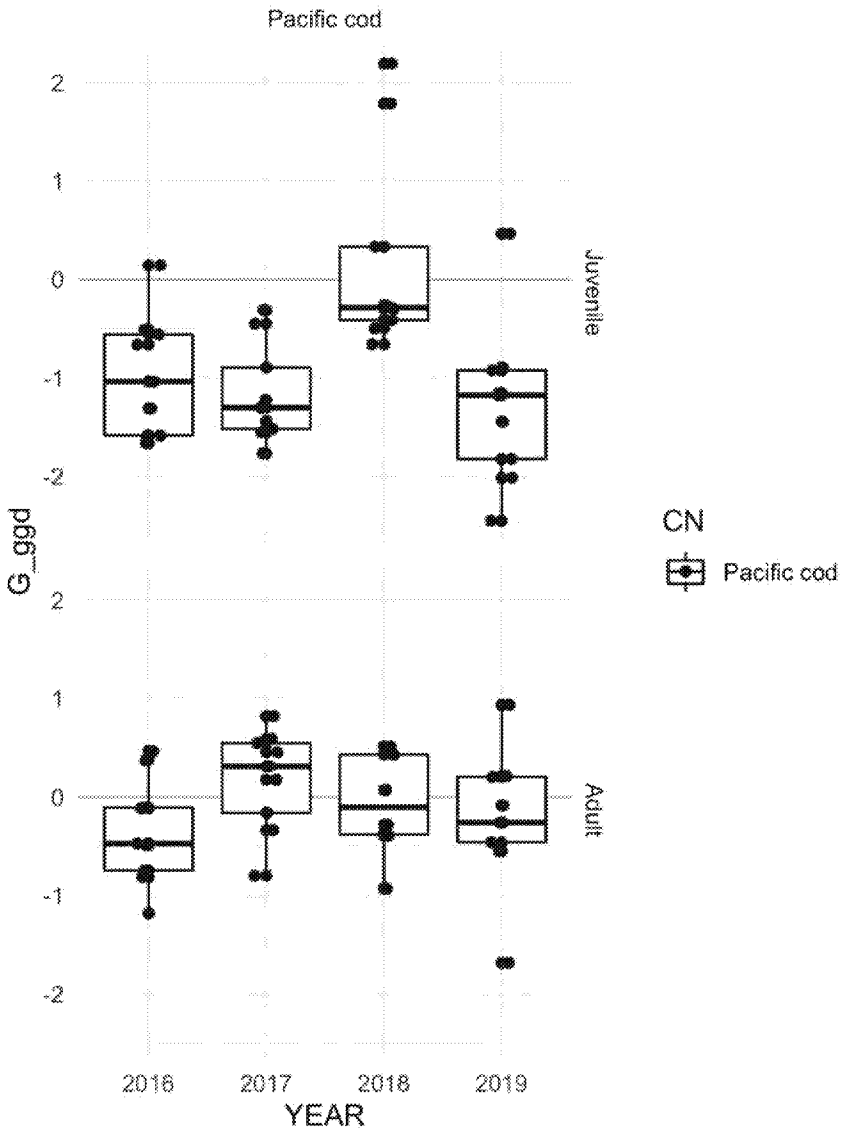

Figure 77: Normalized (i.e., Z-score scaled) bioenergetic (potential) scope for growth (G_ggd) for juvenile and adult fish from 2015–2019. Data is based on biomass-weighted indices for samples collected during NOAA AFSC summer bottom trawl surveys.

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Multispecies Model Estimates of Time-varying Natural Mortality

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Last updated: October 2021

Description of indicator: We report trends in age-1 total mortality for Walleye pollock (*Gadus chalcogrammus*, 'pollock'), Pacific cod (*Gadus macrocephalus*, 'P. cod') and Arrowtooth flounder (*Atheresthes stomias*, 'Arrowtooth') from the eastern Bering Sea. Total mortality rates are based on residual mortality inputs (M1) and model estimates of annual predation mortality (M2) produced from the multi-species statistical catch-at-age assessment model (known as CEATTLE; Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics). See Appendix 1 of the BSAI pollock stock assessment for 2021 as well as Holsman et al. (2016), Holsman and Aydin (2015), Ianelli et al. (2016), and Jurado-Molina et al. (2005) for more information.

Status and trends: The CEATTLE model estimates of age-1 natural mortality (i.e., M1+M2) for pollock, P. cod, and Arrowtooth continue to decline from the 2016 peak mortality. For all three species, age-1 predation mortality rates have remained similar to 2020 and are well below the long-term mean. At 1.3 yr^{-1}, age-1 mortality estimated by the model was greatest for pollock and lower for P. cod and Arrowtooth, with total age-1 natural mortality at around 0.71 and 0.68 yr^{-1}. The 2021 age-1 natural mortality across species is 11% to 46% lower than in 2016 and is below average for pollock (relative to the long-term mean) (Figure 78). Similarly, P. cod and Arrowtooth age-1 mortality are well below the long-term mean.

Patterns in the total biomass of each species consumed by all three predators in the model (typically 1–3 yr old fish) is similar to patterns in age-1 natural mortality but with slight differences in 2021. Pollock and Arrowtooth biomass consumed by all predators in the model is approximately equal to the long-term average, while P. cod biomass consumed is well below average (Figure 79).

Factors influencing observed trends: Temporal patterns in natural mortality reflect annually varying changes in predation mortality that primarily impact age-1 fish (and to a lesser degree ages 2 and 3 fish in the model). Pollock are primarily consumed by older conspecifics, and pollock cannibalism accounts for 57% (on average) of total age-1 predation mortality, with the exception of the years 2006–2008 when predation by Arrowtooth exceeded cannibalism as the largest source of predation mortality of age-1 pollock; Figure 80). The relative proportion of age-1 pollock consumed by older pollock and Arrowtooth increased slightly in 2021, while the relative proportion consumed by P. cod declined slightly.

Combined annual predation demand (annual ration) of pollock, P. cod, and Arrowtooth in 2021 was 5.59 million tons, down slightly from the 6.8 million t annual average during the warm years and large maturing cohorts of 2014–2016. Pollock represent approximately 79% of the model estimates of combined prey consumed with a long term average of 5.76 million tons of pollock consumed annually by all three predators in the model. Individual annual rations remain well above average for all three predator species, driven by anomalously warm water temperatures in the Bering Sea during recent years (Figure 81).

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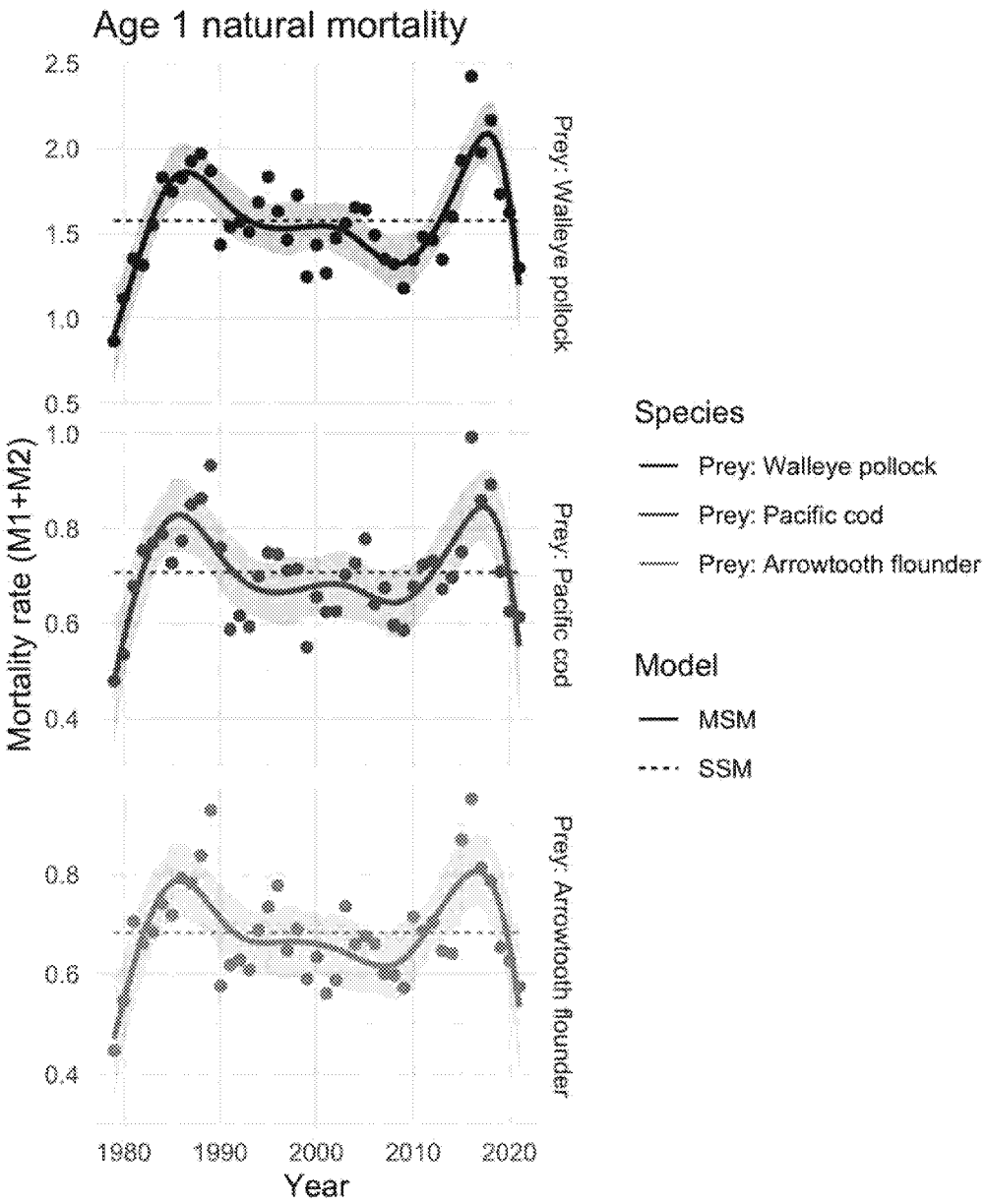

Figure 78: Annual variation in total mortality ($M1_{i1} + M2_{i1,y}$) of age-1 pollock (as prey) (a), age-1 P. cod (as prey) (b), and age-1 Arrowtooth (as prey) (c) from the single-species models (dashed gray line) and the multi-species models with temperature (black line). Updated from Holsman et al. (2016); more model detail can be found in Appendix 1 of the BSAI pollock stock assessment for 2021.

Implications: We find evidence of continued declines in predation mortality of age-1 pollock, P. cod, and Arrowtooth relative to recent high predation years (2014–2016). While warm temperatures continue to lead to high metabolic (and energetic) demand of predators, declines in total predator biomass are contributing to a net decrease in total consumption (relative to 2016) and therefore reduced predation rates and mortality in 2019–2021. This pattern indicates improving top-down conditions for juvenile groundfish survival in 2020 through predator release due to declining biomass of groundfish.

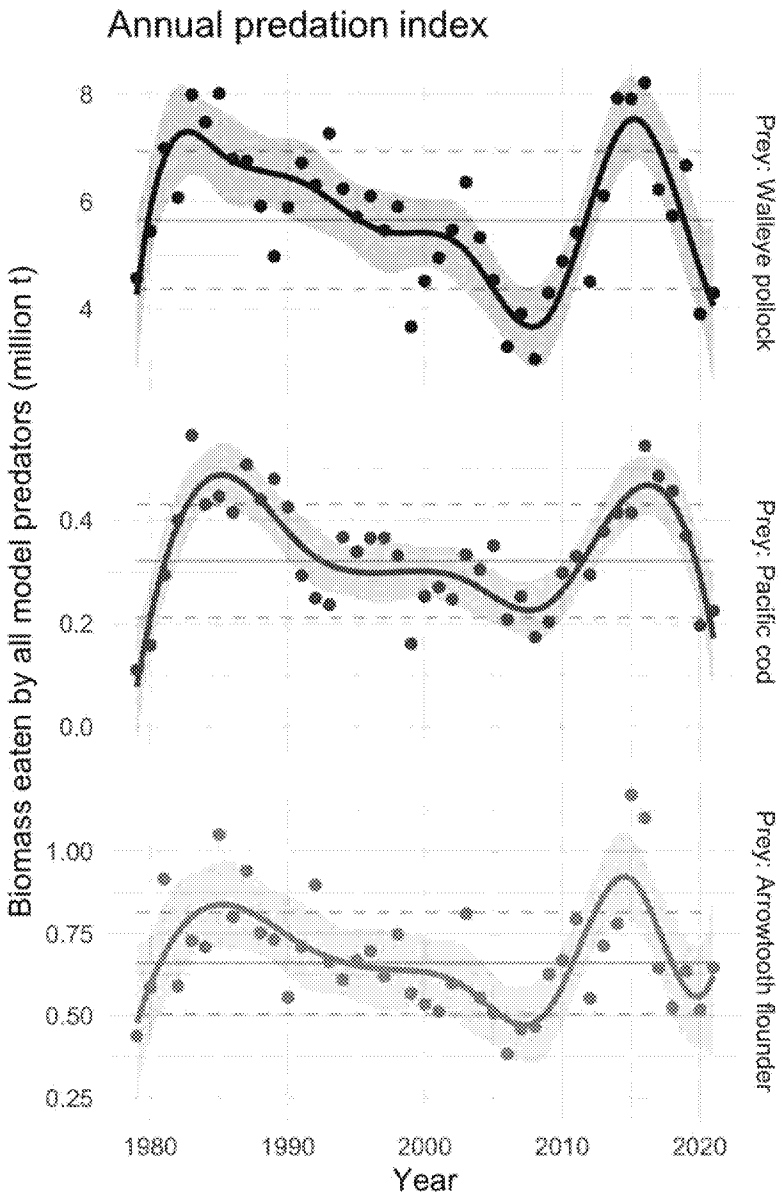

Figure 79: Multispecies estimates of prey species biomass consumed by all predators in the model: a) total biomass of pollock consumed by predators annually b) total biomass of P. cod consumed by predators annually, c) total biomass of Arrowtooth consumed by predators annually. Gray lines indicate 1979–2021 mean estimates for each species.

Between 1980 and 1993, relatively high natural mortality rates reflect patterns in combined annual demand for prey by all three predators that was highest in the mid 1980's (collectively 9.13 million t per year), and in recent years (collectively 6.5 million t per year). The peak in predation mortality of age-1 pollock in 2006 corresponds to the maturation of a large age class of 5-7 year old pollock and 2 year old P. cod that dominated the age composition of the two species in 2006. Similarly, the recent peaks in mortality in 2016 reflect anomalously warm water temperatures combined with the maturation of the large 2010–2012 year class of pollock.

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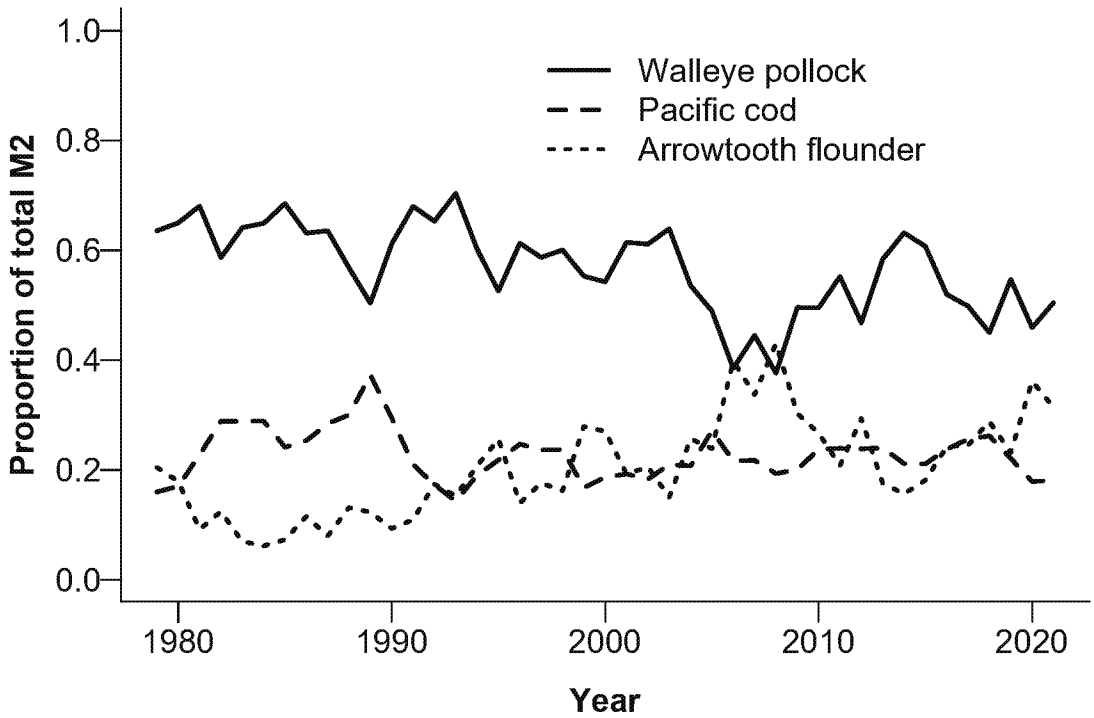

Figure 80: Proportion of total predation mortality for age-1 pollock from pollock (solid), P. cod (dashed), and Arrowtooth (dotted) predators across years. Updated from Holsman et al. (2016); more model detail can be found in Appendix 1 of the BSAI pollock stock assessment for 2021.

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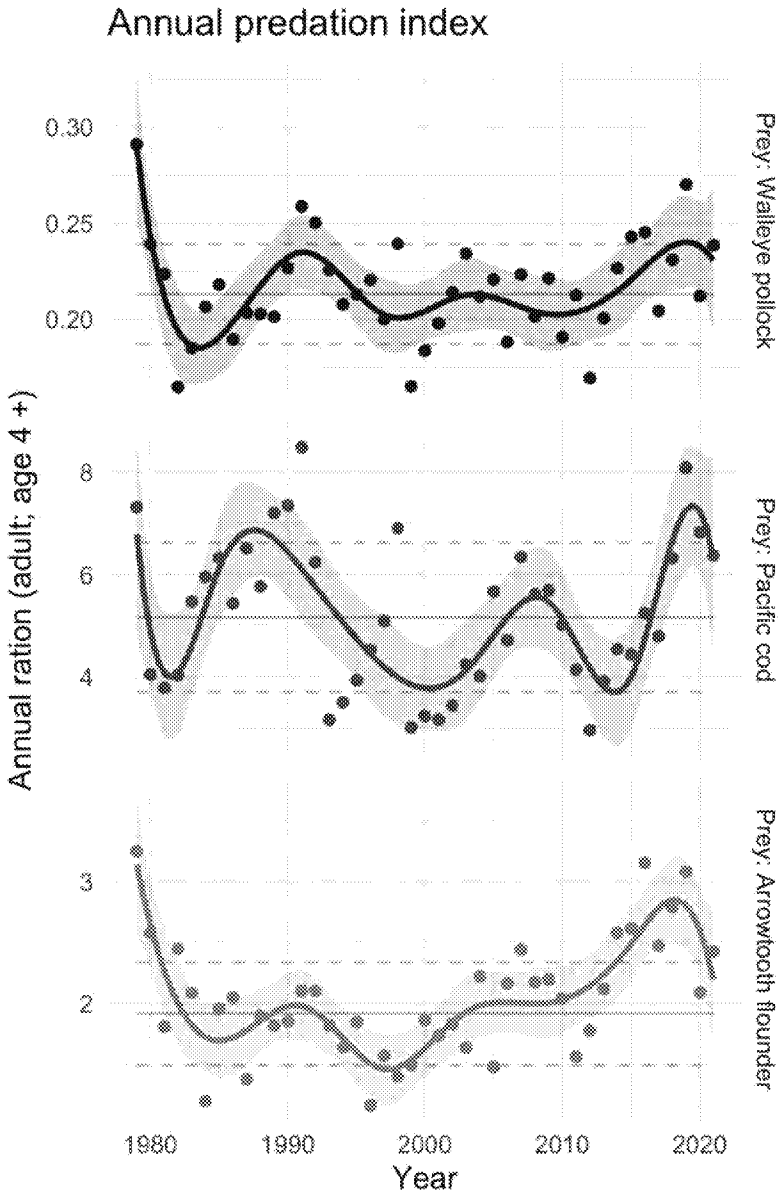

Figure 81: Multispecies estimates of annual ration (kg consumed per individual per year) for adult (age-4+) predators: a) pollock, b) P. cod, and c) Arrowtooth. Gray lines indicate 1979–2021 mean estimates and 1 SD for each species; orange line is a 10-y (symmetric) loess polynomial smoother indicating trends in ration over time.

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Groundfish Recruitment Predictions

Pre- and Post-Winter Temperature Change Index and the Recruitment of Bering Sea Pollock

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Last updated: September 2021

Description of indicator: The temperature change (TC) index is a composite index for the pre- and post-winter thermal conditions experienced by Walleye pollock (*Gadus chalcogrammus*) from age-0 to age-1 in the southeastern Bering Sea (Martinson et al., 2012). The TC index (year t) is calculated as the difference in the average monthly sea surface temperature in June (t+1) and August (t) (Figure 82) in an area of the southern region of the eastern Bering Sea (56.2°N to 58.1°N by 166.9°W to 161.2°W). Time series of average monthly sea surface temperatures were obtained from the NOAA Earth System Research Laboratory Physical Sciences Division website. Sea surface temperatures were based on NCEP/NCAR gridded reanalysis data (Kalnay et al. (1996), data obtained from `http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl` (accessed Sept., 14, 2021)). Less negative values represent a cool late summer during the age-0 phase followed by a warm spring during the age-1 phase for pollock.

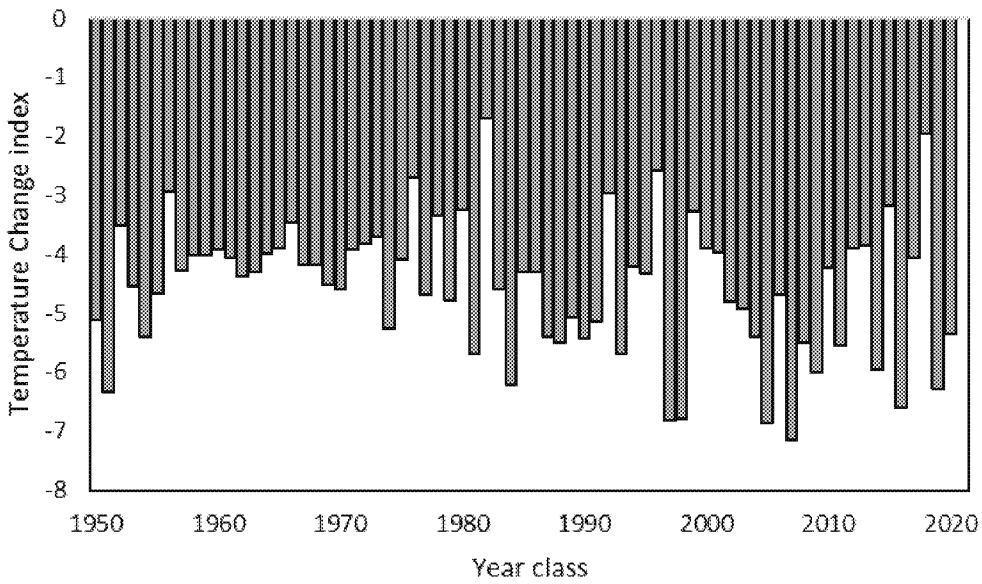

Figure 82: The Temperature Change index values for the 1950 to 2020 year classes of pollock. Values represent the differences in sea temperatures on the southeastern Bering Sea shelf experienced by the 1950–2020 year classes of pollock. Less favorable conditions (more negative values) represent a warm summer during the age-0 life stage followed by a relatively cool spring during the age-1 life stage. More favorable conditions (less negative values) represent a cool summer during the age-0 life stage followed by a relatively warm spring during the age-1 life stage.

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Status and trends: The 2020 year class TC index value is -5.37, higher than the 2019 year class TC index value of -6.30, indicating slightly improved conditions for pollock survival from age-0 to age-1 from 2020 to 2021 than from 2019 to 2020. The low expected survival is due to the larger difference in sea temperature from late summer (warm) to the following spring (warm). The late summer sea surface temperature (August 11.6°C) in 2020 was 1.7°C higher than the longer term average (9.9°C) and spring sea temperature (June 6.2°C) in 2021 was warmer than the long-term average of 5.3°C in spring since 1949.

Factors causing observed trends: According to the original Oscillating Control Hypothesis (OCH), warmer spring temperatures and earlier ice retreat led to a later oceanic and pelagic phytoplankton bloom and more food in the pelagic waters at an optimal time for use by pelagic species (Hunt et al., 2002). The revised OCH indicated that age-0 pollock were more energy-rich and have higher overwintering survival to age-1 in a year with a cooler late summer (Coyle et al., 2011; Heintz et al., 2013). Therefore, the warmer later summers during the age-0 phase followed by warmer spring temperatures during the age-1 phase are assumed unfavorable for the survival of pollock from age-0 to age-1. The 2020 year class of pollock experienced above average summer temperatures during the age-0 stage and a warm spring in 2021 during the age-1 stage indicating below average conditions for overwintering survival from age-0 to age-1.

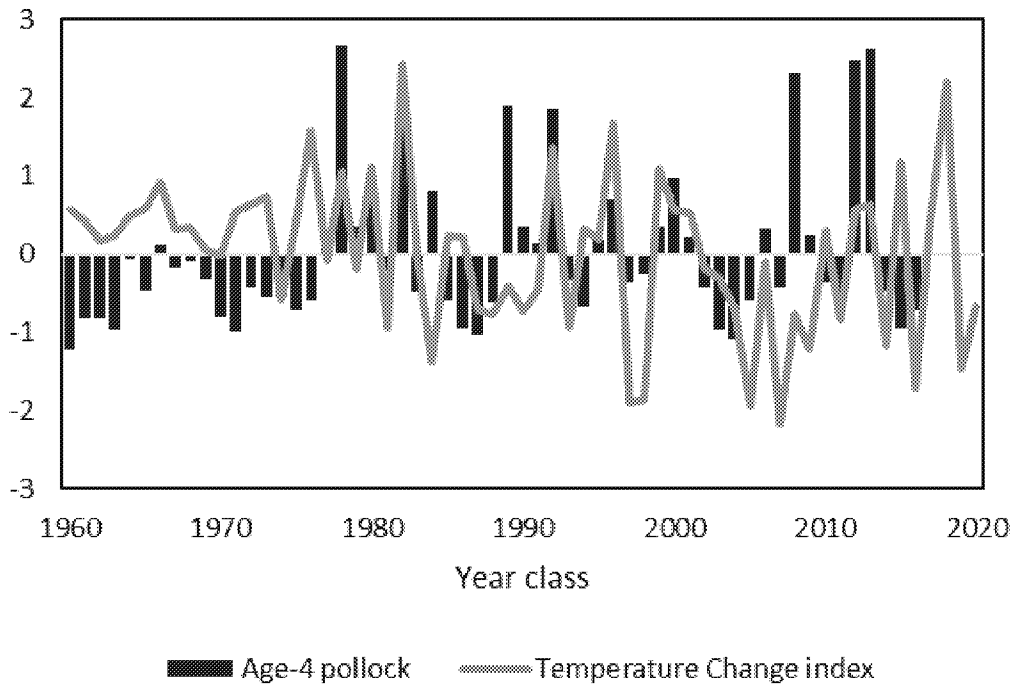

Figure 83: Normalized time series values of the temperature change index indicating conditions experienced by the 1960–2020 year classes of pollock during the summer age-0 and spring age-1 life stages. Normalized values of the estimated abundance of age-4 pollock in the southeastern Bering Sea from 1964–2020 for the 1960–2016 year classes. Age-4 pollock estimates are from Table 29 in Ianelli et al. (2020). The TC index indicates below average conditions for the 2020 year classes of pollock.

Implications: The 2020 TC index value of -5.37 was below the long-term average of -4.58, therefore we expect below average recruitment of pollock to age-4 in 2024 from the 2020 year class (Figure 83).

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Benthic Communities and Non-target Fish Species

Miscellaneous Species - Eastern Bering Sea Shelf

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Last updated: October 2021

Description of indicator: "Miscellaneous" species fall into three groups: eelpouts (Zoarcidae), poachers (Agonidae), and sea stars (Asteroidea). The three species comprising the eelpout group are the wattled eelpout (*Lycodes palearis*) and shortfin eelpout (*L. brevipes*) and to a lesser extent the marbled eelpout (*L. raridens*). The biomass of poachers is dominated by a single species, the sturgeon poacher (*Podothecus acipenserinus*) and to a lesser extent the sawback poacher (*Leptagonus frenatus*). The composition of sea stars in shelf trawl catches are dominated by the purple-orange sea star (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. Relative CPUE by weight (kg per hectare) was calculated and plotted for each species or species group by year for 1982–2021. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (± 1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: The 2021 relative CPUE for eelpouts remained about the same as in 2019 (6% increase), just above the average of the estimates over the last 10 years. The poacher group CPUE increased by 40% from 2019, continuing an increasing trend following an annual decrease observed from 2015 to 2018. The 2021 poacher estimate is still 10% lower than the average for the time series. The sea stars, as a group, increased by 8% from 2019 to 2021, and the 2021 CPUE ranked as the 3rd highest since 1982 and continues an overall increasing trend that started in 2013 (Figure 84).

Factors causing observed trends: Determining whether these trends represent real responses to environmental change or are simply an artifact of standardized survey sampling methodology (e.g., temperature dependent catchability) will require more specific research on survey trawl gear selectivity relative to interannual differences in bottom temperatures and on the life history characteristics of these epibenthic species.

Implications: Eelpouts have important roles in the energy flow within benthic communities. For example, eelpouts are a common prey item of Arrowtooth flounder (*Atheresthes stomias*). However, it is not known at present whether these changes in CPUE are related to changes in energy flow.

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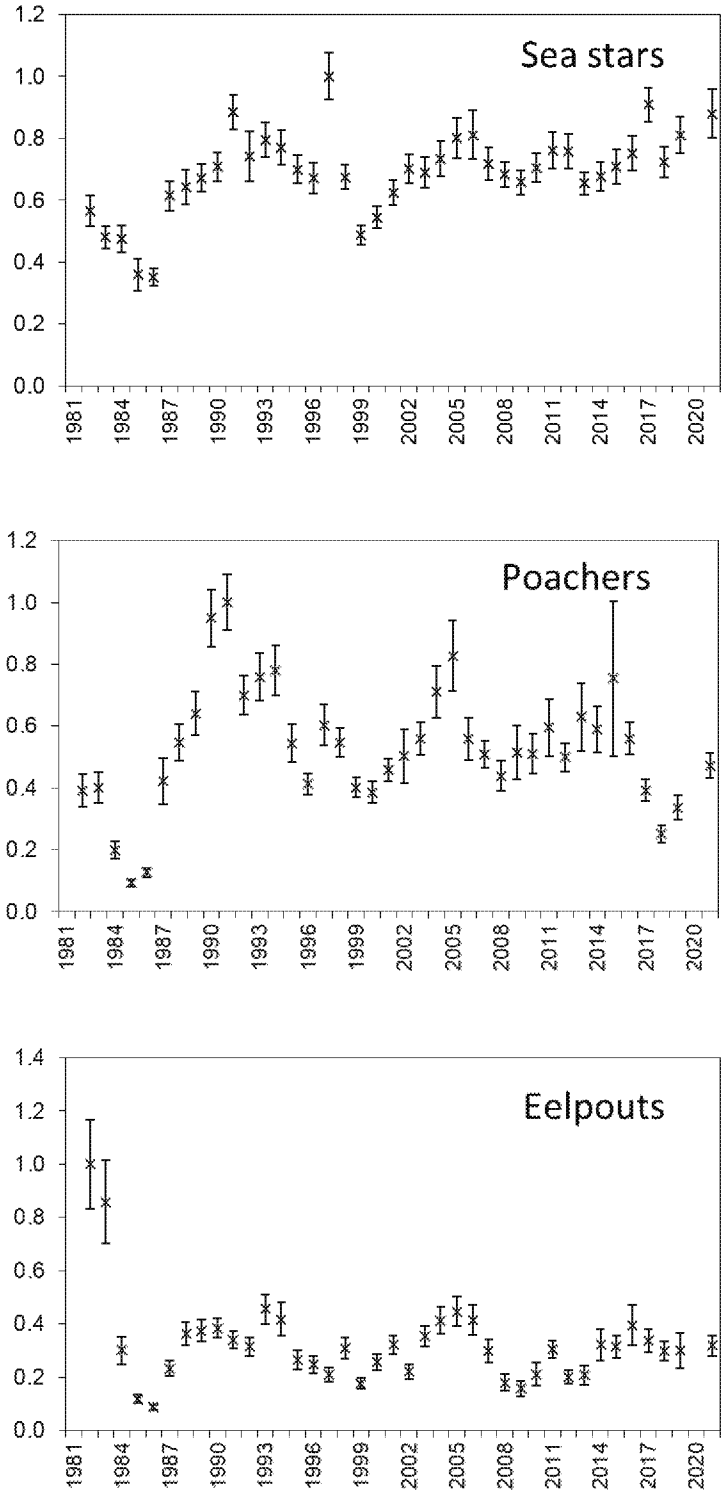

Figure 84: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for miscellaneous fish species during the May to August time period from 1982–2021.

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Eastern Bering Sea Commercial Crab Stock Biomass Indices

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Last updated: September 2021

Description of indicator: This indicator is the commercial crab species biomass time series in the eastern Bering Sea. The eastern Bering Sea bottom trawl survey has been conducted annually since 1975 by the Resource Assessment and Conservation Engineering Division of the Alaska Fisheries Science Center. The purpose of this survey is to collect data on the distribution and abundance of crab, groundfish, and other benthic resources in the eastern Bering Sea. The data provided here include the time series of results from 1998 to the present. In 2021, 375 standard stations were sampled on the eastern Bering Sea shelf from 31 May to 22 July. The observed trends in crab biomass may be indicative of trends in either benthic production, or benthic response to environmental variability. The commercial crab biomass is also indicative of trends in exploited resources over time.

Status and trends: The historical trends of commercial crab biomass and abundance are highly variable (Figure 85). In 2021, Bristol Bay mature male red king crab biomass increased by 28% relative to 2019 estimates, which while a slight rebound, continues a -66% decline since 2014. Mature female red king crab biomass declined by 24%, although abundance decreased similarly, due to remaining females being larger, with this being the lowest estimate since 1995. St. Matthew blue king crab adult males declined by -44%, marking a return to a declining trend observed since 2014. Female blue king crab biomass is not adequately sampled during this survey due to a nearshore distribution around St. Matthew Island. Mature male Tanner crab biomass declined by -21 to -39%. The -39% decline in western district mature males marks a dramatic departure from recent stable/increasing trends, but continues a decline observed in 2019. Mature females increased in the western district (+36%) and increased substantially (+332%) in the eastern district. Total snow crab biomass declined by 77% relative to 2019, and 86% relative to 2018, with this being driven by across the board declines in immature female (-94%), mature female (-72%), immature males (-83%), legal males (-66%), mature males (-55%), and industry preferred males (-57%). Pribilof Islands crab stocks remain extremely depressed with highly variable survey biomass estimates due to trawl survey limitations related to crab habitat and patchy crab distribution.

Factors influencing observed trends: Environmental variability and exploitation affect trends in commercial crab biomass over time. Recent modeling analyses suggest that environmental variability is largely driving inter-annual variability in crab stock recruitment, although a mortality event may be occurring with opilio, the direct driver of which is unknown.

Implications: The implications of the observed variability in crab stocks are dramatic inter-annual and inter-decadal variability in benthic predators and ephemeral (seasonal) pelagic prey resources when crab are in larval stages in the water column or as juveniles on the benthic substrates. Although it is unclear at what life stage crab stock variability is determined, it is likely that environmental variability affecting larval survival and changes in predation affecting juvenile survival are important factors. As such, the environmental conditions affecting larval crab may also be important for larval demersal groundfish and the availability of crab as prey may be important for demersal fish distributions and survival. Disease may also be a factor, although this is speculative.

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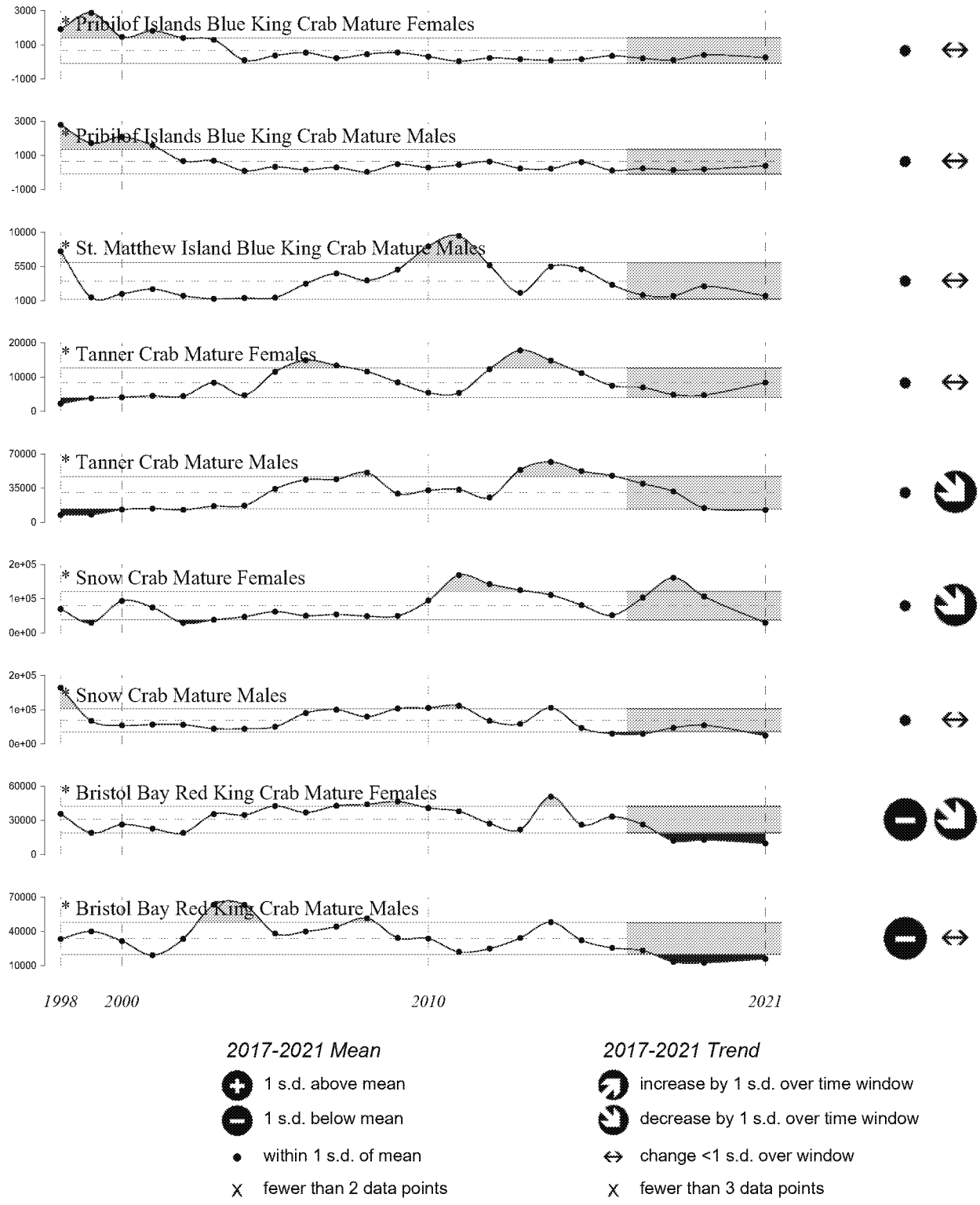

Figure 85: Historical biomass for commercial crab stocks caught on the National Marine Fisheries Service eastern Bering Sea bottom trawl survey, 1998–2021.

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Seabirds

Integrated Seabird Information

This integration is in response to ongoing collaborative efforts within the seabird community and contains contributions from (in alphabetical order):

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NOAA Fisheries contractor
Alaska Fisheries Science Center

Last updated: October 2021

Summary Statement
Migrant short-tailed shearwaters, predominately plankton-eating surface-feeders with some diet variation, experienced a significant mortality peak in August–September 2021. Most carcasses were found along the northern Bering Sea coastline, indicating a widespread lack of euphausiid prey or small fish alternatives (e.g., age-0 fish, sand lance). Other species observed through opportunistic reports of beached birds in 2021 included fish-eating birds (puffins and kittiwakes) and plankton-eating auklets in June, suggesting impacts across trophic levels. However, from July through September, the main species affected other than shearwaters (eating predominantly euphausiids) were fish-eating birds, primarily murres, horned puffins, and black-legged kittiwakes. Mortality was highest in the northern Bering Sea during August–September. Multi-species marine bird die-off events potentially reflect important changes in the biophysical oceanographic conditions in the region and the availability of prey resources.

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Southeastern Bering Sea
On St. Paul Island, although long-term quantitative surveys were not conducted, the timing of breeding and abundance at colonies of fish-eating birds (murres, kittiwakes, puffins) appeared average, while plankton-eating bird abundance was lower than average, based on local observations.

Offshore surveys were minimal in 2021, due to COVID-19 travel restrictions, but those surveys that were conducted indicated average or slightly above average seabird densities across the southeastern Bering Sea.

Northern Bering Sea
On St. Lawrence Island, the colony attendance of fish-eating species (i.e., black-legged kittiwakes, common murres) sharply decreased in 2021, compared to 2020. Broadly, all fish-eating birds had poor reproductive success or complete reproductive failure, on both St. Lawrence Island and Hall Island. The plankton-eating birds had mixed reproductive success – least auklets did well on both Hall Island and St. Lawrence Island, but crested auklets (on St. Lawrence Island) had poor reproductive success. There were few offshore surveys, but those that were conducted indicated average densities of seabirds in the region.

Introduction: Seabirds can be viewed as indicators of ecosystem changes; therefore population-level responses can signal shifts in prey availability that may similarly affect commercial fish populations. In this Integrated Seabird Information section, we synthesize information and observations from a variety of sources (including tribal members, community members, and researchers) to provide an overview of environmental impacts to seabirds and what that may indicate for ecosystem productivity as it pertains to fisheries management. We merge across information sources to derive regional summaries within the southeastern and northern Bering Sea and interpret changes in seabird dynamics with respect to understanding ecosystem productivity.

Approach: We focused on three attributes of seabirds that may serve as broader ecosystem indicators important to fisheries managers. We interpret these attributes as reflective of seabirds' life history and how they sample the ecosystem, either as fish-eating or planktivorous species.

Life History:
Reproductive success reflects feeding conditions in the environment for breeding birds and has implications for seabird population trajectories and food security (i.e., subsistence egging practices). Timing (phenology) of seabird reproductive stages (i.e., lay or hatch) at colonies can reflect ecosystem conditions encountered by birds during the months preceding the breeding season or local weather conditions at the colony when they arrive (e.g., snow cover). Long-lived seabirds may delay or skip breeding if foraging conditions limit their ability to build up energy reserves to support energetic demands during the breeding season. Widespread reproductive failure during the breeding season, such as abandonment of nest sites or widespread egg or chick loss, may indicate that foraging conditions deteriorated rapidly or the presence of disturbance at the colony such as from land-based predators. Differences in reproductive success within a season among plankton-eating, fish-eating, and mixed plankton/fish-eating species may reflect differences among availability of prey resources including differences in abundance, distribution, and nutritional quality.

Colony attendance (numbers) can reflect population and survival trends, or differences in the proportion of birds attempting to breed. Non-breeders also attend the colony (e.g., murres), even in poor years, so attendance patterns must be interpreted with caution.

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Colony attendance (timing) reflects local conditions (e.g., wind, presence of snow) as well as prey availability immediately preceding the breeding season. Earlier colony attendance may indicate that foraging conditions were favorable, such that birds were able to build enough energy reserves to prepare them for the breeding season. Later colony attendance may reflect poor winter foraging conditions or a mismatch in spring bloom timing and subsequent ocean productivity.

Mortality events may indicate broad ecosystem concerns such as harmful algal blooms (HABs) or large-scale decreases in prey location, quality, and/or quantity.

Sampling:
Fish-eating, surface feeding seabirds include kittiwakes, that feed on small schooling fish available at the surface (e.g., capelin, Arctic cod, juvenile pollock, and juvenile herring), thus making them potential indicators of processes affecting juvenile groundfish that migrate to the surface to feed. *Fish-eating, diving seabirds* include thick-billed and common murres that feed on small, schooling fish (e.g., age-0 and age-1 pollock) to depths up to 200m, thus they have access to fish throughout the water column and to the sea floor in shallow areas. Thick-billed murre adults also consume euphausiids at some locations, although both murre species require fish to raise their chicks. Few of these species are obligate fish-eaters; for example, murres are known to eat a large number of euphausiids and kittiwakes take a mix of zooplankton and squid, as well.

Plankton-eating seabirds include least and crested auklets that feed primarily on copepods and euphausiids. Shearwaters and thick-billed murres also consume euphausiids, along with larvae and small fish. All of these species are indicators of regional feeding conditions for planktivorous groundfish species, including the larvae and juveniles of fish-eating species.

Status and Trends
Southeastern Bering Sea (Pribilof Islands)
Reproductive success
Due to COVID-19 restrictions, U.S. Fish & Wildlife Service (USFWS) crews were not able to conduct a field season on St. Paul and St. George Islands. Therefore, standardized reproductive success, timing of breeding, abundance, and diet data are not available for the 2020 or 2021 season. Instead, information from St. Paul Island is provided by Island Sentinels, community members, and tribal members of the Aleut Community of St. Paul Island.

Black-legged kittiwakes and **red-faced cormorants** hatched at least some chicks at St. Paul Island in 2021 (no data on late-season chicks/fledging). **Common murres** laid eggs, but observations were not available past incubation to estimate hatching or chick fledging success. No subsistence harvesting of **thick-billed** or **common murre** eggs occurred in summer 2021 due to low attendance by adult murres and low egg production. Nesting was observed at the Tourist Point Cliff, located on the south facing coast of St. Paul Island, by tribal and community members. From photos taken in mid-July, the timing of **black-legged kittiwake** and **red-faced cormorant** hatching appeared normal, as was the timing of egg laying for **thick-billed murres**, even though numbers of eggs laid was low.

Subsistence fishermen at St. Paul Island reported sea surface temperatures of 8.9°C in early August, unusually warm, which raised concerns about local prey availability for all species, particularly surface feeders, during the chick-rearing period.

Colony attendance (numbers)
The abundance of multiple species nesting at the Tourist Point Cliff was assessed in July by Seabird Youth Network educators and St. Paul Island community members. **Murres** appeared to be slightly less numerous than in the past, but **black-legged kittiwake** and **tufted and horned puffin** numbers appeared average. At what was formerly a thriving, abundant colony at East Landing adjacent to the town of St. Paul, **least auklet** numbers appeared low, as has been the trend over at least the last decade. There were no data collected on the Zapadni colony, which was not observed in 2021.

Although once abundant, **parakeet auklets** have been apparently declining in abundance at St. Paul Island for several years. In fact, in 2020, no parakeet auklets were observed at St. Paul Island. In 2021, parakeet auklets were observed, but no information on abundance or timing was available.

Colony attendance (timing)
Least auklets were observed during their typical arrival period, late April–early May.

Mortality events
Despite ongoing die-offs in the north, beach-based surveys reflected a low-to-average encounter rate of carcasses at the Pribilof Islands in winter through summer 2021 (Figure 86). However, in late September, monitoring teams on St. Paul Island reported 11 shearwaters on Lukanin beach, 4 on Polovina beach, 5 on Benson beach, and 3 on North beach. This peak in September 2021 is significant, as it is greater than 5 times the month-averaged baseline (Figure 1). However, this peak is more than 6 times lower than the peak in shearwaters that occurred in 2019 (see Siddon et al. (2020)). The 2019 peak marked a mass mortality event for short-tailed shearwaters that reflected broader ecosystem-level stresses (i.e., 2nd winter of minimal sea ice, frequent and persistent marine heatwave conditions over the SEBS and NBS). Both the historical norms and recent unprecedented events are important to keep in mind when interpreting the events of 2021.

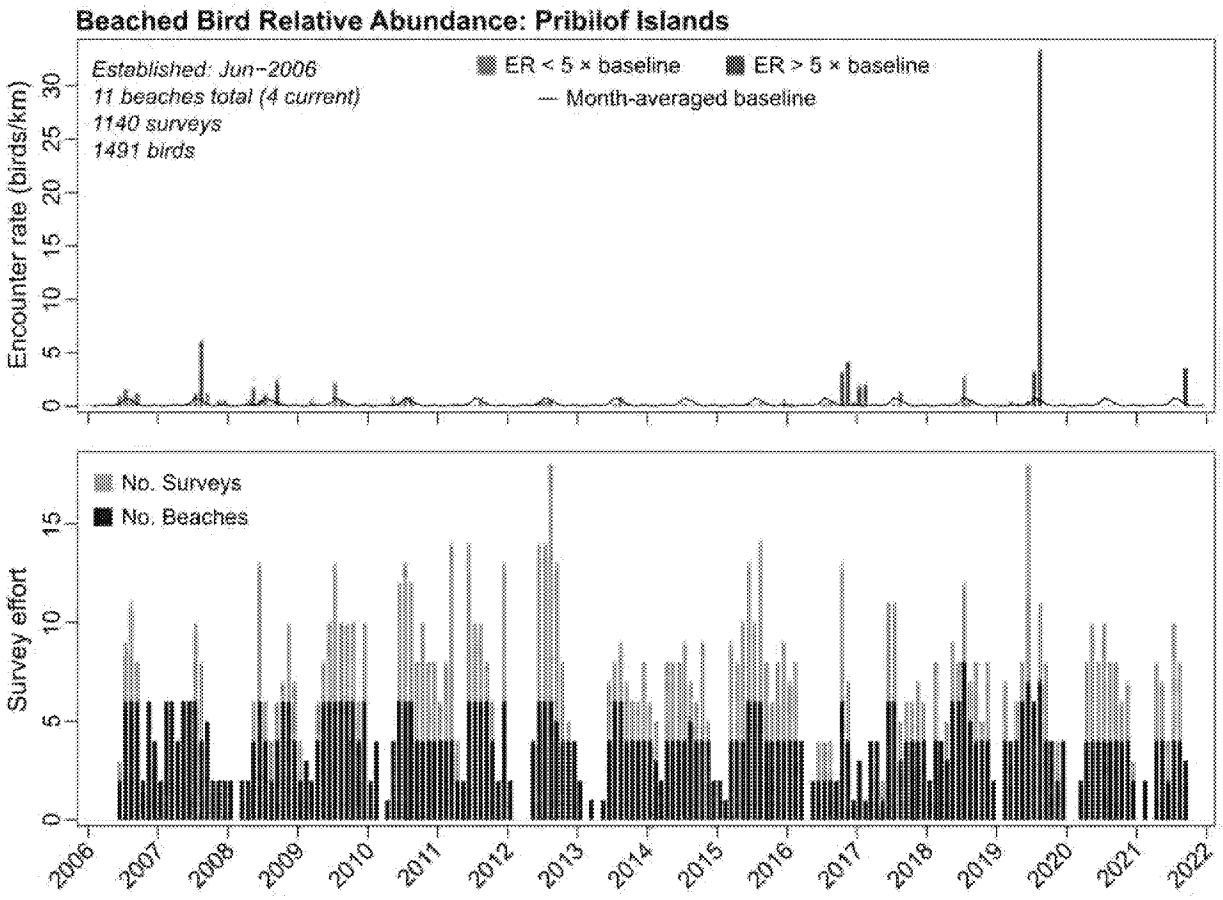

Figure 86: Month-averaged beached bird carcass abundance, standardized per km of survey effort, for the Pribilof Islands. The top panel shows the month-averaged encounter rate (ER: birds per km). The bottom panel shows survey effort at the monthly scale.

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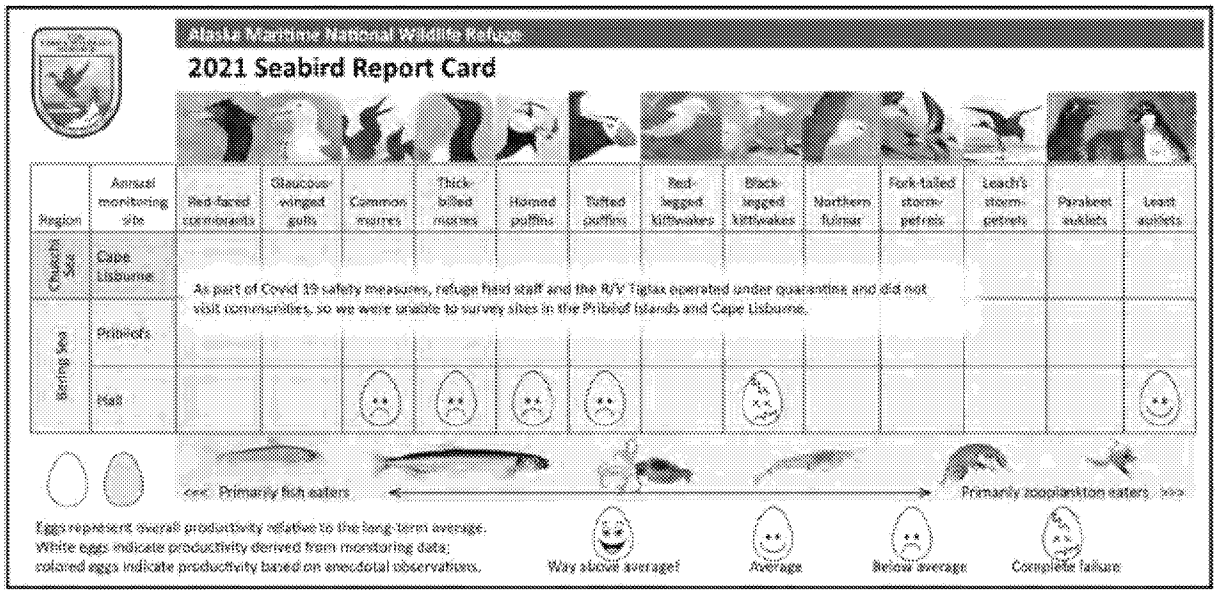

Figure 87: Reproductive success of seabird species in the northern Bering Sea. Quantitative data were collected for murres and kittiwakes, but no long term data were available for comparison. Kittiwakes exhibited complete reproductive failure. Data on puffins and auklets were qualitative.

Northern Bering Sea (including Hall Island, St. Lawrence Island, and the Bering Strait region)

Reproductive success

Hall Island, off the northwest end of St. Matthew Island, was visited by the USFWS in summer 2021. Both **murres** and **puffins** had low reproductive success (Figure 87) and **murre** nesting was very late at Hall Island. In fact, a small number of recently hatched chicks were still present when USFWS departed the island in late August 2021.

Murres at Kevipaq, St. Lawrence Island had near complete reproductive failure in 2021, similar to failures observed in 2018 following the marine heatwave and unprecedented low levels of sea ice. In 2021, snow remained on the cliffs through spring, even into late July in some places, and may have contributed to low breeding efforts of murres. Murres nearly abandoned the breeding cliffs in early August, despite having had relatively high adult attendance at study plots at the end of July (Figure 87, top left).

Black-legged kittiwakes on Hall Island experienced complete reproductive failure (Figure 87), and the same was true at Kevipaq, St. Lawrence Island where no chicks were produced (Figure 88, top right).

Least Auklets did well in 2021 at both Hall Island and St. Lawrence Island. At Hall Island, least auklets had an apparently average year (Figure 87). Although no quantitative data were collected on least auklets at Hall Island, the colony was well attended and adults were observed carrying food loads.

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At the Kitnik site on St. Lawrence Island, **least auklets** had an average year. Least auklets hatched and fledged about 1 week earlier than 2016–2020 at St. Lawrence Island. **Crested auklets**, on the other hand, had a below average year reflecting variability in planktonic prey and/or competition between the two auklet species (Figure 88, bottom). Opportunistic observations of least auklet and crested auklet chick meals indicated both species continued to consume primarily euphausiids, a pattern observed since 2017.

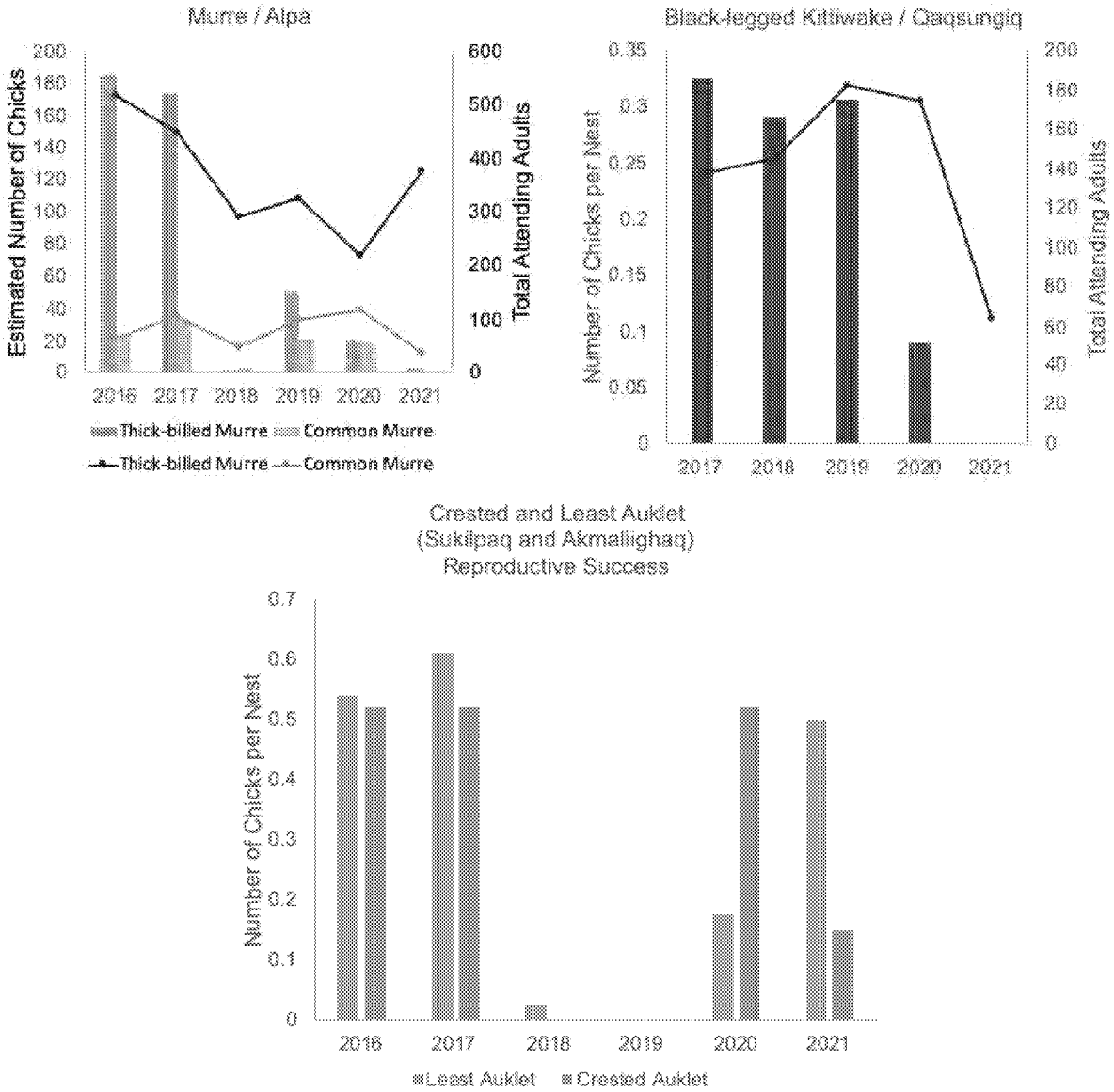

Figure 88: *Top left:* Murre reproductive success index (bars, left axis) and adult attendance counts (lines, right axis) at Kevipaq, St. Lawrence Island. *Top right:* Kittiwake reproductive success index (bars, left axis) and adult attendance counts (lines, right axis) at Kevipaq, St. Lawrence Island. *Bottom:* Auklet reproductive success index for least auklets (gray bars) and crested auklets (orange bars) at Kitnik, St. Lawrence Island.

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Colony attendance (numbers)
At St. Lawrence Island, **black-legged kittiwakes** had low attendance at all observed cliffs with a 50% reduction in attendance in 2021 compared to 2020 (Figure 88, top right). Observers described **murre** cliffs at St. Lawrence Island as being free of guano; one ledge that had been abandoned by adult murres was littered with several dead chicks.

Colony attendance (timing)
Hunting for pelagic **cormorant** chicks began about a month earlier than normal at St. Lawrence Island.

Mortality events
During May–September 2021 in the Bering Strait/Chukchi Sea region, two beaches were surveyed for beached birds; each beach was surveyed twice. Observers saw an average deposition of beached birds compared to the time series average (Figure 89). Investigation of three common groups revealed **shearwaters** had a mortality peak in August 2021 (Figure 90), but standardized surveys did not reflect that **kittiwakes** or **murres** had elevated deposition in 2021.

In 2021, the northern Bering Sea was the location of several large mortality counts of over 100 carcasses each: predominantly **shearwaters** at the mouth of the Kuskokwim River in July, **shearwaters** near Wales and Nome, Alaska in August, and **shearwaters** and **murres** on St. Lawrence Island in September (Figure 91). Some (n=10) dead **crested auklets** were observed on beaches near breeding colonies near Savoonga on St. Lawrence Island in mid-August 2021, but these numbers were not unusual.

At the same time that **short-tailed shearwaters** began to show up in high numbers in the northern Bering Sea (Figure 91), British Columbia to northern California began seeing unprecedented numbers of short-tailed shearwaters, August–October 2021 (Figure 92, a and c). Southbound migrant short-tailed shearwaters departed the Bering Sea much earlier and presumably benefited from consistently productive waters of the California Current, especially the Columbia River plume (also a known stopover location for northward-migrating shearwaters). Sooty shearwaters, which range only as far north as Bristol Bay, did not show a mass migration from Alaska, and had average counts, August–October 2021 (Figure 92, b and d).

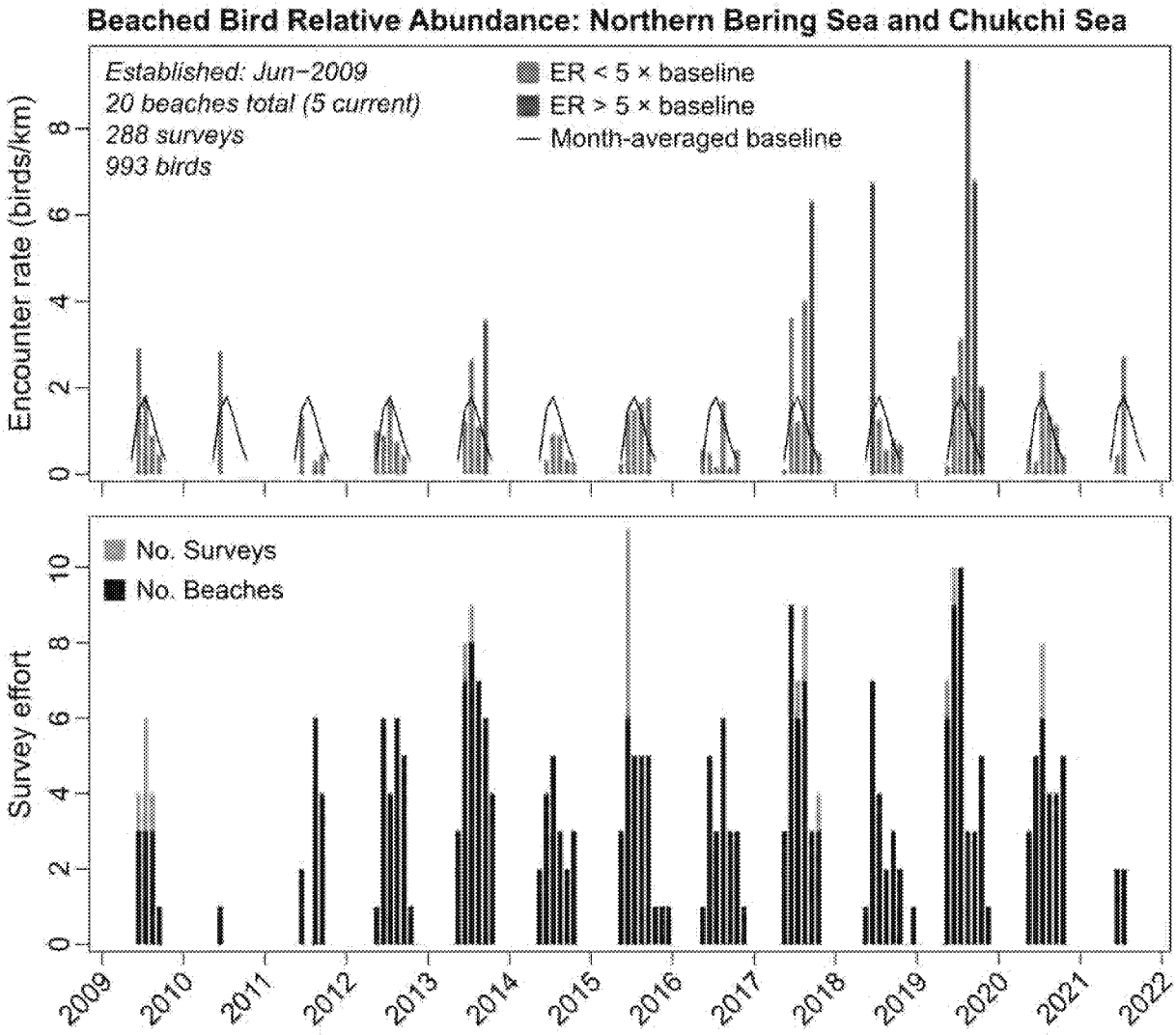

Figure 89: Month-averaged beached bird carcass abundance, standardized per km of survey effort, for the Bering Strait/Chukchi Sea. The top panel shows the month-averaged encounter rate (ER: birds per km). The bottom panel shows survey effort at the monthly scale.

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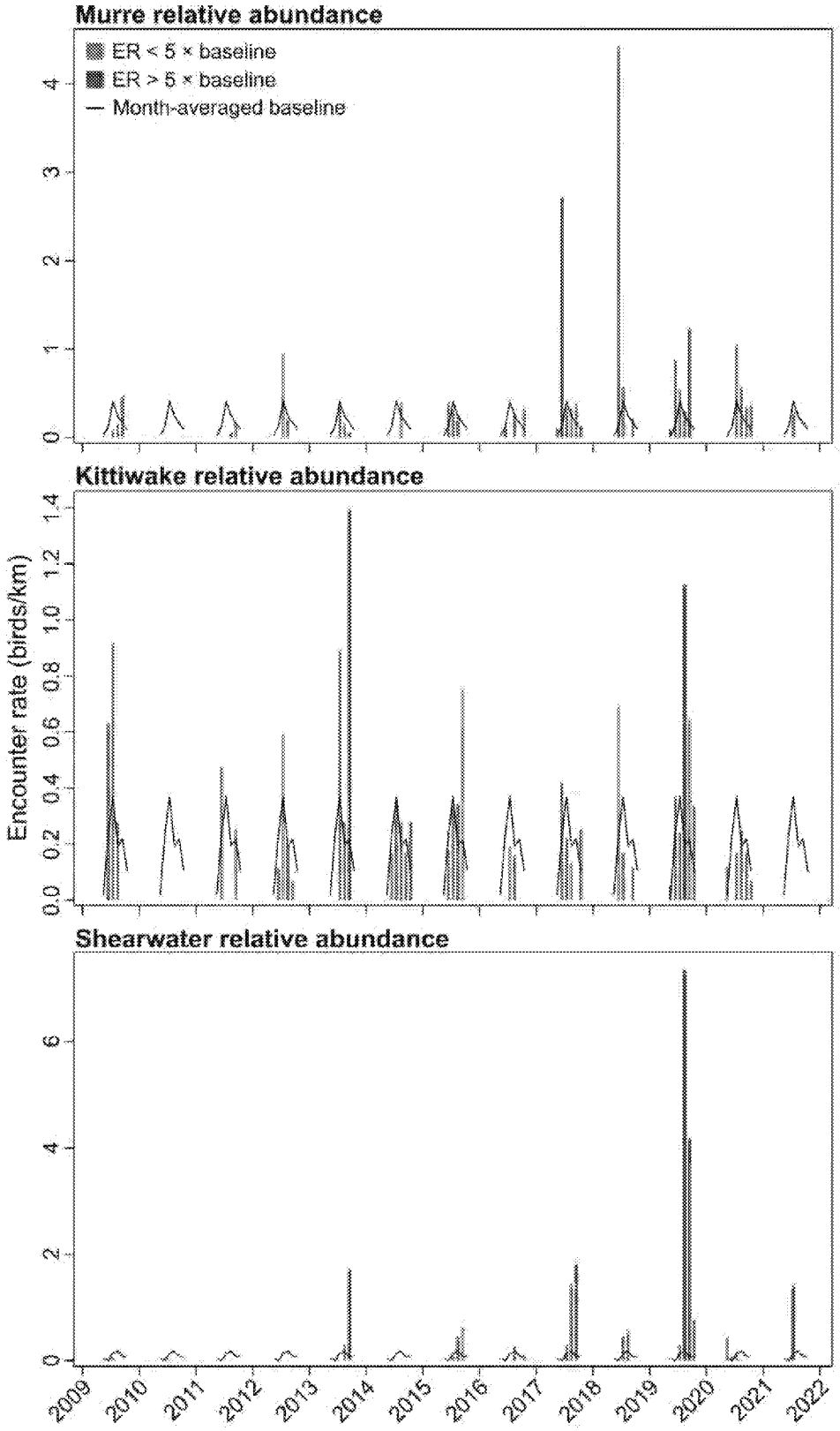

Figure 90: Month-averaged beached bird carcass abundance, standardized per km of survey effort, for the Bering Strait/Chukchi Sea for murres, kittiwakes, and shearwaters. Each panel shows the month-averaged encounter rate (ER: birds per km).

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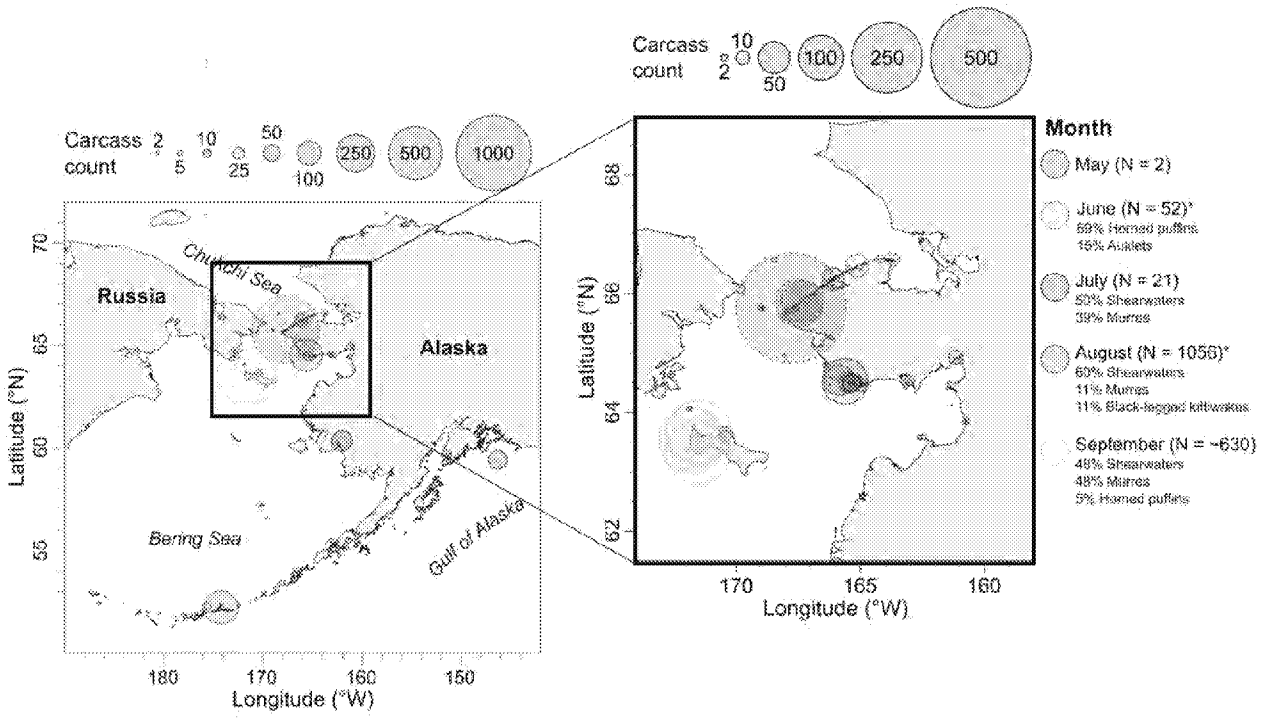

Figure 91: Seabird die-off map for Alaska during May–September 2021. Inset shows northern Bering Sea/Chukchi Sea carcass counts (**note** difference in scale). Data provided by National Park Service, Kawerak, Inc. staff, UAF Alaska Sea Grant faculty, as well as coastal community members reporting to ADF&G, COASST, Kawerak, Inc., UAF-Alaska Sea Grant, and USFWS. *: species composition is of birds identified to species/group. However, in August a large proportion (60%) of birds were not identified. Circles represent reports of seabird carcass abundance and are not standardized for variable observer effort among locations. The absence of reports in certain locations may indicate gaps in current knowledge OR an actual absence of bird carcasses. Reports from aerial surveys (dashed circles) are distinguished from other beach-based reports (solid circles) due to major differences in area observed.

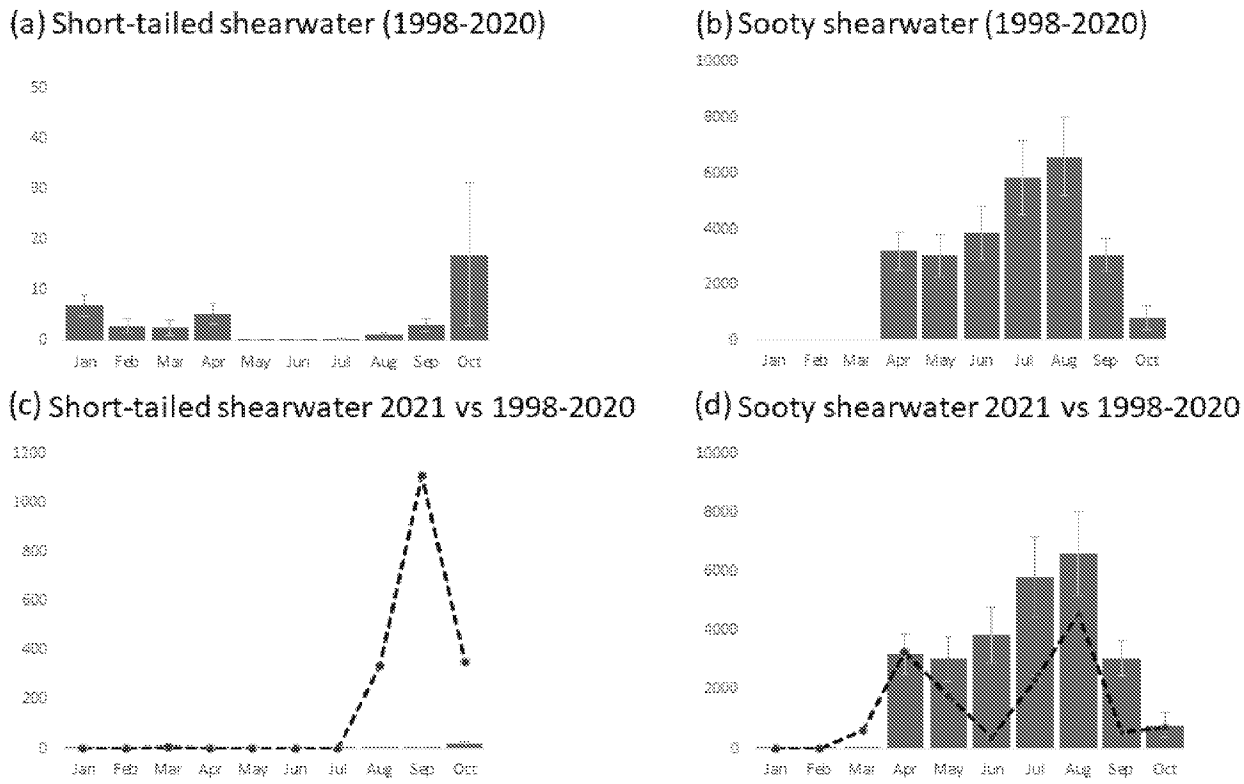

Figure 92: (a) Short-tailed shearwater counts on Westport Pelagic Seabird Cruises (WA), 1998–2020, error is standard error, note the Y axis; (b) Sooty shearwater counts on Westport Pelagic Seabird Cruises (WA), 1998–2020, error is standard error; (c) Short-tailed shearwater counts in 2021 (dotted line) compared to long-term average, 1998–2020, note the differences in the Y axes 10a, 10c; (d) Sooty shearwater counts on cruises in 2021 (dotted line) compared to long-term average, 1998–2020. Across the time series, cruises did not occur Nov–Dec. Data publicly available and retrieved from `https://westportseabirds.com/Oct2021`.

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Marine Mammals

Marine Mammal Stranding Network: Eastern Bering Sea

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Last updated: September 2021

Description of indicator: Since 1985, members of the NMFS Alaska Marine Mammal Stranding Network (AMMSN) have collected and compiled reports on marine mammal strandings throughout the state. These reports are indices of events witnessed by members of the stranding network, the scientific community, and the general public, with varying degrees of knowledge regarding marine mammal biology and ecology. Over the last five years, the AMMSN has received over 1,600 reports of stranded marine mammals within Alaska. The causes of marine mammal strandings are often unknown but some causes are disease, exposure to contaminants or harmful algal blooms, ship strikes, entanglement in fishing gear, or ingestion of marine debris.

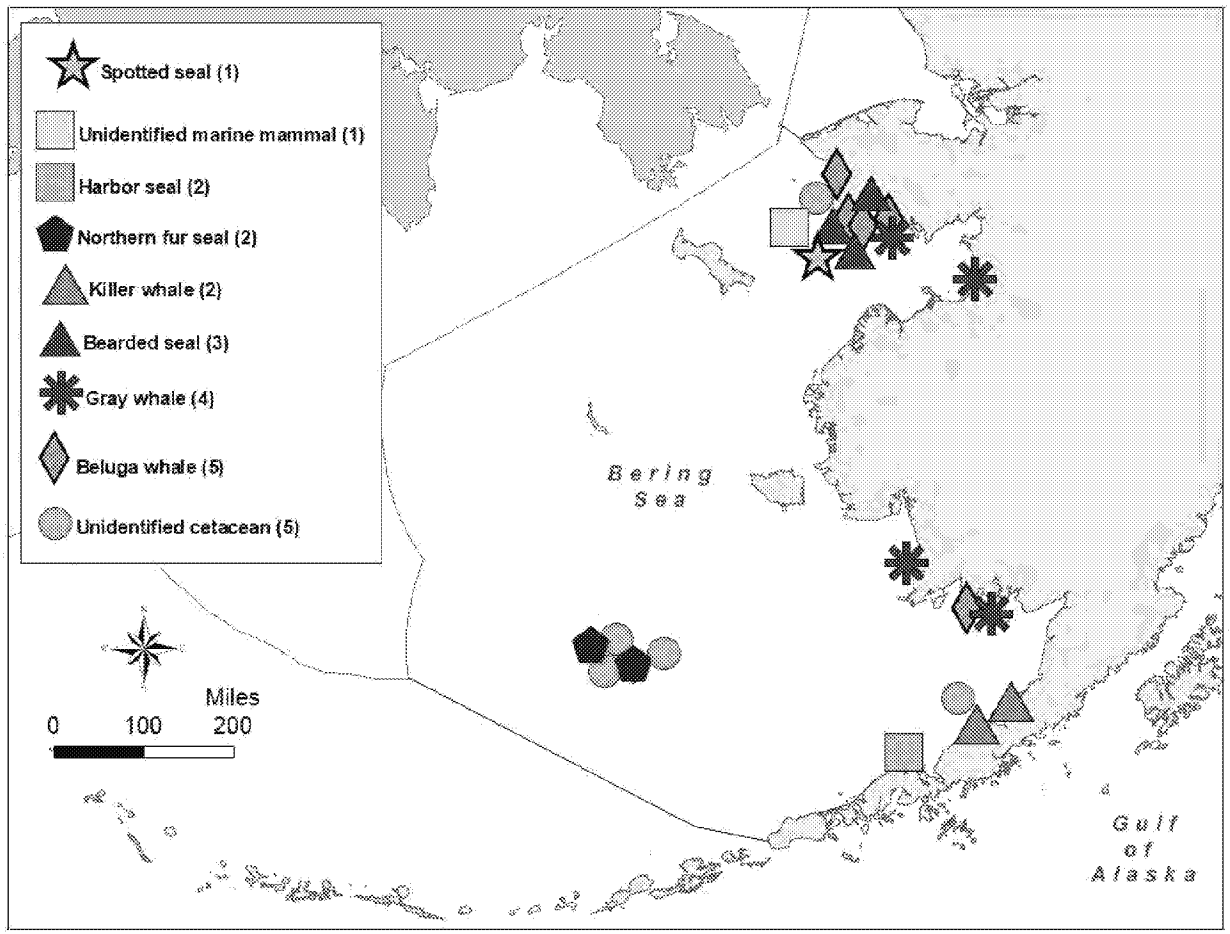

Figure 93: Reported stranded marine mammals between January 1, 2021 and September 18, 2021.

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When a stranded marine mammal is reported, information is collected including species, location, age or size. In some cases, the initial photos and observations reported to AMMSN may be the only opportunity to collect information on the event. When possible, trained and authorized members respond and collect life history data and samples as part of a partial or full necropsy. Photos and carcasses are evaluated for potential human interactions such as vessel strikes. These responses are conducted under the Marine Mammal Protection Act authorization either under a 112c agreement issued by NMFS to AMMSN members through a Stranding Agreement or under 109(h) authority exercised by local, state, federal or tribal entities.

Status and trends: The number of reported strandings in Alaska has increased over time. So far in 2021, 25 stranded marine mammals have been reported (confirmed reports only) in the eastern Bering Sea region, the majority of reports being near more populated areas (Figure 93) where AMMSN members are located. Reported strandings in the eastern Bering Sea region since 2016 varied between years without an overall pattern or consistent increase in reports (Table 3). The 2021 stranding data includes confirmed strandings reported between Jan 1–Sept 18, 2021.

Factors influencing observed trends: It is important to recognize that stranding reports represent effort, which has varied substantially over time and location, and overall has increased over time and in areas with higher human population densities. Unusual Mortality Events (UMEs) including the 2018 ice seal and the 2019 gray whale UME can have a large influence on variability between years in this area (Table 3). Under the Marine Mammal Protection Act, an UME is defined as "a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response."

Implications: Other factors that may influence the number and species of marine mammals being reported include changing populations of some species including the increase in northern fur seals using Bogoslof Island for breeding. Further, the number of stranded marine mammals in an area can vary due to the potential conflict with fishery resources either directly through prey competition or indirectly through interactions with fishing gear such as increased whale entanglements in gear. Further, human population and activity in an area influences the potential for a carcass or stranded marine mammal to be observed and reported.

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Table 3: Reported stranded NMFS marine mammal species for the last five years in the eastern Bering Sea by species and year.

	2016	2017	2018	2019	2020	2021
Beluga whale	18	12	11	14	13	5
Harbor porpoise		3	4	6	3	
Fin whale	1				2	
Gray whale	4	7	7	14	15	4
Humpback whale	1	2	4	3	1	
Minke whale				2	1	
Killer whale	5		2		1	2
Sperm whale						
Unidentified cetacean	3	8		1	2	1
Unidentified small cetacean	2	2				
Unidentified large whale	1	7	7	11	2	
Total Cetaceans	35	41	35	51	40	12
Harbor seal	2		1	4	2	2
Northern fur seal	10	6	10	18	2	2
Bearded seal		1	32	20	8	3
Ribbon seal				2		
Ringed seal	3	8	31	8	2	
Steller sea lion	1	3	1		4	
Spotted seal	1	5	17	14	4	1
Unidentified pinniped	2	3	19	26	8	
Unidentified marine mammal	3	7	5	2		1
Total Pinnipeds	22	33	116	94	30	9
Total Cetaceans and Pinnipeds	57	74	151	145	70	21

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Ecosystem or Community Indicators

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys on the Eastern and Northern Bering Sea Shelf, 1982–2021

Contributed by Franz Mueter[1] and Lyle Britt[2]
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[2]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: fmueter@alaska.edu
Last updated: October 2021

Description of indicator: The index provides a measure of the overall biomass of demersal and benthic fish and invertebrate species. We estimated annual mean catch-per-unit-effort (CPUE in kg ha) of all fish and major invertebrate taxa using all successful hauls completed during standardized bottom trawl surveys on the eastern Bering Sea shelf (EBS) from 1982—2021 and on the northern Bering Sea shelf (NBS) in 2010, 2017, 2019, and 2021. Total CPUE for each haul was computed as the sum of the CPUEs of all fish and major invertebrate taxa. To obtain an index of average CPUE by year for each survey region, we modeled log-transformed total CPUE (N = 14,466 hauls in the EBS, N = 572 hauls in the NBS) as a smooth function of Julian day and location (latitude/longitude), with year-specific intercepts, using an Additive Model. The CPUE index does not account for gear or vessel differences, which are confounded with interannual differences and may affect results prior to 1990. Therefore we only show trends from 1990–2021. To highlight differences between recent trends in the EBS and NBS, we also computed the mean CPUE by region and year for the four years with complete surveys in the NBS using an additive model to account for seasonal trends (smooth function of Julian day) and account for spatially correlated errors that were assumed to decrease exponentially with distance.

Status and trends: Total log(CPUE) in the EBS shows no significant trend (linear regression, adjusted for temporal autocorrelation, t=0.291, p=0.773)(Figure 94) but large fluctuations between 1990 and 2021. The highest observed value in the time series occurred in 2014 and total CPUE declined thereafter with a sharp and significant drop between 2017 and 2018. Total CPUE increased again in 2019, followed by another significant decrease between 2019 and 2021 to the lowest level since 2009. Total CPUE in the NBS increased between 2010 and 2019, and decreased substantially between 2019 and 2021 (Figure 95).

Factors influencing observed trends: Commercially harvested species accounted for approximately 95% of survey catches. Fishing is expected to be a major factor determining trends in survey CPUE, but environmental variability is likely to account for a substantial proportion of the observed variability in CPUE through variations in recruitment, growth, distribution, and catchability. The increase in survey CPUE in the early 2000s in the EBS primarily resulted from increased abundances of Walleye pollock (*Gadus chalcogrammus*) and a number of flatfish species (Arrowtooth flounder, *Atheresthes stomias*; Yellowfin sole, *Limanda aspera*; Rock sole, *Lepidopsetta bilineata*; and Alaska plaice, *Pleuronectes quadrituberculatus*) due to strong recruitments in the 1990s. Decreases in 2006–2009 and subsequent increases are largely a result of fluctuations in pollock recruitment and abundance. Models including bottom temperature suggest that, in the EBS, CPUE tends to be lower in years with low bottom water temperatures, as evident in reduced CPUEs in

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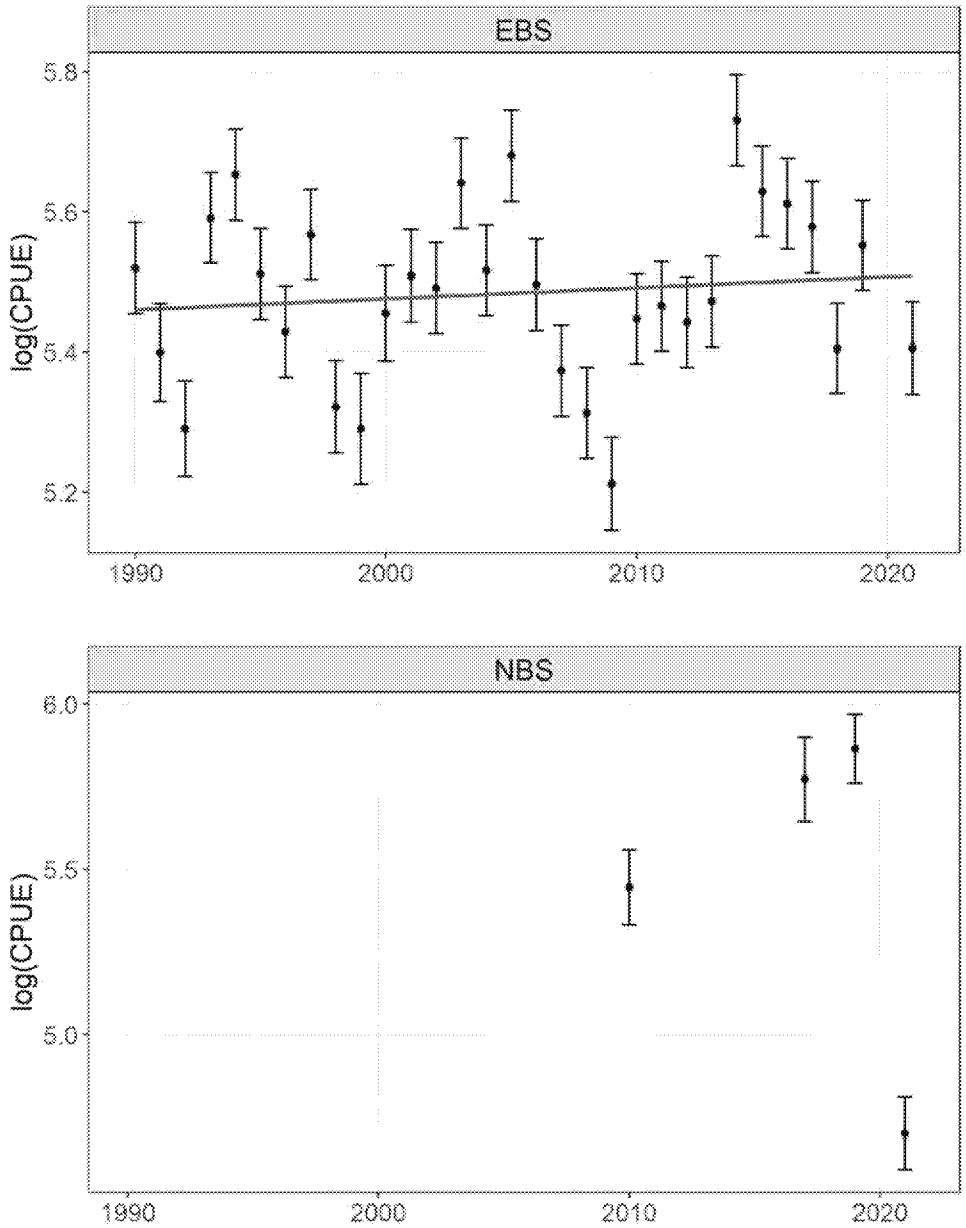

Figure 94: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from 1990 to 2021 in the eastern Bering Sea (EBS) and northern Bering Sea (NBS) with approximate pointwise 95% confidence intervals and linear time trend (EBS only). Estimates were adjusted for differences in day of sampling and sampling locations among years. The linear time trend was estimated using a generalized least squares regression assuming 1st order auto-correlated residuals and was not statistically significant. Note differences in y-axis scales.

1999 and 2006–2013, when the cold pool covered a substantial portion of the shelf. Overall, there is a moderate positive relationship between average bottom temperatures and CPUE in the same year (r=0.46, p=0.0087), but not in the following years. Reduced CPUE during cold periods is likely due to a combination of temperature-dependent changes in catchability of certain species (e.g., flatfish, crab), changes in distribution as a result of the extensive cold pool displacing species

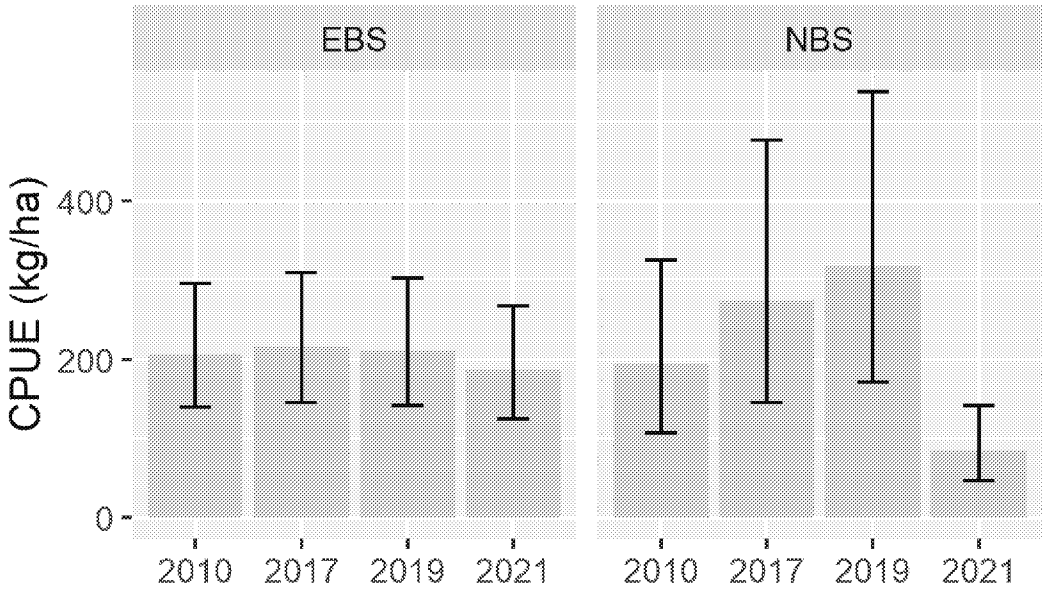

Figure 95: Mean CPUE of all macrofauna (fish and invertebrates) sampled during bottom trawl surveys in 2010, 2017, 2019, and 2021 with 95% confidence intervals. Estimates by region and year, adjusted for day of sampling, based on an additive model with spatially auto-correlated errors (exponential correlation structure).

into shallower (e.g., red king crab) or deeper (e.g., Arrowtooth flounder) waters, or changes in vertical distribution of semi-demersal species. The large decrease in the EBS in 2018 was primarily due to a decrease in the CPUE of pollock, as well as that of Pacific cod (*G. macrocephalus*) and most flatfish species, except Arrowtooth flounder. The subsequent increase in 2019 and decrease in 2021 were primarily due to changes in pollock catches, whereas the CPUE of other dominant species remained stable. In contrast, the drop in total CPUE in the NBS between 2019 and 2021 was much more pronounced (Figure 95) and reflected large decreases in all of the dominant species, including pollock, yellowfin sole, Alaska plaice, Pacific cod, snow crab, and skates. Of the 37 major taxa examined here, 28 decreased from 2019 to 2021 (Figure 96)

Implications: This indicator can help address concerns about maintaining adequate prey for upper trophic level species and other ecosystem components. Relatively stable or increasing trends in the total biomass of demersal fish and invertebrates suggest that the prey base has remained stable over recent decades, but displays substantial fluctuations over time, largely as a result of variability in pollock biomass.

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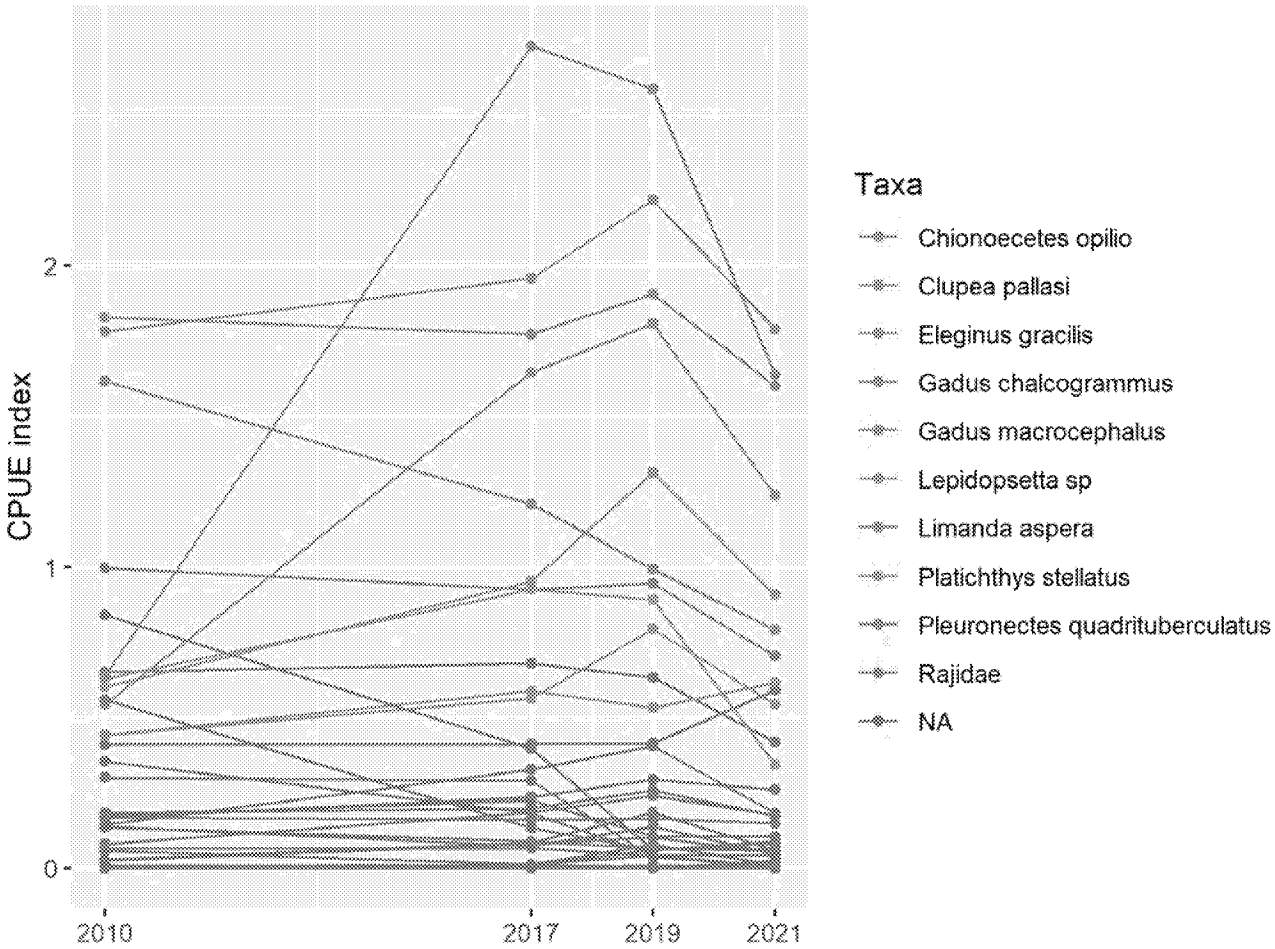

Figure 96: Changes in mean, fourth-root transformed CPUE of 41 major taxa in the northern Bering Sea based on surveys conducted in 2010, 2017, 2019, and 2021. 'NA' denotes all other taxa. A total of 28 taxa decreased between 2019 and 2021, with only 9 taxa increasing.

Average Local Species Richness and Diversity of the Eastern Bering Sea and Northern Bering Sea Groundfish Community

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Last updated: October 2021

Description of indicator: Indices of local species richness and diversity are based on standard bottom trawl surveys in the eastern Bering Sea (EBS) and northern Bering Sea (NBS). We computed the average number of fish and major invertebrate taxa per haul (richness) and the average Shannon index of diversity (Magurran, 1988) by haul based on CPUE (by weight) of each taxon. Indices for the EBS were based on 45 fish and invertebrate taxa that were consistently identified throughout all surveys since 1982 (Table 1 in Mueter and Litzow (2008), excluding Arctic cod *Boreogadus saida* because of unreliable identification in early years). Annual average indices of local richness and diversity were estimated by first computing each index on a per-haul basis, then estimating annual averages with confidence intervals across the survey area using an Additive Model that accounted for the effects of variability in sampling locations (latitude/longitude), depth, and date of sampling. In addition to trends over time, we mapped average spatial patterns for each index across the eastern Bering Sea survey region.

Status and trends: Species richness and diversity on the EBS shelf have undergone significant variations from 1982 to 2021 (Figure 97). The average number of species per haul increased by one to two species per haul from 1995 to 2004, remained relatively high through 2011 and both richness and diversity decreased through 2014, followed by a return to relatively high levels through 2021, with an unusually high Shannon diversity observed in 2018. Richness tends to be highest along the 100 m isobath, while diversity tends to be highest on the middle shelf (Figure 98). Local richness is lowest along the slope and in the northern part of the survey region, while diversity is lowest in the inner domain. Local richness was lower by 2–3 species on average in the NBS and varied little among the four survey years, whereas local Shannon diversity increased between 2010 and the most recent years (Figure 99).

Factors influencing observed trends: Local richness and diversity reflect changes in the spatial distribution, abundance, and species composition that may be caused by fishing, environmental variability, or climate change. If species are, on average, more widely distributed in the sampling area, the number of species per haul increases. Spatial shifts in distribution from year to year can cause high variability in local species richness in certain areas, for example along the 100m contour. These shifts appear to be the primary drivers of changes in species richness over time. Local species diversity is a function both of how many species are caught in a haul and how evenly CPUE is distributed among these species, hence time trends (Figures 97 and 99) and spatial patterns (Figure 98) in species diversity differ from those in species richness.

Implications: There is evidence from many systems that diversity is associated with ecosystem stability, which depends on differential responses to environmental variability by different species or functional groups (e.g., McCann (2000)). To our knowledge, such a link has not been established for marine fish communities. In the EBS, local species richness may be particularly sensitive to long-

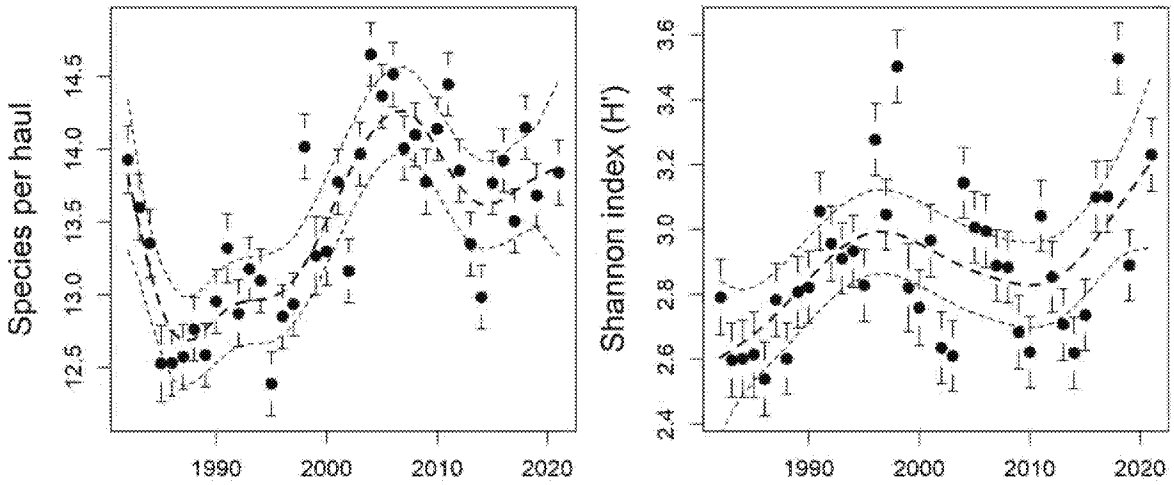

Figure 97: Model-based annual averages of local species richness (left, average number of species per haul), and species diversity (Shannon index, right) in the eastern Bering Sea, 1982–2021, based on 45 fish and invertebrate taxa collected by standard bottom trawl surveys with pointwise 95% confidence intervals (bars) and loess smoother with 95% confidence band (dashed/dotted lines). Model means were adjusted for differences in depth, date of sampling, and geographic location.

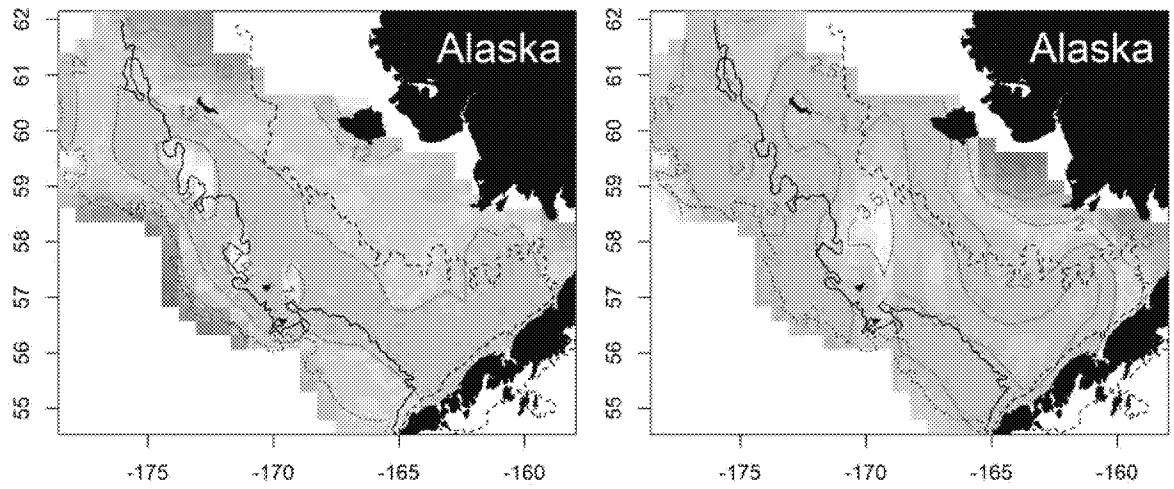

Figure 98: Average spatial patterns in local species richness (left, number of taxa per haul) and Shannon diversity in the eastern Bering Sea. The 50m (dashed), 100m (solid), and 200 m (dotted) depth contours are shown. Note highest richness along 100 m contour, highest diversity on middle shelf.

term trends in bottom temperature as the cold pool extent changes (Mueter and Litzow, 2008) and provides a useful index for monitoring responses of the groundfish community to projected climate warming (Alabia et al., 2020).

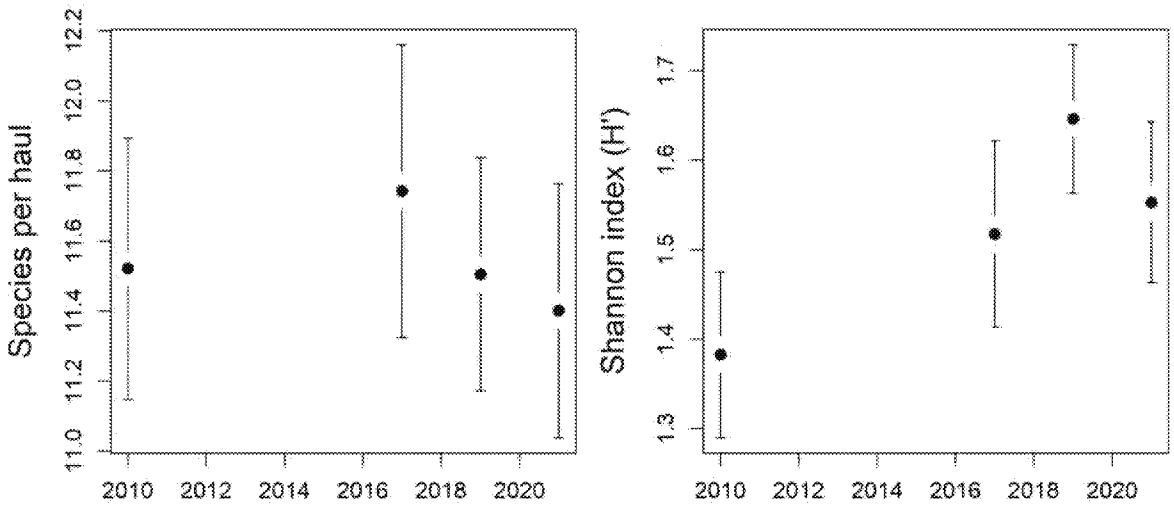

Figure 99: Model-based annual averages of local species richness (left, average number of species per haul), and species diversity (Shannon index, right) in the northern Bering Sea (2010, 2017, 2018, 2019) based on 45 fish and invertebrate taxa collected by standard bottom trawl surveys with pointwise 95% confidence intervals. Model means were adjusted for differences in depth, date of sampling, and geographic location.

Spatial Distribution of Groundfish Stocks in the Bering Sea

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Description of indicator: We provide indices of changes in the spatial distribution of groundfish on the eastern Bering Sea (EBS) shelf. The first index provides a simple measure of the average North-South displacement of major fish and invertebrate taxa from their respective centers of gravity (e.g., Woillez et al. (2009)) based on AFSC-RACE EBS bottom trawl surveys for the 1982–2021 period. Annual centers of gravity for each taxon were computed as the CPUE-weighted mean latitude across 285 standard survey stations that were sampled each year and an additional 58 stations sampled in all but one survey year. Each station (N=343) was also weighted by the approximate area that it represents. Initially, we selected 46 taxa as in Table 1 of Mueter and Litzow (2008). Taxa that were not caught at any of the selected stations in one or more years were not included, resulting in a total of 39 taxa for analysis. In addition to quantifying N-S shifts in distribution, we computed CPUE and area-weighted averages of depth to quantify changes in depth distribution. Because much of the variability in distribution is likely to be related to temperature variability, we removed linear relationships between changes in distribution and temperature by regressing distributional shifts on annual mean bottom temperatures. Residuals from these regressions are provided as an index of temperature-adjusted shifts in distribution.

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Status and trends: Both the latitudinal and depth distribution of the demersal community on the EBS shelf show strong directional trends over the last four decades, indicating significant distributional shifts to the north and into shallower waters (Figure 100). The distribution shifted slightly to the south and deeper in recent cold years (2006–2013) and shifted back to the north and shallower from 2014 to 2019 with a substantial shift to the northwest in 2016. The distribution shifted slightly south in 2017, but remained near its northern maximum through 2019. Between 2019 and 2021, the mean distribution across species shifted back to the southeast. Strong shifts in distribution remain evident even after adjusting for linear temperature effects (Figure 100). The center of gravity of most individual species shifted to the northwest along the shelf or to the northeast onto the shelf in 2016, the warmest year in the survey time series (Figure 101). Cooler temperatures in 2017 appeared to result in an immediate and substantial southeastward shift, in contrast to a more moderate response to similar cooling in 2006. Following the return to higher bottom temperatures in 2018 and 2019, the overall center of gravity shifted slightly to the northwest, but in 2021 shifted back to the southeast. However, northern Bering Sea (NBS) surveys since 2017 suggest that much of the biomass of fishes in some recent years occurred in the NBS. The latitudinal gradient in overall density of all major fish and invertebrate taxa combined declined from south to north in 2010 but increased from south to north in 2021, with much higher estimated densities near Bering Strait than off the Alaska Peninsula (Figure 102). This trend reversed again in 2021, with mean densities near Bering Strait declining from ~300 kg/ha in 2019 to <100 kg/ha in 2021. These patterns were primarily driven by changes in the distribution of pollock and Pacific cod (Figure 102, see also Stevenson and Lauth (2012); Thorson et al. (2020)).

Factors influencing observed trends: Many populations shift their distribution in response to temperature variability. Such shifts may be the most obvious response of animal populations to global warming (Parmesan and Yohe, 2003). However, distributional shifts of demersal populations in the Bering Sea are not a simple linear response to temperature variability (Mueter and Litzow (2008); Figure 100). The reasons for strong residual shifts in distribution that are not related to temperature changes remain unclear but could be related to density-dependent responses (Spencer, 2008) in combination with internal community dynamics (Mueter and Litzow, 2008). Unlike groundfish in the North Sea, which shift to deeper waters in response to warming (Dulvy et al., 2008), the Bering Sea groundfish community shifted to shallower waters during warm periods (Figure 100) because of the retreat of the cold pool from the middle shelf that allows subarctic species to expand from the outer shelf into shallower regions.

Implications: Changes in distribution have important implications for the entire demersal community, other populations dependent on these communities, the fishing industry, and for stock assessments. The demersal community is affected because distributional shifts change the relative spatial overlap of different species, thereby affecting trophic interactions (Hunsicker et al., 2013; Spencer et al., 2016) and, ultimately, the relative abundances of different species. Upper trophic level predators, for example fur seals and seabirds, are affected because the distribution and hence availability of their prey changes. Fisheries are directly affected by changes in the distribution of commercial species, which alters the economics of harvesting because fishing success within established fishing grounds may decline and travel distances to new fishing grounds may increase (Haynie and Pfeiffer, 2013). Finally, stock assessments are affected by shifts outside the standard survey area, such as the substantial redistribution of Pacific cod into the NBS in 2018 and the apparent redistribution of much of the overall biomass in the Bering Sea to the NBS shelf in 2019. This was followed in 2021 by substantial declines in mean density at most latitudes with the largest overall declines in the NBS (Figure 102).

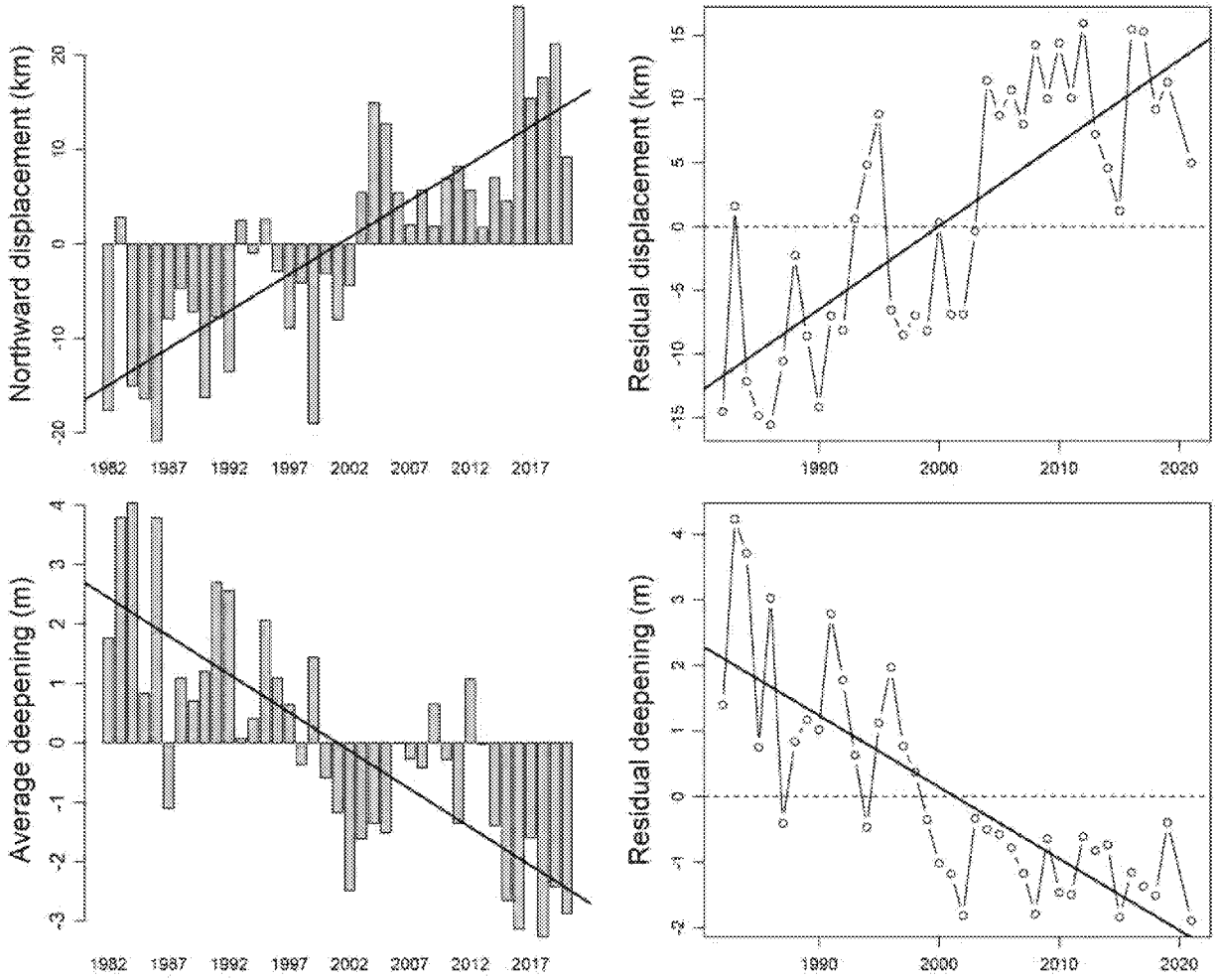

Figure 100: Left: Distributional shifts in latitude (average northward displacement in km from species-specific mean latitudes) and shifts in depth distribution (average vertical displacement in m from species-specific mean depth, positive indices indicate deeper distribution). Right: Residual displacement from species-specific mean latitude (top) and species-specific mean depth (bottom) after adjusting the indices on the left for linear effects of mean annual bottom temperature on distribution. Residuals were obtained by linear regression of the displacement indices on annual average temperature (Northward displacement: R^2=0.22, t=4.74, p<0.001; Deepening: R^2=0.26, t=-4.89, p<0.001). Solid trend lines denote linear regressions over time (Northward displacement: R^2=0.62, t=6.31, p<0.001; Residual northward displacement: R^2=0.56, t=4.64, p<0.001; Deepening: R^2=0.87, t=-5.94, p<0.001; residual deepening: R^2=0.63, t=-7.87, p<0.001).

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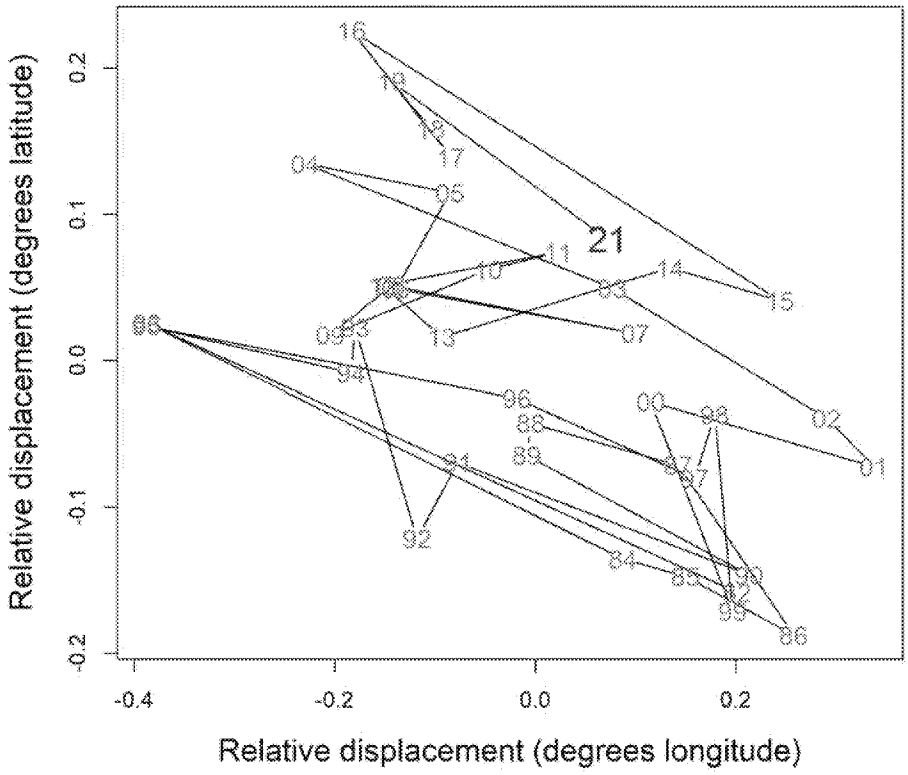

Figure 101: Average North-South and East-West displacement across 39 taxa on the eastern Bering Sea shelf relative to species-specific centers of distribution.

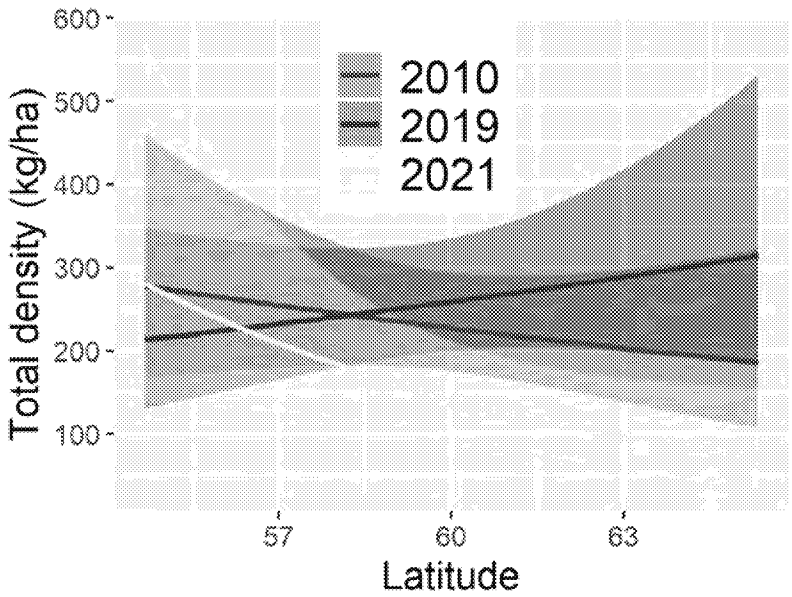

Figure 102: Estimated latitudinal trends in average macrofaunal density for all fish and invertebrate taxa combined from the Alaska Peninsula in the south to the Bering Strait in the North. Estimates are based on generalized additive models of log(catch-per-unit-effort) as a function of latitude and depth by year with an exponential spatial autocorrelation structure.

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Mean Lifespan of the Fish Community

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Description of indicator: The mean lifespan of the community is a proxy for the turnover rate of species and communities and reflects the resistance of the community to perturbations (Shin et al., 2010). The indicator for mean lifespan of the groundfish community is modeled after the method for mean lifespan presented in Shin et al. (2010). Lifespan estimates of groundfish species regularly encountered during the NMFS/AFSC annual summer bottom-trawl survey of the eastern Bering Sea were retrieved from the AFSC Life History Database[14]. The groundfish community mean lifespan is weighted by biomass indices calculated from the bottom-trawl survey catch data.

This indicator specifically applies to the portion of the demersal groundfish community that is efficiently sampled by the trawling gear used by NMFS during this survey at the standard survey sample stations (for survey details see Conner and Lauth (2016)). Species that are infrequently encountered or not efficiently caught by the bottom-trawling gear are excluded from this indicator (e.g., sharks, grenadiers, myctophids, pelagic smelts). The survey index used here is the same as that used for fish and invertebrate biomass indices on the report card (Figure 1).

Walleye pollock is a biomass dominant species in the eastern Bering Sea and may drive the value of community indicators. Therefore this indicator is presented as two time series, one that includes and one that excludes walleye pollock.

Status and trends:
With pollock included: The mean lifespan of the eastern Bering Sea demersal fish community in 2021 is 30.54 years and is the second highest over the time series (Figure 103, black circles), just up from 30.53 years in 2019. Mean groundfish lifespan has generally been stable over the time series with only a small amount of year-to-year variation, and shows no indication of a long-term trend.

Without pollock included: The mean lifespan of the eastern Bering Sea groundfish community without pollock in 2021 is 30.3 years (Figure 103, gray triangles). Over the times series, the patterns and trends are similar between the two series with the values being slightly lower for the series without pollock. The exception to this pattern was 1985 when the mean lifespan was 32.0 with pollock included and 32.9 without pollock.

Factors influencing observed trends: Fishing can affect the mean lifespan of the groundfish community by preferentially targeting larger, older fishes, leading to decreased abundance of longer-lived species and increased abundance of shorter-lived species (Pauly et al., 1998). Interannual variation in mean lifespan can be influenced by the spatial distribution of species and the differential selectivity of species and age classes to the trawling gear used in the survey. Strong recruitment events or periods of week recruitment could also influence the mean community lifespan by altering

[14]`https://access.afsc.noaa.gov/reem/LHWeb/Index.php`

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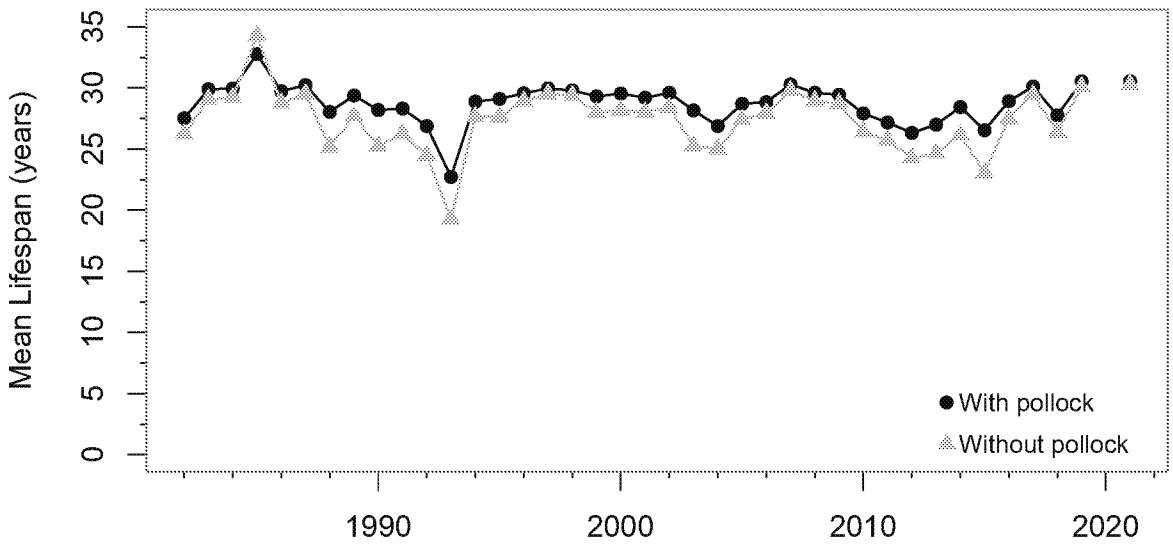

Figure 103: The mean lifespan of the eastern Bering Sea demersal fish community, weighted by biomass indices calculated from the NMFS/AFSC annual summer bottom-trawl survey. The black circles are the series with pollock included and the gray triangles are the series without pollock included.

the relative abundance of age classes and species. For example, the low value observed in 1993 reflects a year of peak biomass index for capelin, a shorter-lived species. The peak mean lifespan for both series in 1985 was in part elevated by high biomass indices for long-lived species, such as sablefish. The lifespan of pollock is slightly higher than the mean groundfish lifespan without pollock. When pollock are removed from this indicator, there is a small decrease in value but the same overall trend is followed.

Implications: The groundfish mean lifespan has been stable over the time series of the summer bottom-trawl survey. There is no indication longer-lived species have decreased in relative abundance or are otherwise being replaced by shorter lived-species. Species that are short-lived are generally smaller and more sensitive to environmental variation than larger, longer-lived species (Winemiller, 2005). Longer-lived species help to dampen the effects of environmental variability, allowing populations to persist through periods of unfavorable conditions and to take advantage when favorable conditions return (Berkeley et al., 2004; Hsieh et al., 2006).

Mean Length of the Fish Community

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Last updated: October 2021

Description of indicator: The mean length of the groundfish community tracks fluctuations in the size of groundfish over time. This size-based indicator is thought to be sensitive to the effects of commercial fisheries because larger predatory fish are often targeted by fisheries and their selective removal would reduce mean size (Shin et al., 2005). This indicator is also sensitive to shifting community composition of species with different mean sizes. Fish lengths are routinely recorded during the NMFS bottom trawl survey of the eastern Bering Sea, which has occurred each year from 1982 to 2021, except in 2020. Mean lengths are calculated for groundfish species (or functional groups of multiple species; e.g., eelpouts) from the length measurements collected during the trawl survey. The mean length for the groundfish community is calculated with the species mean lengths, weighted by biomass indices (Shin et al., 2010) calculated from the bottom-trawl survey catch data.

This indicator specifically applies to the portion of the demersal groundfish community that is efficiently sampled with the trawling gear used by NMFS during the summer bottom-trawl survey of the EBS at the standard survey sample stations (for survey details see Conner and Lauth (2016)). Species that are infrequently encountered or not efficiently caught by the bottom-trawling gear are excluded from this indicator (e.g., sharks, grenadiers, myctophids, pelagic smelts). The survey index used here is the same as that used for fish and invertebrate biomass indices on the report card (Figure 1).

Species (or functional groups) infrequently sampled for lengths (less than five times over the time series) are excluded from this indicator (e.g., capelin, eulachon, greenlings). Twenty-two species are included in this indicator. Eleven species had their lengths sampled in all 39 years of the time series. Another eleven species were sampled between 11 and 36 times over the time series. In those years where lengths were not sampled for a species, we replaced it with a long-term mean for that species.

Walleye pollock is a biomass dominant species in the eastern Bering Sea and may drive the value of community indicators. Therefore this indicator is presented as two time series, one that includes and one that excludes walleye pollock.

Status and trends:
With pollock included: The mean length of the eastern Bering Sea groundfish community in 2021 is 35.7 cm, down from a peak value of 38.3 cm in 2018, but still above the long term mean of 32.4 cm (Figure 104, black circles). The mean length trended upward from 2012 to 2018 and has decreased each survey year since. The status in 2020 is unknown.

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Without pollock included: The mean length of eastern Bering Sea groundfish without pollock is 34.5 cm in 2021, down from a peak value of 38.3 cm in 2018 (Figure 104, gray triangles). This series trended upward from 2012 to 2018, but has declined in 2019 and 2021 although it remains above the long term mean of 29.4 cm.

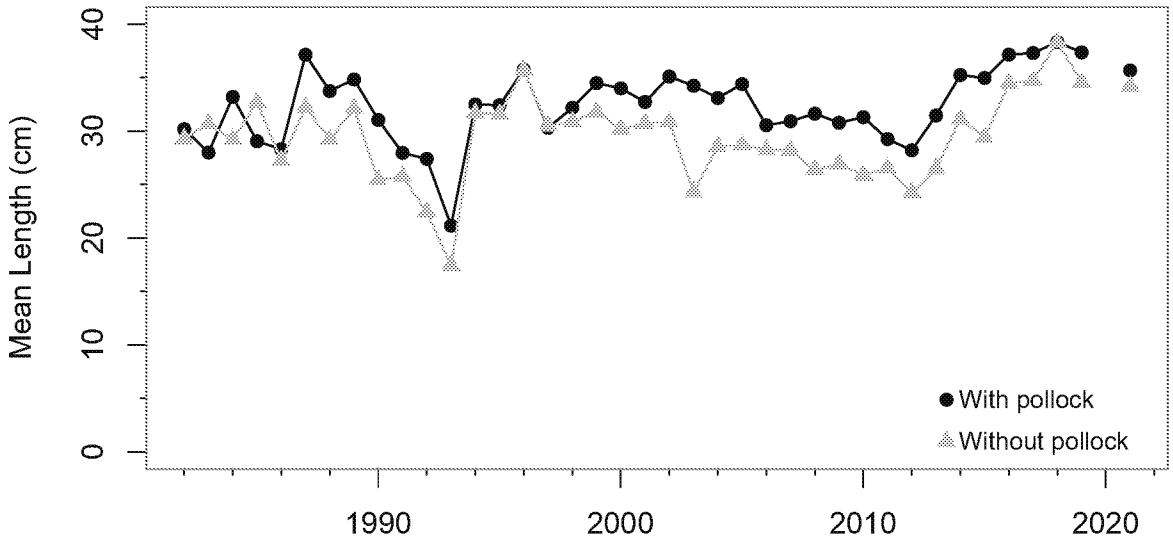

Figure 104: Mean length of the groundfish community sampled during the NMFS/AFSC annual summer bottom-trawl survey of the eastern Bering Sea (1982–2021). The groundfish community mean length is weighted by the relative biomass of the sampled species. The black circles are the mean length with pollock included and the gray triangles are the series without pollock.

Factors influencing observed trends: This indicator is specific to the fishes that are routinely caught and sampled during the NMFS summer bottom-trawl survey. The estimated mean length can be biased if specific species-size classes are sampled more or less than others, and is sensitive to spatial variation in the size distribution of species. Changes in fisheries management or fishing effort could also affect the mean length of the groundfish community. Modifications to fishing gear, fishing effort, and targeted species could affect the mean length of the groundfish community if different size classes and species are subject to changing levels of fishing mortality. The mean length of groundfish could also be influenced by fluctuations in recruitment, where a large cohort of small forage species could reduce mean length of the community. Environmental factors could also influence fish growth and mean length by effecting the availability and quality of food or by direct temperature effects on growth rate.

Walleye pollock is a biomass dominant component of this ecosystem and year-to-year fluctuations in their mean size and biomass have a noticeable effect on this indicator. In 1993, their biomass index was above average but their mean size was the fifth lowest of the time series. Additionally, 1993 was a pronounced peak in the biomass index of capelin. This reduced the proportional contribution of other species to the total groundfish biomass index, thus reducing the indicator value (i.e., mean length) in 1993. Years where this indicator attained its highest values (1987, 2016–2019) generally correspond to years of above average mean size and/or biomass index for pollock, except 2018 where pollock mean size was average but their biomass index was below average.

The series without pollock mirrored the overall trends in the series with pollock included, but was generally lower. This was because the mean length of pollock was generally a few cm greater

than the mean length of the rest of the groundfish community. Exceptions occurred in 1983, 1985, and 2018 when the mean length of pollock was less than the mean of the rest of the groundfish community. In these three instances, the indicator value was higher for the series without pollock.

Implications: The mean length of the groundfish community in the eastern Bering Sea has been stable over the bottom-trawl time series (1982–2021) with some interannual variation. The collective stability of the combined biomass of relatively larger groundfish species has helped to maintain this indicator at its recent high values. Previous dips in this indicator were in part attributable to spikes in abundance of smaller forage species (e.g., capelin) as opposed to a sustained shift in community composition or reductions in species mean length.

Stability of Groundfish Biomass

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Last updated: October 2021

Description of indicator: The stability of the groundfish community total biomass is measured with the inverse biomass coefficient of variation (1 divided by the coefficient of variation of total groundfish biomass (1/CV[B])). This indicator provides a measure of the stability of the ecosystem and its resistance to perturbations. The variability of total community biomass is thought to be sensitive to fishing and is expected to increase with increasing fishing pressure (Blanchard and Boucher, 2001). This metric is calculated following the methods presented in Shin et al. (2010). The CV is the standard deviation of the groundfish biomass index over the previous 10 years divided by the mean over the same time span. The biomass index for groundfish species was calculated from the catch of the NMFS/AFSC annual summer bottom-trawl survey of the eastern Bering Sea (EBS). Since 10 years of data are required to calculate this metric, the indicator values start in 1991, the tenth year in the trawl survey time series (1982–2021). This metric is presented as an inverse, so as the CV increases the value of this indicator decreases, and if the CV decreases the value of this indicator increases.

This indicator specifically applies to the portion of the demersal groundfish community that is efficiently sampled by the trawling gear used by NMFS during the annual summer survey at the standard survey sample stations (for survey details see Conner and Lauth (2016)). Species that are infrequently encountered or not efficiently caught by the bottom-trawling gear are excluded from this indicator (e.g., sharks, grenadiers, myctophids, pelagic smelts). The survey index used here is the same as that used for fish and invertebrate biomass indices on the report card (Figure 1).

Walleye pollock is a biomass dominant species in the eastern Bering Sea and may drive the value of this community indicator. Therefore this indicator is presented as two time series, one that includes and one that excludes pollock.

Status and trends:
With pollock included: The state of this indicator in 2021 is 6.18, which is down from the series high of 8.54 in 2019 (Figure 105, black circles). The previous high of 7.90 was observed in 1992,

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which was followed by a steady decrease to a low of 3.84 in 2002. Since then it gradually increased to a value of 5.84 in 2018 before sharply increasing to its new high in 2019. The status in 2020 is unknown. This indicator is currently above the long term mean of 5.2.

Without pollock included: This indicator has dropped to 7.05 in 2021 from a high value of 9.78 in 2019 (Figure 105, gray triangles). This indicator dropped sharply from 7.49 in 1992 to 3.41 in 1993, and remained below four until 2003, where the value increased to 5.44. The indicator value remained relatively stable until 2010, when the indicator began a steady upward trend to the series high value in 2019.

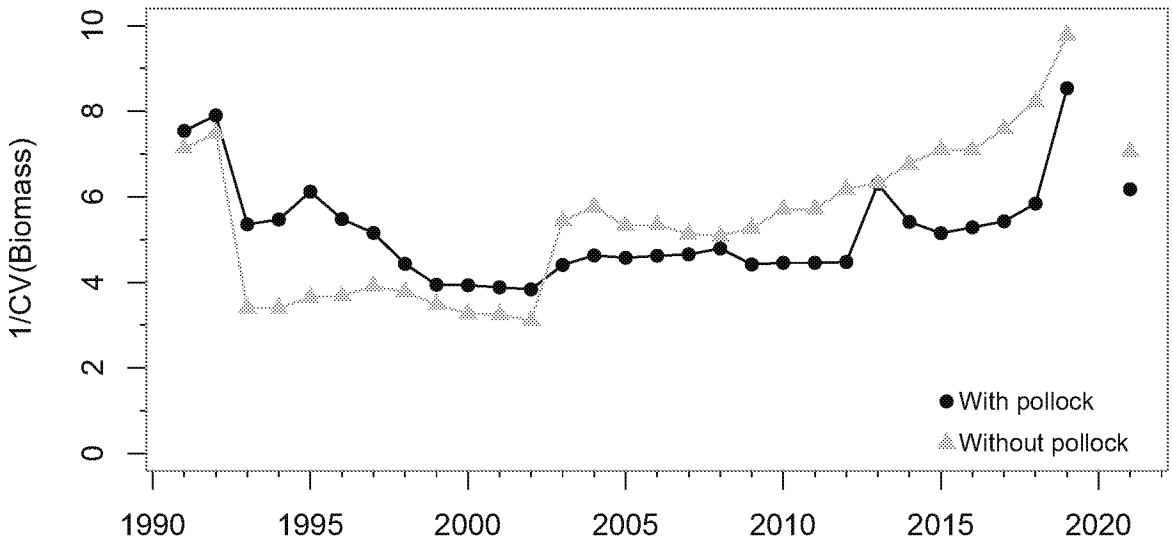

Figure 105: The stability of groundfish in the eastern Bering Sea represented with the inverse biomass coefficient of variation of total groundfish biomass (1/CV[B]). Ten years of data are required to calculate this metric, so this time series begins in 1991 after the tenth year of the NMFS/AFSC annual summer bottom-trawl survey. The black circles are the series with pollock included in the index, and the gray triangles are the same series but with pollock excluded.

Factors influencing observed trends: Fishing is expected to influence this metric as fisheries can selectively target and remove larger, long-lived species affecting population age structure (Berkeley et al., 2004; Hsieh et al., 2006). Larger, longer-lived species can become less abundant and be replaced by smaller shorter-lived species (Pauly et al., 1998). Larger, longer-lived individuals help populations to endure prolonged periods of unfavorable environmental conditions and can take advantage of favorable conditions when they return (Berkeley et al., 2004). A truncated age-structure could lead to higher population variability (CV) due to increased sensitivity to environmental dynamics (Hsieh et al., 2006). Interannual variation in this metric could also be influenced by interannual variation in species abundance in the trawl survey catch, patchy spatial distribution for some species, or species distribution shifts (Stevenson and Lauth, 2019; Thorson, 2019). This metric, as calculated here with trawl-survey data, reflects the stability of the portion of the groundfish community that is represented in the catch data of the annual summer bottom-trawl survey. Both sharp increases or decreases in species index values can increase variability and reduce the indicator value.

The high values for this indicator in 2019 and at the start of the time series are indicative of stable groundfish biomass with a relatively low CV during the previous ten years. The CVs for

both time series in 2019 were the lowest over their respective time series resulting in their highest indicator values. The sharp drop in total biomass in 2021, particularly for pollock, increased the CV resulting in lower indicator values in 2021. Previously, both series (with and without pollock) dropped sharply from 1992 to 1993. This was because the index for capelin in 1993 was anomalously high which increased variability and reduced the indicator value. In 2003, both series increased, which was in part due to the high capelin value in 1993 no longer being a part of the most recent 10 years.

In 2009, the series without pollock began a steady increase towards its high value in 2019. The series with pollock included has a more modest positive trend over the same span, with high values in 2013 and 2019. Pollock is a biomass dominant species in the eastern Bering Sea and interannual fluctuations in their biomass are sufficient to increase variability for the total groundfish community and thus, reduce the indicator value. The series without pollock is more sensitive to fluctuations of other species, such as capelin. The sharp increase in the capelin index in 1993 kept this series lower than the series with pollock included from 1993–2002.

Implications: The measure 1/CV[B] indicates that the eastern Bering Sea groundfish community has been generally stable over the time period examined here. While the drop in biomass from 2019 to 2021 has reduced both indicators, with and without pollock, both remain above long term mean levels.

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Emerging Stressors

Ocean Acidification

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Description of indicator: The oceanic uptake of anthropogenic CO_2 is decreasing ocean pH and carbonate saturation states in a process known as ocean acidification (OA). The cold, carbon rich waters of the Bering Sea are already naturally more corrosive than other regions of the global ocean, making this region more vulnerable to rapid changes in ocean chemistry. Ship-based sampling has already identified subsurface waters corrosive to aragonite (a soluble form of calcium carbonate used by many marine shell-building organisms), denoted by aragonite saturation states (Ω_{arag})<1 (Mathis et al., 2011). The projected areal expansion and shallowing of these waters with continued absorption of anthropogenic CO_2 from the atmosphere poses a direct threat to marine calcifiers and an indirect threat to other species through trophic interactions. These OA risks demonstrate a clear need to track and forecast the spatial extent of acidified waters in the Bering Sea.

Here, we present carbonate chemistry output from the Bering Sea ROMS model (Bering10K; Pilcher et al. (2019)), consisting of the current hindcast that runs from 2003 to August 15, 2021. We show spatial plots for Bering Sea bottom water conditions, including both the hindcast 2003–2020 average and the 2021 anomaly (Figure 106). We focus on bottom waters and the late summer timeframe because this is where we expect the most acidic waters to develop, due to seasonal biological respiration. This is also when temperatures are close to their highest and are thus most likely to have synergistic negative effect on crabs (Swiney et al., 2017). This model output is used to develop indices for both pH and the aragonite saturation state (Ω_{arag}) using threshold values of biological significance (Figure 107). Negative effects to the condition index and survival of red king and tanner crab have previously been found at pH<7.8 (Long et al., 2013), and Ω_{arag}<1 represents when the dissolution of aragonite becomes favorable. The goal of this index time series, along with the spatial anomaly plot, is to provide a quick assessment of the summer water pH and Ω_{arag} conditions compared to previous years.

Status and trends: pH and Ω_{arag} in bottom waters for 2021 are near average for most of the inner and middle shelf, with some slightly more acidic areas in the southeastern shelf and some slightly less acidic waters in the northern Bering Sea near St. Lawrence Island (Figure 106). Notably, outer shelf waters are relatively more acidic (warmer colors) than average, particularly in bottom waters southwest of St. Matthew Island where pH conditions are 0.3–0.5 units lower than average. This continues a multi-year pattern of anomalously more acidic waters for the outer shelf domain that emerged in 2018, though the magnitude of this anomaly decreased this year for the southeastern

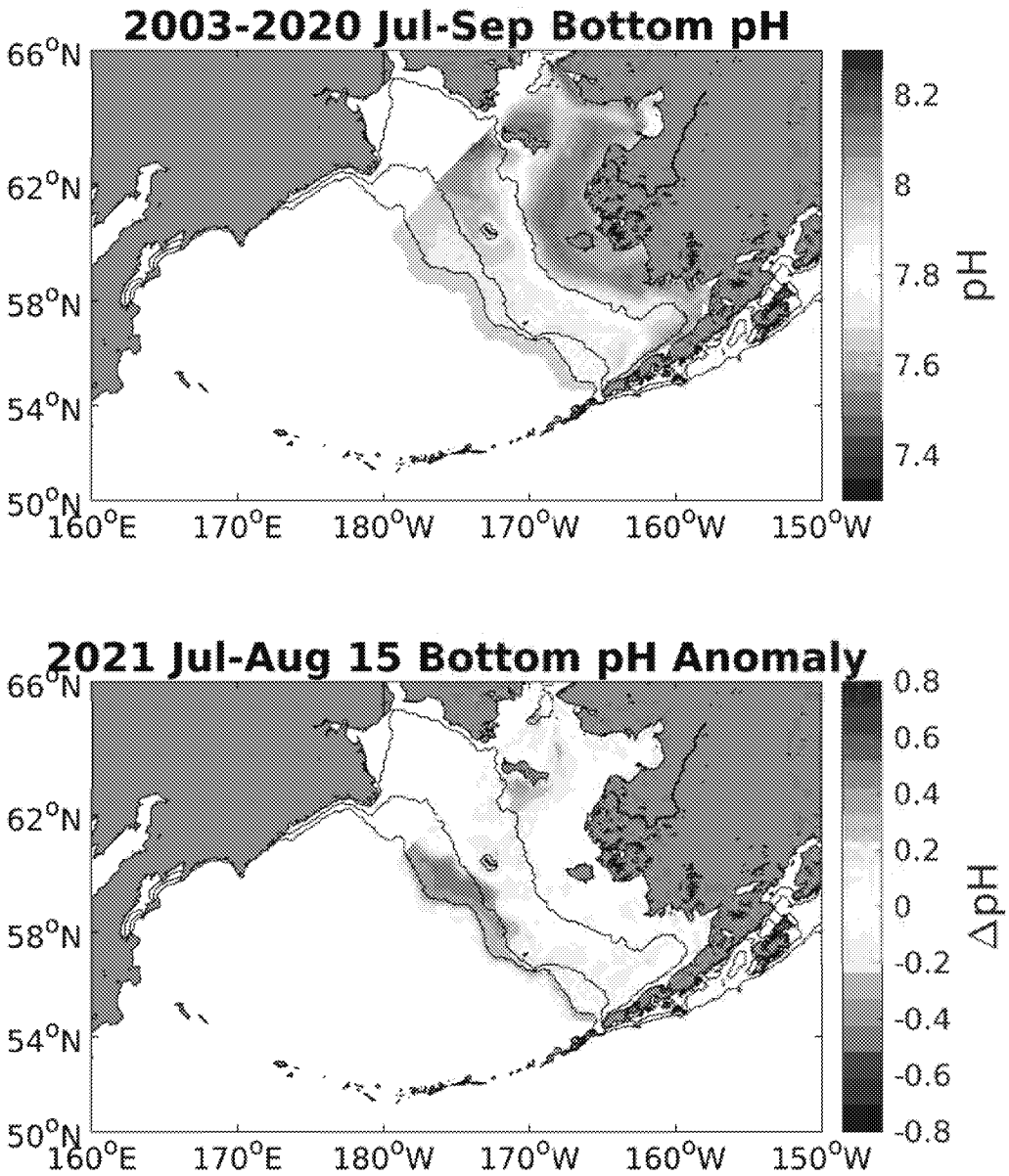

Figure 106: Model spatial maps of July–September averaged bottom water pH for the (top) 2003–2020 hindcast and (b) the 2021 nowcast (updated through August 15) anomaly compared to the 2003–2020 average. Contour lines denote the 50m, 100m, and 200m isobaths. Regions that are outside of the eastern Bering Sea management region are omitted.

outer shelf. Both index values suggest slightly less acidic conditions overall than 2020 and are near the 2003–2020 average.

Factors influencing observed trends: It is likely that the persistent region of lower pH located on the outer shelf is ultimately a result of changes in circulation and not ocean acidification. This water mass is also relatively high in salinity and nutrients, with relatively low dissolved oxygen concentrations. Analysis of the modeled water dissolved inorganic carbon and total alkalinity

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concentrations suggests that the source of this water is upwelling of deep water from the Bering Sea basin. This is consistent with the anomalously strong southerly winter winds in recent years, which have also greatly reduced sea ice extent (Stabeno and Bell, 2019).

Implications: Based on the sensitivity of red king crab to pH, previous work suggests that OA may have significant negative impacts to the red king crab fishery (Seung et al., 2015; Punt et al., 2016). However, these effects are not expected to emerge at present, as other environmental variables (e.g., temperature) are better predictors of red king crab movements. Modeled pH and Ω_{arag} water conditions in Bristol Bay for 2021 are near average and the shallower inner shelf waters that serve as habitat for juvenile red king crab are relatively well buffered. Although outer shelf bottom waters are substantially lower in pH in 2021 than the 2003–2020 mean, these waters are relatively more acidic at baseline. Furthermore, this region serves as habitat for snow crab populations, which may be more resilient to OA based on initial biological experiments (C. Long, unpublished data). At this time, there is no evidence that OA can be linked to recent declines in surveyed snow crab and red king crab populations.

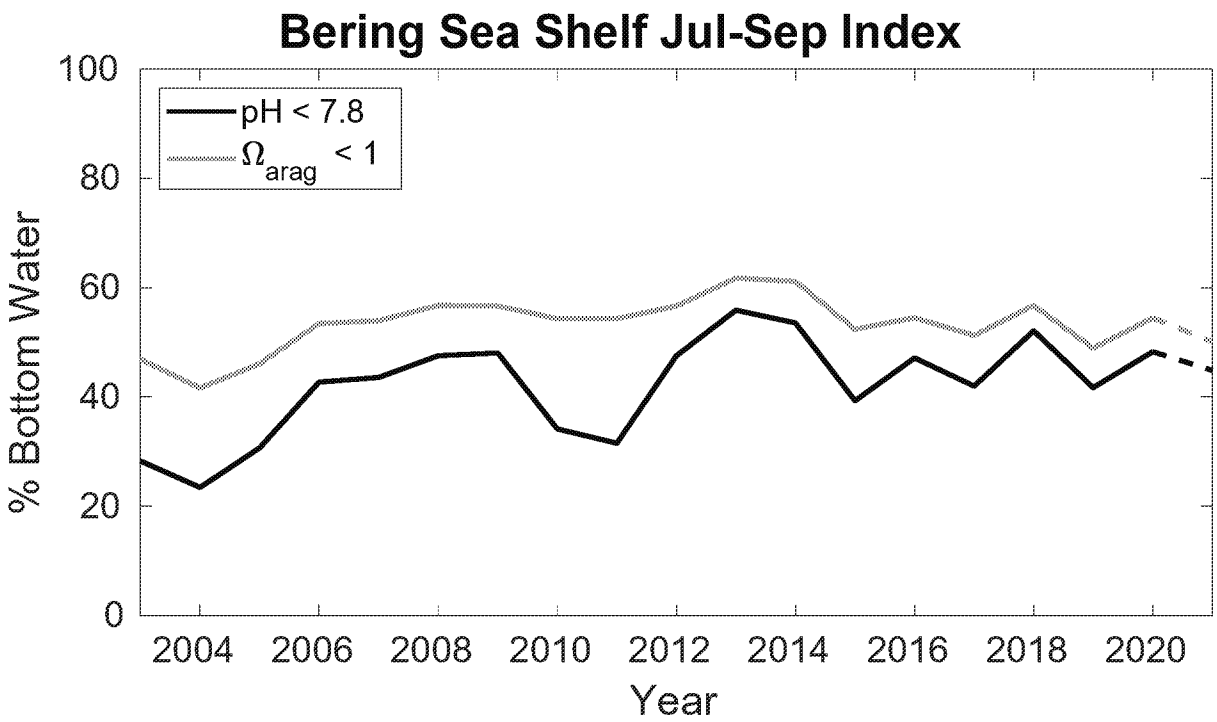

Figure 107: Model time series of the July–September (black line) pH index and (grey line) Ω_{arag} undersaturation index. Each index is calculated as the percent of spatial area of the Eastern Bering Sea region (Figure 106) where bottom waters have a July–September average below the denoted value. The dashed portion at the end represents the incomplete 2021 value, which is run up through August 15.

Harmful Algal Blooms

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[3] Woods Hole Oceanographic Institution, Woods Hole, MA
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Last updated: September 2021

Sampling Partners:

Alaska Ocean Observing System
Alaska Veterinary Pathologists
Aleutian Pribilof Island Association
Central Council of Tlingit and Haida*
Chilkoot Indian Association*
Craig Tribal Association*
Hoonah Indian Association*
Hydaburg Cooperative Association*
Kachemak Bay NERR
Ketchikan Indian Association*
Klawock Cooperative Association*
Knik Tribe of Alaska
Kodiak Area Native Association
Metlakatla Indian Community*
NOAA Kasitsna Bay Lab
NOAA WRRN-West
North Slope Borough
Organized Village of Kake*
Organized Village of Kasaan*
Petersburg Indian Association*
Qawalangin Tribe of Unalaska
Sitka Tribe of Alaska*
Skagway Traditional Council*
Southeast Alaska Tribal Ocean Research
Sun'aq Tribe of Kodiak*
UAF-Alaska Sea Grant
USGS Alaska Science Center
Woods Hole Oceanographic Institution
Wrangell Cooperative Association*
Yakutat Tlingit Tribe*

**Partners of Southeast Alaska Tribal Ocean Research (SEATOR)*

Description of indicator: Alaska's most well-known and toxic harmful algal blooms (HABs) are caused by *Alexandrium* spp. and *Pseudo-nitzschia* spp. *Alexandrium* produces saxitoxin which can cause paralytic shellfish poisoning (PSP) and has been responsible for five deaths and over 100 cases of PSP in Alaska since 1993 (see DHSS fatality report[15]). Analyses of paralytic shellfish toxins are commonly reported as of toxin/100 g of tissue, where the FDA regulatory limit is 80/100g. Toxin levels between 80–1000/100 g are considered to potentially cause non-fatal symptoms, whereas levels above 1000/100g ($\sim$ 12x regulatory limit) are considered potentially fatal.

Pseudo-nitzschia produces domoic acid which can cause amnesic shellfish poisoning and inflict

[15] http://www.dhss.alaska.gov/News/Documents/press/2020/DHSS_PressRelease_PSPFatality_20200715.pdf

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permanent brain damage. *Pseudo-nitzschia* has been detected in 13 marine mammal species and has the potential to impact the health of marine mammals and birds in Alaska. No human health impacts of domoic acid have been reported in Alaska.

The State of Alaska tests all commercial shellfish harvest, however there is no state-run shellfish testing program for recreational and subsistence shellfish harvest. Regional programs, run by Tribal, agency, and university entities, have expanded over the past five years to provide test results to inform harvesters and researchers and reduce human health risk (Figure 108). All of these entities are partners in the Alaska Harmful Algal Bloom Network which was formed in 2017 to provide a statewide approach to HAB awareness, research, monitoring, and response in Alaska. More information on methods can be found on the Alaska HAB Network website[16] or through the sampling partners listed above.

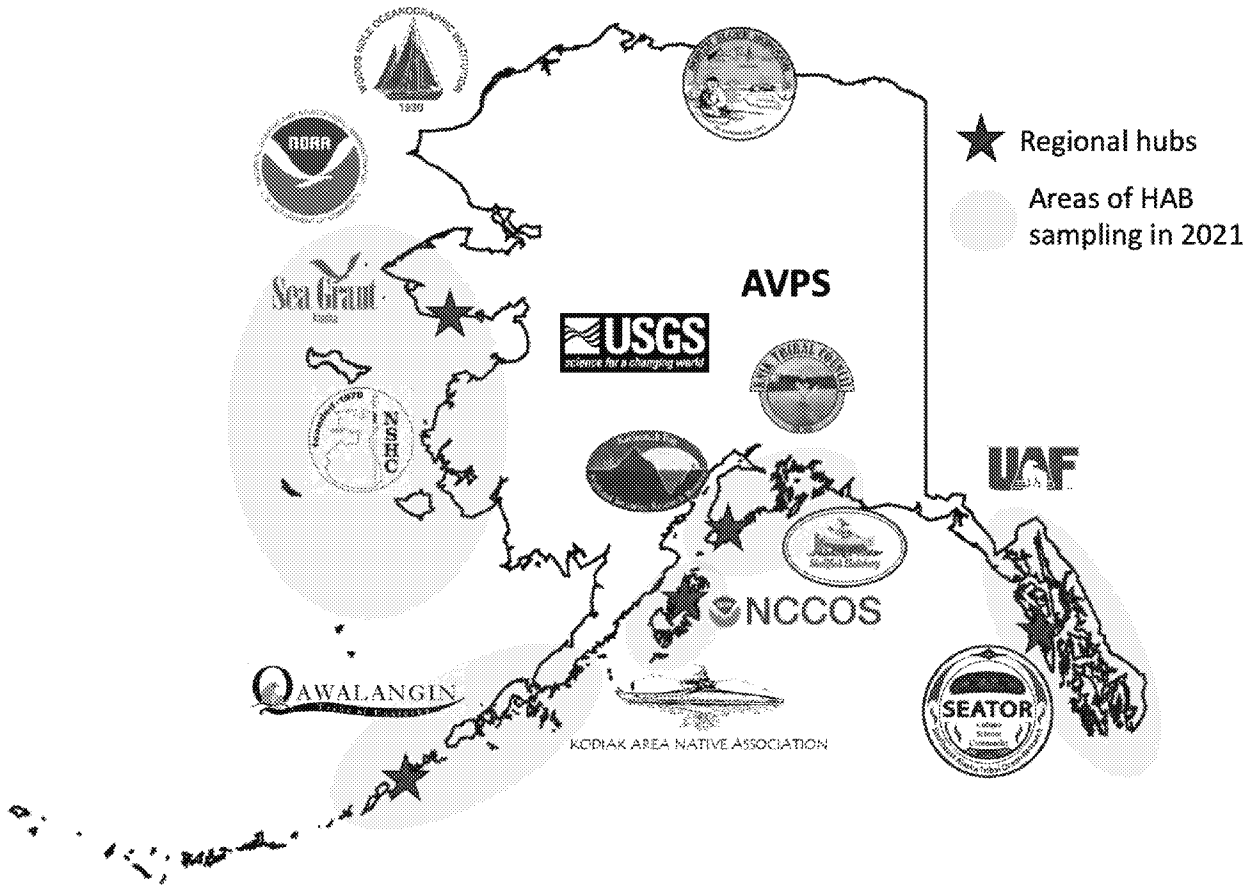

Figure 108: Map of HABs sampling areas and sampling partners in 2021.

[16] https://aoos.org/alaska-hab-network/

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Status and trends:
Alaska Region: Results from shellfish and phytoplankton monitoring showed a consistent presence of harmful algal blooms (HABs) throughout all regions of Alaska in 2021. Bivalve shellfish from areas that are well known for having PSP levels above the regulatory limit, including Southeast Alaska and Kodiak, continued to test above the regulatory limit. Shellfish in other areas, which have seen high levels only in recent years (e.g., the Aleutian Islands), continued to show high levels in 2021. Overall, 2021 seems to have been slightly less active for blooms and toxin levels than 2019 and 2020, but many areas continue to have HAB organisms in the water, and shellfish testing well above the regulatory limit, especially between March and September. Over the last few years, the dinoflagellate *Dinophysis* has become more common and abundant in water samples, and 2021 continued that trend.

Northern Bering Sea: Water samples were collected regularly in and near Nome, AK for microscopy to identify phytoplankton target species of *Alexandrium* spp., *Dinophysis*, and *Pseudo-nitzschia*. Identification is in the process of review through NOAA's NWFSC. Other samples of phytoplankton, cysts, clams, and worms to test for saxitoxin and domoic acid were collected at several locations in Diomede.

Sediment and water samples were collected during a Northern Bering Sea cruise for detection of *Alexandrium* spp. cysts and cells; water samples will also be analyzed for *Pseudo-nitzschia*. Shore-based water sampling kits were sent to the communities of Nome, Diomede, Savoonga, Gambell, Utqiaġvik, and Shishmaref. Weekly samples from each community have been preserved and will be analyzed using both microscopy and molecular methods for HAB species.

Through the ECOHAB project "Harmful algal bloom toxins in Arctic food webs", community samplers and researchers are collecting samples throughout the food web to test for HAB toxins. More information about this project can be found on p. 185.

Factors influencing observed trends: HABs are likely to increase in intensity and geographic distribution in Alaska waters with warming water temperatures. Observations in Southeast and Southcentral Alaska suggest *Alexandrium* spp. blooms occur at temperatures above 10°C and salinities above 20 (Vandersea et al., 2018; Tobin et al., 2019; Harley et al., 2020).

Implications: HABs pose a risk to human health when present in wildlife species that people consume, including shellfish, birds, and marine mammals. Research across the state is attempting to better understand the presence and circulation of HABs in the food web. HAB toxins have been detected in stranded and harvested marine mammals from all regions of Alaska in past years (Lefebvre et al., 2016).

ECOHAB: Harmful Algal Bloom (HAB) Toxins in Arctic Food Webs

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Last updated: September 2021

Description of indicator: There is clear evidence that multiple harmful algal bloom (HAB) toxins are present in Arctic and Subarctic food webs (Figure 109). Two of the most common toxin types include domoic acid (DA; produced by *Pseudo-nitzschia* species) and Paralytic Shellfish Toxins (PSTs; produced by *Alexandrium* species). The risks of these toxins include human illness and death associated with seafood consumption as well as health impacts to marine wildlife at multiple trophic levels. Many commercially valuable shellfish and finfish are impacted by these toxins, as well as marine mammals, invertebrates, seabirds, and filter-feeding fishes that are harvested for subsistence purposes and consumed by Alaska's coastal communities.

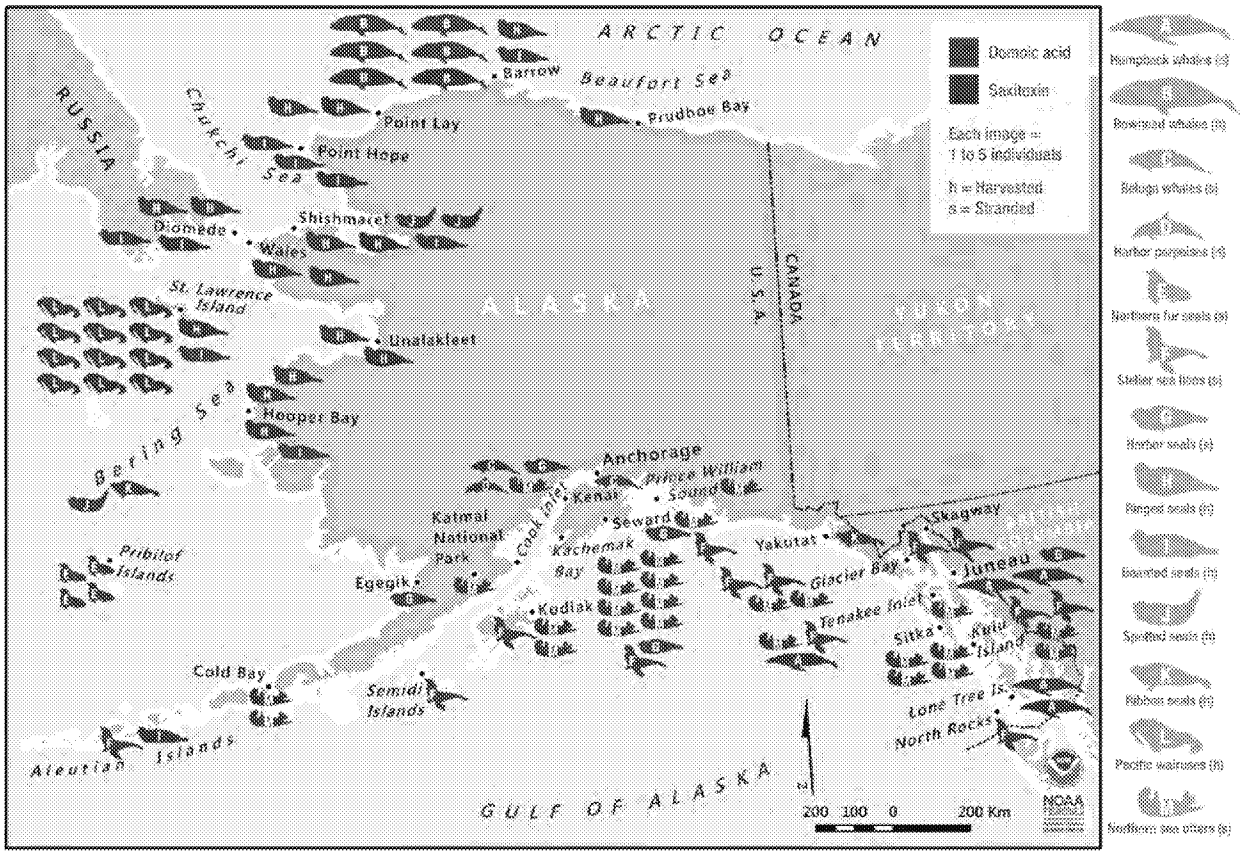

Figure 109: Algal toxins detected in stranded and harvested marine mammals suggest widespread prevalence of HABs throughout the food web in all regions of Alaska (Lefebvre et al., 2016).

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Status and trends: As the climate has warmed over the past few decades, the Pacific sector of the Arctic Ocean has warmed with dramatic consequences. The quality, quantity, and duration of sea ice has decreased markedly due to earlier melting and a delayed freeze-up (Frey et al., 2014). The input of Pacific water northwards through the Bering Strait has increased, warmed, and freshened (Woodgate et al., 2012). Warmer air temperatures have led to larger negative air-sea heat fluxes in summer (ocean warming), peaking earlier in the season (Pickart et al., 2013). Summertime northeasterly winds have also increased, leading to more upwelling-favorable conditions along the western Alaskan coast (Pickart et al., 2011). Combined, these physical changes have made conditions more favorable for HAB species, particularly the dinoflagellate *Alexandrium catenella* and diatoms in the genus *Pseudo-nitzschia* (Anderson et al., 2012). Recent studies reveal increasing toxin prevalence in food webs (Figure 110) and the potential for increased cyst germination in certain cyst-dense areas, such as the seafloor in the northeastern Chukchi Sea, which are directly linked to warmer ocean bottom temperatures (Anderson et al., 2021). A potential increase in cyst germination will result in a corresponding increase in HAB events and HAB toxin exposure risks to the Arctic marine ecosystem, including people, marine mammals, seabirds, fish, and other marine wildlife.

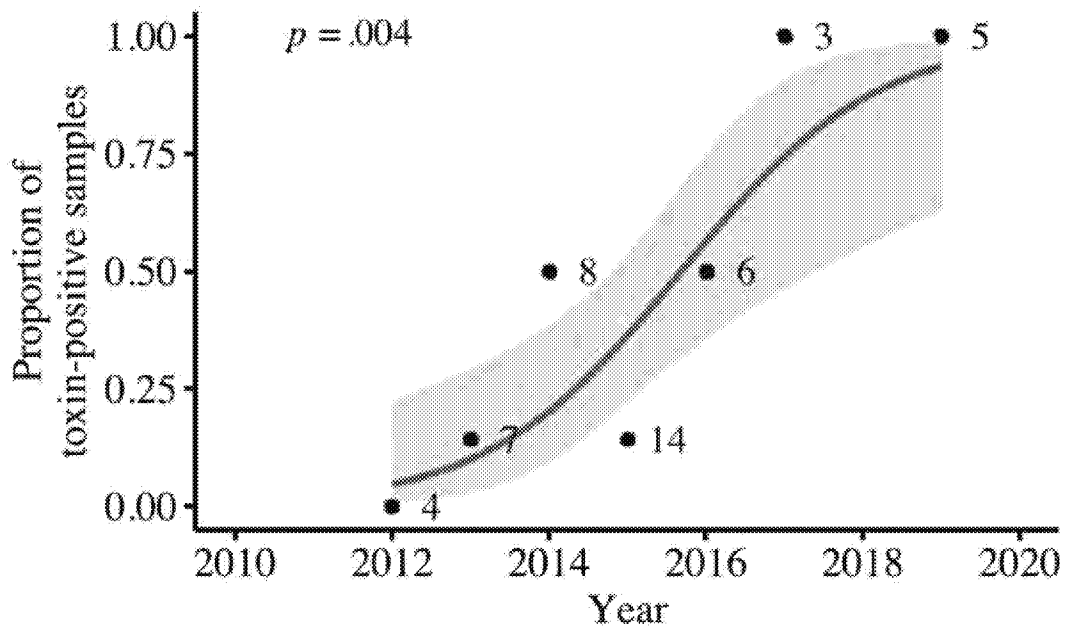

Figure 110: Increasing prevalence of the HAB toxin, domoic acid, in subsistence harvested bearded seals (*Erignathus barbatus*) in the Bering Sea, Alaska (Hendrix et al., 2021). Numbers represent the number of animals sampled each year.

Factors influencing observed trends: Increasing HAB toxin prevalence is linked to warming ocean temperatures throughout the water column (both surface and bottom) and increased sunlight associated with the loss of sea ice cover.

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Implications: The impacts of increased biotoxin exposure include increased risks to ecosystem, wildlife, and public health in Northern Arctic regions. Impacts also include food security concerns to Arctic coastal peoples as well as conservation concerns for many species of marine resources, including several marine mammals currently listed under the Endangered Species Act (ESA). The increasing trend for HAB events highlights the lack of: 1) monitoring efforts for HAB toxin levels, 2) testing of non-commercial harvests (i.e., subsistence harvest) essential in remote off-road locations throughout the Arctic, and 3) transboundary communications with the Russian federation that not only has management authority of the same stocks of marine resources as NOAA but also have coastal peoples that utilize the same marine resources for consumption throughout the northern Bering and Chukchi Seas. Increases in HAB toxin presence in Arctic waters may impact commercially important fish species and should be considered in management decisions. Although there are currently no U.S. commercial fisheries in the Chukchi or Beaufort Seas, some commercially important fish species cross into these regions from the Bering Sea. For example, Russia began commercial fishing for pollock in the Chukchi Sea in 2020.

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Fishing and Human Dimensions Indicators

Indicators presented in this section are intended to provide a summary of the status of several ecosystem-scale indicators related to fishing and human economic and social well-being. These indicators are organized around objective categories derived from U.S. legislation and current management practices (see Table 1 for a full list of objective categories and resulting indicators):

- Maintaining diversity
- Maintaining and restoring fish habitats
- Sustainability (for consumptive and non-consumptive uses)
- Seafood production
- Profits
- Recreation
- Employment
- Socio-cultural dimensions

The indicators presented are meant to represent trends in different aspects of the general management objective, but some indicators are better proxies than others. For example, seafood production is a fairly good proxy for the production of seafood to regional, national, and international markets but ex-vessel and wholesale value are imperfect proxies for harvesting and processing sector profits. This suite of indicators will continue to be revised and updated to provide a more holistic representation of human/environment interactions and dependencies.

The Ecosystem Status Report (ESR) team places high value on including human dimensions information in our analysis of the status of the ecosystem to inform the North Pacific Fisheries Management Council's harvest specification process. This year, AFSC is reexamining what economic and social science information is most useful to the Council in the context of these ESRs and other Council documents. As a result, we have only updated some previous contributions in this section for 2021. Following the NPFMC's Science and Statistical Committee's October 2021 meeting discussion, the ESRs will be part of a holistic review of how economic and social science information is communicated and applied to the Council's harvest specification process.

NOAA's Alaska Fisheries Science Center's Economic and Social Science Research department has stated the following — *Previous human dimensions indicators (landings by functional group, fishery value and unit value (price) by functional group, trends in groundfish discards, trends in unemployment, and trends in human population) are being cut back for 2021 to better align the focus of the ESR specifically on informing next year's Allowable Biological Catch (ABC) determination. Going forward, we intend to focus on human dimensions contributions to the ESR which can provide near-term information on the health of a particular stock or region, primarily those currently considered fishing performance metrics (those effects that are upstream from fishing). Many of the removed indicators that speak to general ecosystem health (landings, volume, and unit value by functional group) appear to be more appropriate for the other products such as the Eastern Bering Sea FEP's*

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upcoming Fisheries Ecosystem Health Card. This then properly aligns the human dimensions contributions across Council productions and allows the focus of the Ecosystem and Socioeconomic Profiles (ESPs) to be solely on single species stock health related ecosystem, economic, and social indicators. However, downstream impacts of the fishery on human well-being is outside the scope of the focus of the ESR and is treated more comprehensively in the Groundfish Economic SAFE, Crab Economic SAFE, and the Annual Community Engagement and Participation Overview (ACEPO). Figure 111 shows the AFSC's conceptualization of where human dimensions information is included in various NPFMC documents, including the Economic Performance Reports (EPRs) which are included within the stock assessment (or as an appendix), as well as the ESR and ESPs, and the upcoming FEP health card. Additional information on human dimensions indicators can be found at the following website: `https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities`.

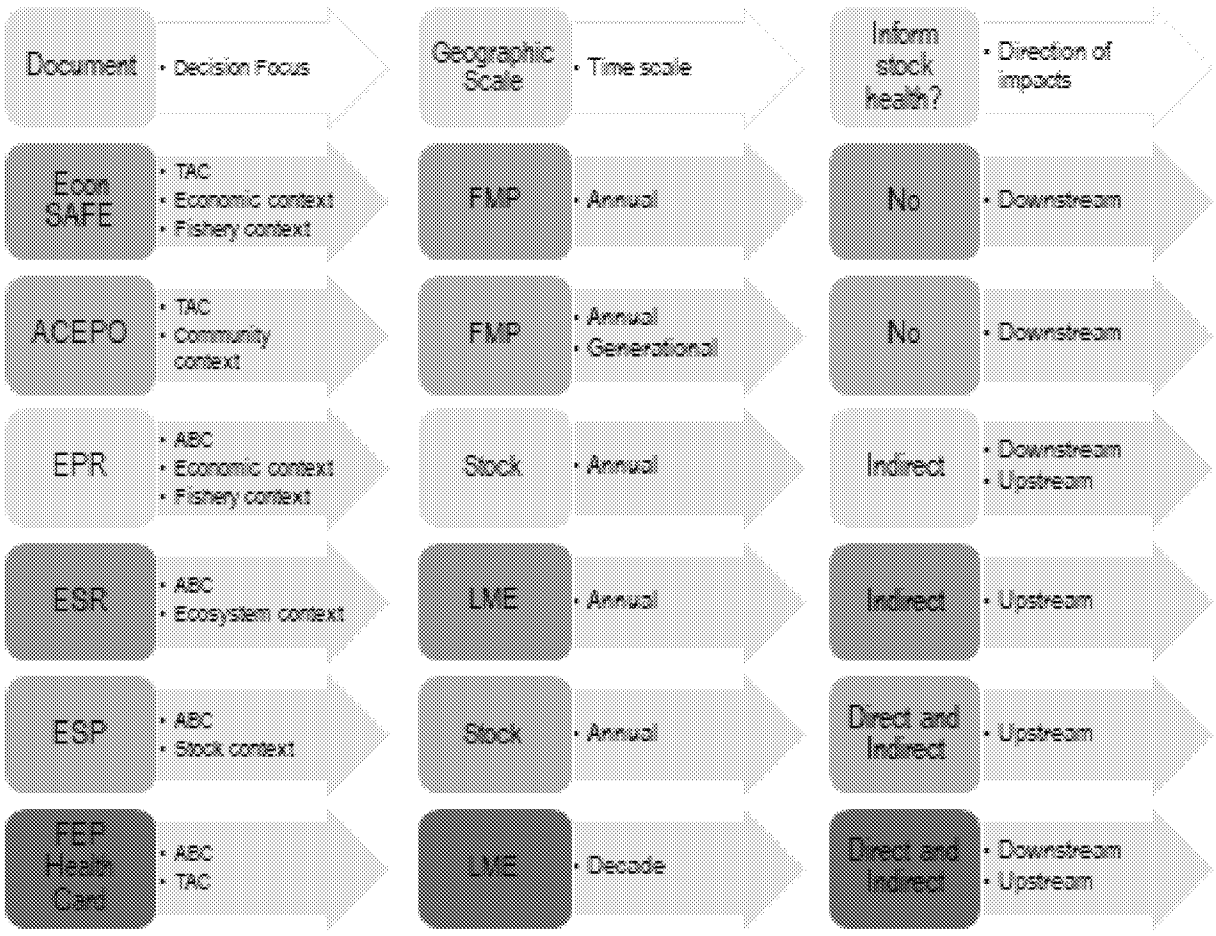

Figure 111: NOAA Alaska Fisheries Science Center's human dimensions indicators mapping

Maintaining Diversity: Discards and Non-Target Catch

Time Trends in Groundfish Discards

Contributed by Jean Lee
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Last updated: September 2021

Description of indicator: Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Region's blend data, while estimates for 2003 and later come from the Alaska Region's Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards in the North Pacific. Discard rates as shown in Figure 112 below are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area-gear-target sector. Where rates are described below for species or species groups, they represent the total discarded weight of the species/species group divided by the total catch weight of the species/species group for the relevant area-gear-target sector. *These estimates include only catch of FMP-managed groundfish species within the FMP groundfish fisheries.* Discards of groundfish in the halibut fishery and discards of forage fish and species managed under prohibited species catch limits, such as halibut, are not included.

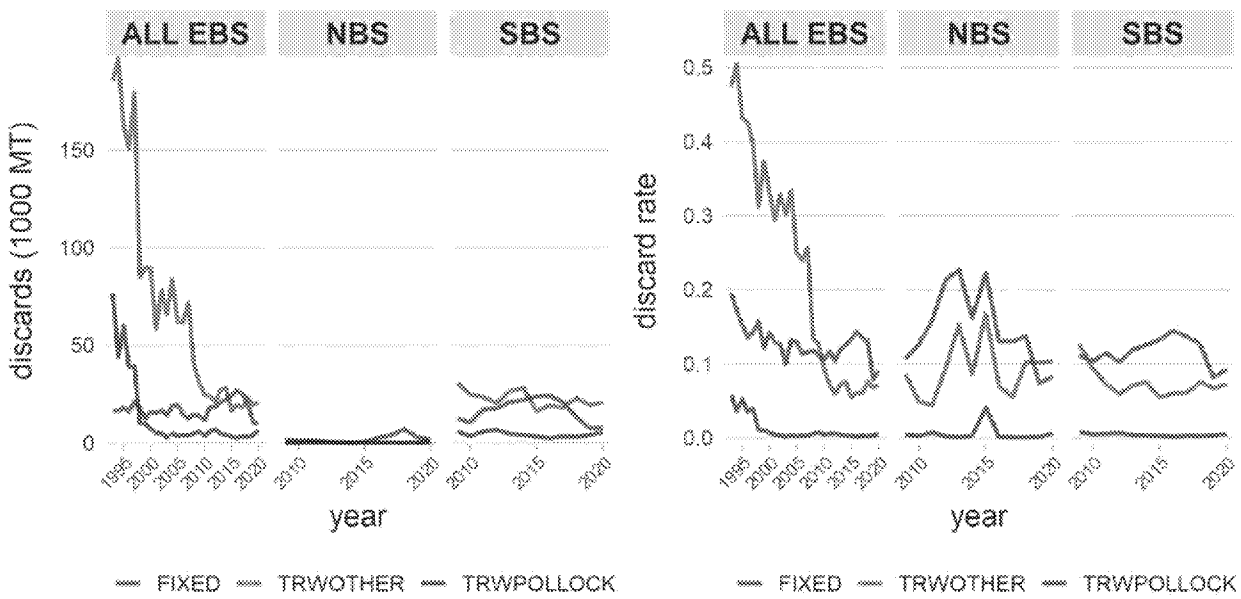

Figure 112: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear (FIXED), pollock trawl (TRWPOLLOCK), and non-pollock trawl sectors (TRWOTHER) for the eastern Bering Sea (ALL EBS) region, 1993–2020; and for northern (NBS) and southern (SBS) subregions, 2009–2020. Discard rates are calculated as total discard weight of FMP groundfish divided by total retained and discarded weight of FMP groundfish for the sector (includes only catch counted against federal TACs).

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Status and trends: Since 1993, discard rates of groundfish in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock and non-pollock trawl fisheries in the eastern Bering Sea (EBS) (Figure 112). Annual discard rates in the EBS pollock trawl sector declined from 20% to about 1% in 1999 and have since remained below this level. Rates in the non-pollock trawl sector have declined from a high of 50% in 1994 and have remained at 8% or lower since 2011. Discard rates and volumes in the fixed gear (hook-and-line and pot) sector trended upward from 2010 to 2016, reaching the highest annual discard biomass (26.7K metric tons) over the entire time series before declining from 2017 to 2020. Fixed gear discards in the northern Bering Sea trended upward from 2016 to 2018 as some vessels targeting Pacific cod moved their fishing activity northward, but these increases were offset by declines in discard biomass in the southern subregion. Through week 33 of 2021, discard biomass for both trawl sectors is trending higher relative to the 2016–2020 period, while fixed gear discards are trending lower to date (Figure 113).

Factors influencing observed trends: Fishery discards may occur for economic or regulatory reasons. Economic discards include discarding of lower value and unmarketable fish, while regulatory discards are those required by regulation (e.g., upon reaching an allowable catch limit for a species). Minimizing discards is recognized as an ecological, economic, and moral imperative in various multilateral initiatives and in National Standard 9 of the Magnuson-Stevens Fishery Conservation and Management Act (Alverson et al., 1994; FAO, 1995; Karp et al., 2011). In the North Pacific groundfish fisheries, mechanisms to reduce discards include:

- Limited access privilege programs (LAPPs), which allocate catch quotas and may reduce economic discards by slowing down the pace of fishing
- In-season closure of fisheries once target or bycatch species quotas are attained
- Minimum retention and utilization standards for certain fisheries
- Maximum retainable amounts (MRAs), which allow for limited retention of species harvested incidentally in directed fisheries.

In the eastern Bering Sea, management and conservation measures aimed at reducing bycatch have contributed to an overall decline in groundfish discards since the early 1990s (NPFMC, 2016, 2017). Pollock roe stripping, wherein harvesters discard all but the highest value pollock product, was prohibited in 1991 (56 Federal Register 492). Throughout the 1990s, declines in total catch and discard of non-pollock groundfish in the pollock fishery coincided with the phasing out of bottom trawl gear in favor of pelagic gear, which allows for cleaner pollock catches (Graham et al., 2007). Full retention requirements for pollock and Pacific cod were implemented in 1998 for federally-permitted vessels fishing for groundfish (62 Federal Register 63880). Between 1997 and 1998 annual discard rates for cod fell from 13% to 1% in the non-pollock trawl sector and from 50% to 3% in the trawl pollock sector; pollock discards also declined significantly across both trawl gear sectors. In the trawl pollock fishery, discards of pollock have remained at nominal levels since passage of the American Fisheries Act, which established a sector-based LAPP and implemented more comprehensive observer requirements for the fishery in 2000.

Low retention rates in the non-AFA trawl catcher processor (head and gut) fleet prompted Amendments 79 and 80 to the BSAI Groundfish FMP in 2008 (NPFMC, 2016). Amendment 79 established a Groundfish Retention Standard (GRS) Program with minimum retention and utilization requirements for vessels at least 125 feet LOA; industry-internal monitoring of retention rates has since

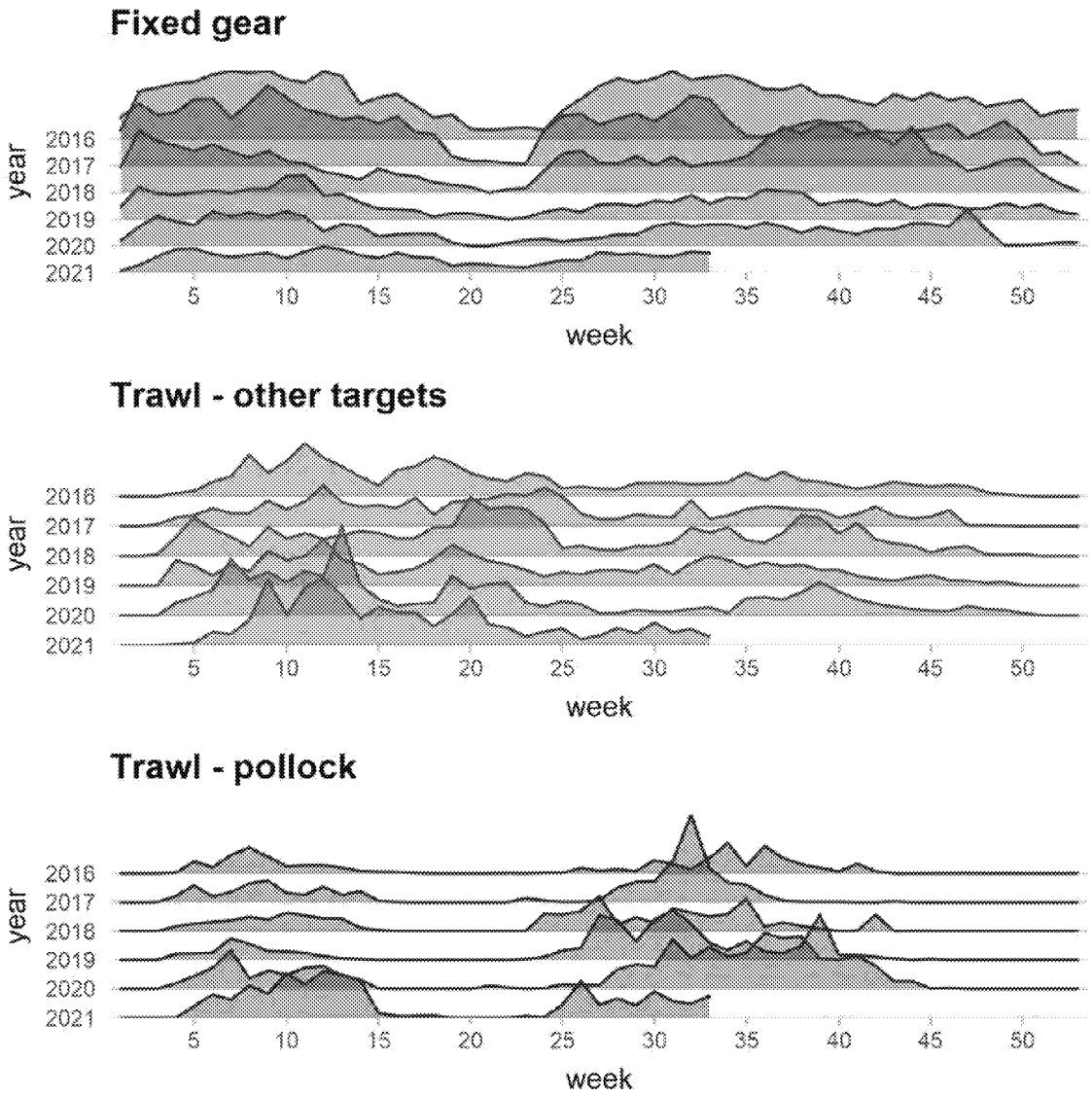

Figure 113: Total biomass of FMP groundfish discarded in the eastern Bering Sea region by sector and week, 2016–2021 (data for 2021 is shown through week 33). Plotted heights are not comparable across sectors.

replaced the program. Amendment 80 expanded the GRS program to all vessels in the fleet and established a cooperative-based LAPP with fixed allocations of certain non-pollock groundfish species. In combination with the GRS program, these allocations are intended to remove the economic incentive to discard less valuable species caught incidentally in the multi-species fishery. In 2013, NMFS revised MRAs for groundfish caught in the BSAI Arrowtooth flounder fishery, including an increase from 0 to 20 percent for pollock, cod, and flatfish (78 Federal Register 29248). Groundfish discard rates in the trawl flatfish fishery fell from 23% to 12% between 2007 and 2008 and have continued on a gradual decline since then.

Since 2003 across all Bering Sea sectors combined, discard rates for species groups historically managed together as the "other groundfish" assemblage (skate, sculpin, shark, squid, and octopus)

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have ranged from 65% to 80%, with skates representing the majority of discards by weight. In the fixed gear sector other groundfish typically account for at least 70% of total groundfish discards annually. Fluctuations in discard volumes and rates for these species may be driven by changes in market conditions and in fishing behavior within the directed fisheries in which these species are incidentally caught. For example, low octopus catch from 2007–2010 may be attributable to lower processor demand for food-grade octopus and decreases in cod pot-fishing effort stemming from declines in cod prices (Conners et al., 2016).

Implications: Fishery bycatch adds to the total human impact on biomass without providing a benefit to the Nation and as such is perceived as "contrary to responsible stewardship and sustainable utilization of marine resources" (Kelleher, 2005). Bycatch may constrain the utilization of target species and increases the uncertainty around total fishing-related mortality, making it more difficult to assess stocks, define overfishing levels, and monitor fisheries for overfishing (Alverson et al., 1994; Clucas, 1997; Karp et al., 2011). Although ecosystem effects of discards are not fully understood, discards of whole fish and offal have the potential to alter energy flow within ecosystems and have been observed to result in changes to habitat (e.g., oxygen depletion in the benthic environment) and community structure (e.g., increases in scavenger populations) (Queirolo et al., 1995; Alverson et al., 1994; Catchpole et al., 2006; Zador and Fitzgerald, 2008). Monitoring discards and discard rates provides a means of assessing the efficacy of measures intended to reduce discards and increase groundfish retention and utilization.

Time Trends in Non-Target Species Catch

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Last updated: July 2021

Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the Eastern Bering Sea (EBS). In previous years we included the catch of "other" species, "non-specified" species, and forage fish in this contribution. However, stock assessments have now been developed or are under development for all groups in the "other species" category (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), some of the species in the "non-specified" group (giant grenadier, other grenadiers), and forage fish (e.g., capelin, eulachon, Pacific sand lance, etc.), therefore we no longer include trends for these species/groups here[17]. Invertebrate species associated with habitat areas of particular concern, previously known as HAPC biota (seapens/whips, sponges, anemones, corals, and tunicates) are now referred to as structural epifauna. Starting with the 2013 Ecosystem Status Report, the three categories of non-target species we continue to track here are:

[17]See AFSC stock assessment website at `https://www.fisheries.noaa.gov/alaska/population-assessments/north-pacific-groundfish-stock-assessments-and-fishery-evaluation`

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1. Scyphozoan jellyfish
2. Structural epifauna (seapens/whips, sponges, anemones, corals, tunicates)
3. Assorted invertebrates (bivalves, brittle stars, hermit crabs, miscellaneous crabs, sea stars, marine worms, snails, sea urchins, sand dollars, sea cucumbers, and other miscellaneous invertebrates).

Total catch of non-target species is estimated from observer species composition samples taken at sea during fishing operations, scaled up to reflect the total catch by both observed and unobserved hauls and vessels operating in all FMP areas. Catch since 2003 has been estimated using the Alaska Region's Catch Accounting System (Cahalan et al., 2014). This sampling and estimation process does result in uncertainty in catches, which is greater when observer coverage is lower and for species encountered rarely in the catch.

For this contribution the catch of non-target species/groups from the Bering Sea includes the reporting areas 508, 509, 512, 513, 514, 516, 517, 521, 523, 524, and 530 (https://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones).

Status and trends: The catch of jellyfish decreased from 2019 to 2020 and is the second lowest since 2011 (Figure 114). Highs in the catch of jellyfish occurred in 2011 and 2014, and were each followed by a sharp decrease in catch the following year. The catch of jellyfish in 2014 was more than double the catch in 2015 and was more than five times the catch in 2016, which is the lowest over the time period examined. Jellyfish are primarily caught in the pollock fishery.

The catch of structural epifauna was relatively steady from 2011 to 2018 but decreased in 2019 and again in 2020, to its lowest over the time period examined (Figure 114). Benthic urochordate caught in non-pelagic trawls were the dominant component of the structural epifauna catch in 2012 and 2015–2020. In 2013 and 2014, anemones caught in the Pacific cod fishery were the dominant part of the structural epifauna catch. Sponge were the dominant component of the structural epifauna catch in 2011 and were primarily caught in non-pelagic trawls.

Sea stars comprise more than 85% of the assorted invertebrate catch in all years (2011–2020) and are primarily caught in flatfish fisheries (Figure 114). The catch of assorted invertebrates generally trended upward from 2011–2015, then declined from 2015 to 2020.

Factors influencing observed trends: The catch of non-target species may change if fisheries change, if ecosystems change, or both. Because non-target species catch is unregulated and unintended, if there have been no large-scale changes in fishery management in a particular ecosystem, then large-scale signals in the non-target catch may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish in the EBS are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellyfish including temperature, sea ice phenology, wind-mixing, ocean currents, and prey abundance (Brodeur et al., 2008). The lack of a clear trend in the catch of scyphozoan jellyfish may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries.

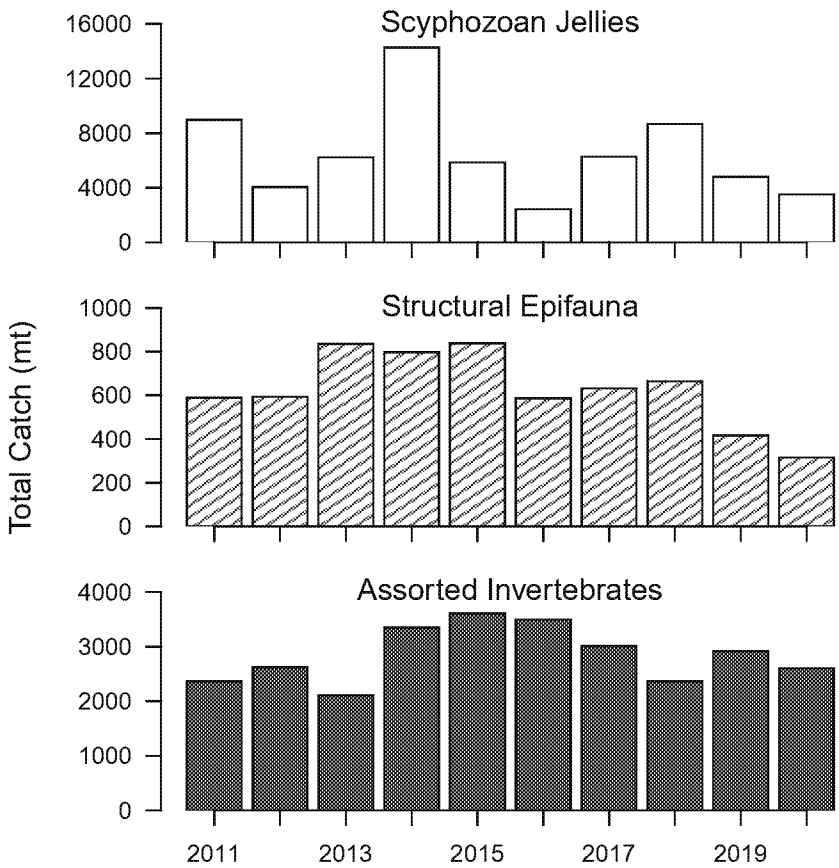

Figure 114: Total catch of non-target species (tons) in EBS groundfish fisheries (2011–2020). **Please note the different y-axis scales** between the species groups.

Implications: The catch of structural epifauna species and assorted invertebrates is very low compared with the catch of target species. Structural epifauna species may have become less available to the EBS fisheries (or the fisheries avoided them more effectively) since 2005. Abundant jellyfish may have a negative impact on fishes as they compete with planktivorous fishes for prey resources (Purcell and Arai, 2001), and additionally, jellyfish may prey upon the early life history stages (eggs and larvae) of fishes (Purcell and Arai, 2001; Robinson et al., 2014).

Seabird Bycatch Estimates for Groundfish Fisheries in the Eastern Bering Sea, 2011–2020

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Last updated: August 2021

Description of indicator: This report provides estimates of the number of seabirds caught as bycatch in commercial groundfish fisheries operating in federal waters of the U.S. Exclusive Economic Zone of the eastern Bering Sea for the years 2011 through 2020. Estimates of seabird bycatch from earlier years using different methods are not included here. Fishing gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic trawl. These numbers do not apply to gillnet, seine, or troll fisheries. Data collection on the Pacific halibut longline fishery began in 2013 with the restructured North Pacific Observer Program.

Estimates are based on two sources of information: (1) data provided by NMFS-certified fishery observers deployed to vessels and floating or shoreside processing plants (AFSC, 2011), and (2) industry reports of catch and production. Observer deployment plans are reviewed and updated annually in the Annual Deployment Plan[18]. The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2010, 2014). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. CAS also estimates non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. The CAS produces estimates based on these two current data sets, which may have changed over time.

Estimates of seabird bycatch from the eastern Bering Sea include the reporting areas 508, 509, 512, 513, 514, 516, 517, 521, and 524[19].

Status and trends: The numbers of seabirds estimated to be caught incidentally in the eastern Bering Sea fisheries in 2020 (2,975 birds) decreased from 2019 (6,185 birds) by 52%, and was below the 2011–2019 average of 5,067 birds by 41% (Table 4, Figure 115). Northern fulmars, shearwaters, and gulls were the most common species or species groups caught incidentally in the eastern Bering Sea fisheries in 2020 that could be identified. In 2020, the number of northern fulmars and shearwaters decreased by 22% and 90%, respectively, compared to 2019, and were below the 2011–2019 average of 3,090 and 1,014 birds by 32% and 68%, respectively. In 2020, the number of gulls increased by 12% compared to 2019 but was below the 2011–2019 average of 659 birds by 74%. While no black-footed albatross were reported as taken in the EBS, two short-tailed albatross were reported taken in demersal longline fisheries (as discussed below). The number of Laysan albatross decreased by 38% compared to 2019 and was below the 2011–2019 average of 35 birds by 77% (Figure 116).

[18]The 2021 plan is available at: `https://www.fisheries.noaa.gov/resource/document/2021-annual-deployment-plan-observers-and-electronic-monitoring-groundfish-and`

[19]`https://www.fisheries.noaa.gov/alaska/commercial-fishing/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones`

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Table 4: **Estimated** seabird bycatch in eastern Bering Sea groundfish fisheries for all gear types, 2011 through 2020. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Unidentified Albatross	0	0	0	12	0	0	0	0	0	0
Short-tailed Albatross	0	0	0	11	0	0	0	0	0	11
Laysan Albatross	28	37	9	13	13	12	25	166	13	8
Black-footed Albatross	1	0	0	6	0	0	0	0	0	0
Northern Fulmar	5,287	2,778	2,733	677	2,334	5,046	3,477	2,808	2,670	2,086
Shearwaters	157	477	196	116	358	3,161	979	545	3,133	327
Gull	1,565	810	451	576	927	575	372	504	155	173
Kittiwake	6	5	3	4	12	5	22	37	18	24
Murre	14	6	3	47	0	52	10	0	0	6
Puffin	0	0	0	0	0	10	0	0	0	0
Auklets	0	7	4	67	18	1	25	0	0	0
Other Alcid	0	0	0	0	0	0	0	6	6	0
Cormorant	0	0	0	0	3	0	0	0	0	0
Other Bird	0	0	0	0	0	0	63	0	0	7
Unidentified	355	300	268	73	144	282	250	77	190	333
Grand Total	7,413	4,420	3,667	1,602	3,809	9,144	5,223	4,143	6,185	2,975

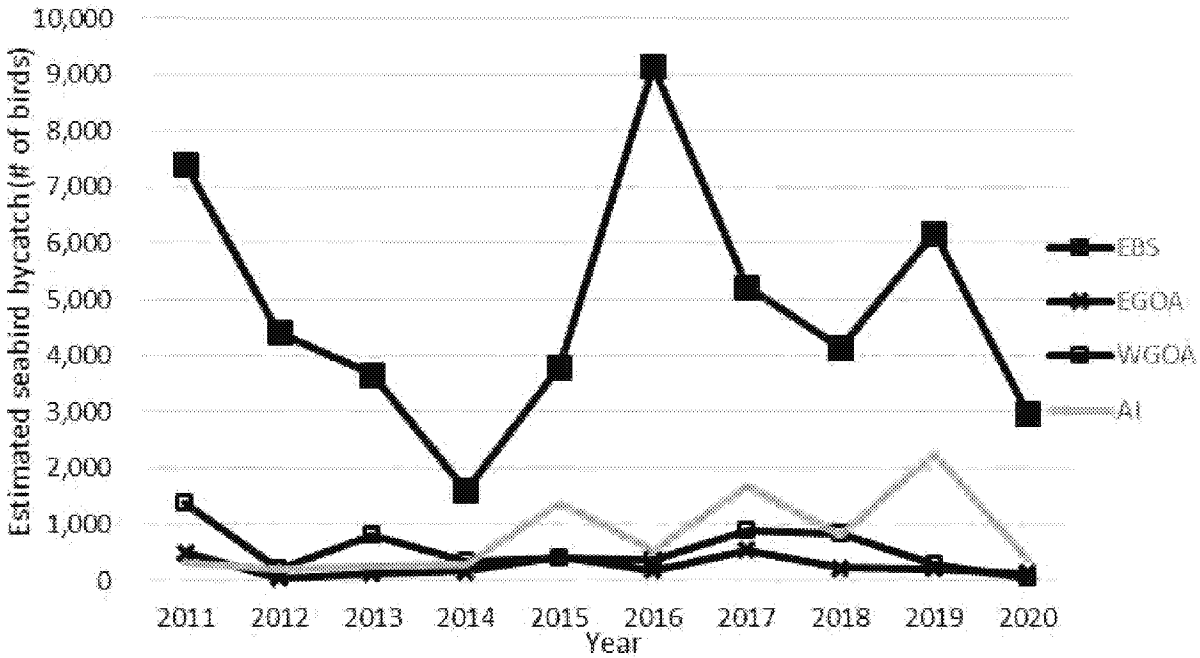

Figure 115: Total estimated seabird bycatch in eastern Bering Sea (EBS), Eastern Gulf of Alaska (EGOA), Western Gulf of Alaska (WGOA), and Aleutian Islands (AI) groundfish fisheries, all gear types combined, 2011–2020.

BSAI Pacific cod fisheries using demersal longline are responsible for the majority of seabird bycatch in the EBS – the average annual seabird bycatch for 2011 through 2019 was 4,741 birds per year (Table 13 in Krieger and Eich (2021)). In 2020, the estimated seabird bycatch was below the 2011–2019 average by 48% (2,487 birds; Table 13 in Krieger and Eich (2020)). Figure 117 shows the spatial distribution of observed seabird bycatch from 2015–2020 from the Pacific cod hook and line fisheries overlaid onto heat maps depicting fishing effort for the fishery.

Focusing solely on the bycatch of albatross (unidentified, short-tailed, Laysan, and black-footed) in the EBS, an average of 114 albatross were taken per year from 2011 through 2020 (Krieger and Eich, 2021). Two takes of short-tailed albatross were observed in the groundfish fisheries in 2020[20]. Both takes occurred in the EBS and from vessels fishing in the BSAI demersal longline fishery. The incidental take statement in the 2015 biological opinion on the groundfish fisheries, which was the current biological opinion when the takes occurred, anticipated the take of no more than six short-tailed albatross in a 2-year period (either by demersal longline or trawl; USFWS (2015)). This was the first observed take of short-tailed albatross in the groundfish fisheries (either by demersal longline, trawl, or pot) since December 2014.

Aside from the endangered short-tailed albatross, two species of eider are also listed under the U.S. Endangered Species Act. These are the threatened spectacled eider (*Somateria fischeri*) and the threatened Alaska-breeding population of Steller's eider (*Polysticta stelleri*). Two other populations of Steller's eider occur in waters off Alaska but only the Alaska-breeding population is listed under the U.S. Endangered Species Act. Prior to 2019, there had been no reported takes of either the

[20] https://www.fisheries.noaa.gov/bulletin/ib-20-76-noaa-fisheries-reports-take-short-tailed-albatross-bsai;https://www.fisheries.noaa.gov/bulletin/ib-20-80-noaa-fisheries-reports-take-second-short-tailed-albatross-bsai

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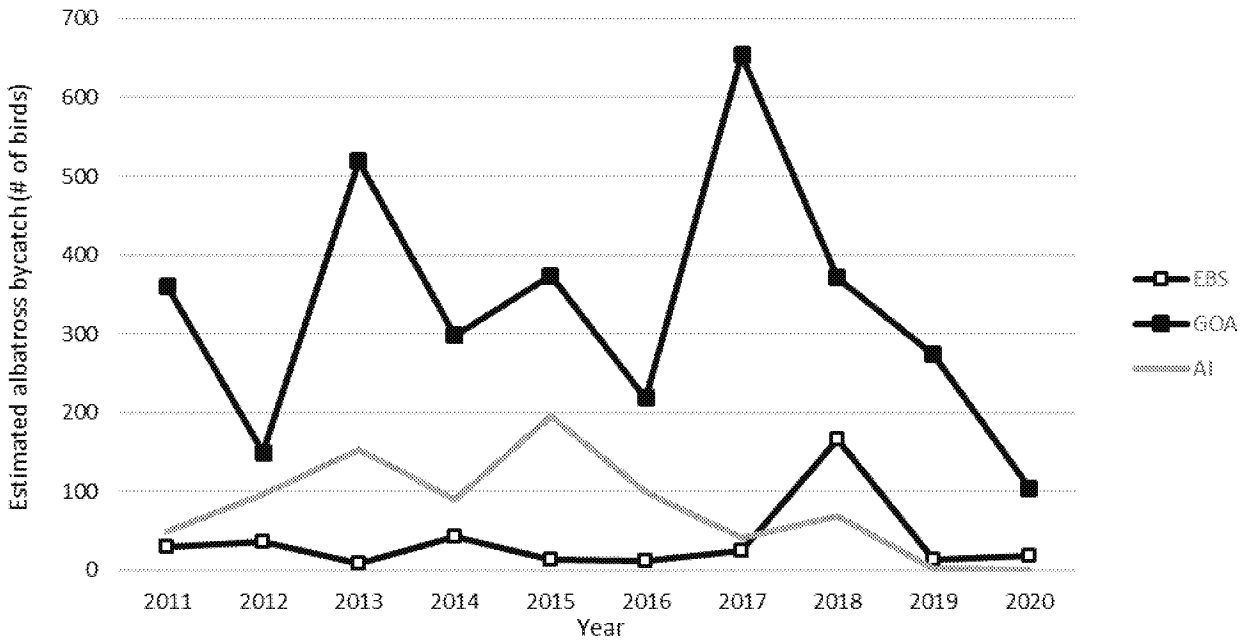

Figure 116: Total estimated albatross bycatch in eastern Bering Sea (EBS), Gulf of Alaska (GOA), and Aleutian Islands (AI) groundfish fisheries, all gear types combined, 2011–2020.

spectacled eider or the Alaska-breeding population of Steller's eider by vessels operating in federal fisheries off Alaska. However, in October of 2019, twenty-two spectacled eider fatally collided with a demersal longline vessel in the EBS (NMFS did not receive a report on this take until 2020)[21]. Then in March of 2020, a Steller's eider collided with another demersal longline vessel in the EBS[22]. These vessels were not fishing at the time of the bird strike mortality events. Since these birds were not taken by fishing gear, they are not included in the bycatch estimates provided in this report.

Because of the take of threatened spectacled and Steller's eider, NMFS reinitiated formal consultation under section 7 of the ESA with USFWS to ensure that the BSAI and GOA groundfish fisheries are not likely to jeopardize the continued existence of either the spectacled eider or Steller's eider or adversely modify their designated critical habitat. In March of 2021, the USFWS finalized a new Biological Opinion (USFWS, 2021) which supersedes the 2015 Biological Opinion.

Factors influencing observed trends: There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. Further, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates may be downward biased.

While a reduction in seabird bycatch in the Federal fisheries off Alaska is positive, several events occurred during the 2020 fishing seasons which may partially explain this reduction. As with many other things in 2020, the COVID-19 pandemic disrupted normal fishing operations throughout

[21] https://www.fisheries.noaa.gov/bulletin/ib-20-26-nmfs-reports-vessel-strike-mortality-event-22-spectacled-eiders-bering-sea

[22] https://www.fisheries.noaa.gov/bulletin/ib-20-32-nmfs-reports-vessel-strike-mortality-alaska-breeding-population-stellers

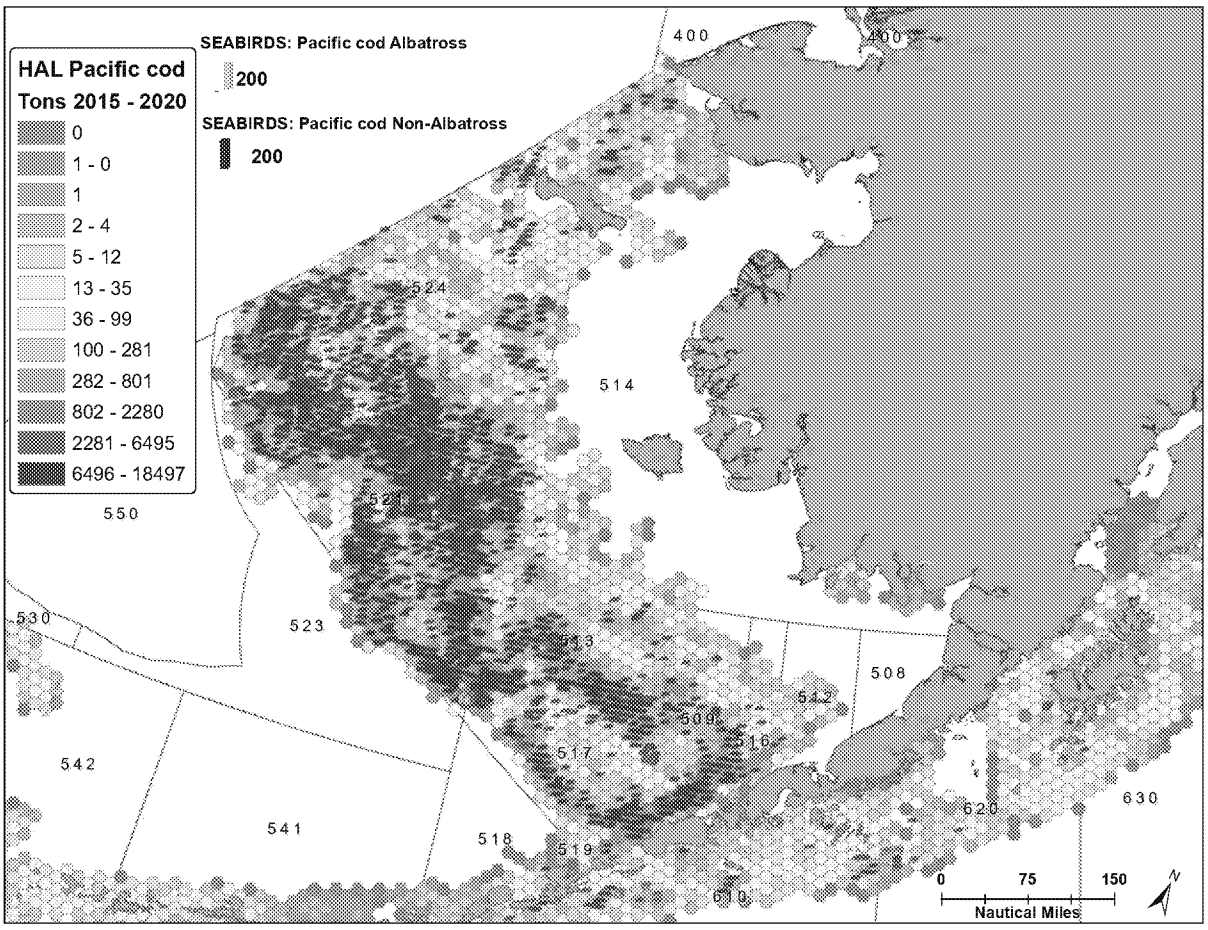

Figure 117: Spatial distribution of observed seabird bycatch from 2015–2020 from the Pacific cod (P. Cod) hook and line fisheries. Colored vertical bars indicate the sum of incidental takes at a location grouped within 1/10 of a degree of latitude and longitude. Incidental takes are separated between takes of albatross and takes of non-albatross seabirds. Figure includes locations of incidental takes of seabirds overlaid on to a heatmap depicting fishing effort. Note the difference of scale of observed takes of seabirds.

Federal fisheries. In Alaska, such disruptions included lost fishing days due to closures and stand-downs (primarily at the beginning of the pandemic) and reduced market prices for fish as restaurants and other buyers were not operating at normal levels and thus were not purchasing as much fish product. Less fishing effort would reduce the opportunities for interactions with seabirds and result in less seabird bycatch. Aside from disruptions associated with the COVID-19 pandemic, there was also a major shift in gear usage in the sablefish IFQ fishery that could partially explain the relatively low seabird bycatch estimates in 2020, however more so in the GOA than EBS. Many vessels in this fishery shifted from using hook-and-line gear to using pot gear. This was primarily done in an attempt to avoid whale depredation on sablefish catch. Take of seabirds by pot gear is relatively rare compared to take of seabirds by hook-and-line gear. If the sablefish IFQ fishery continues to increase its use of pot gear over hook-and-line gear, we would expect to see reduced take of seabirds in this fishery.

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Dietrich and Fitzgerald (2010) found in an analysis of 35,270 longline sets from 2004 to 2007 that the most predominant species, northern fulmar, only occurred in 2.5% of all sets. Albatross, a focal species for conservation efforts, occurred in less than 0.1% of sets. Thus, while annual seabird bycatch estimates number in the 1,000's, given the vast size of the fishery, actual takes of seabird remains relatively uncommon (Krieger and Eich, 2021).

Implications: Estimated seabird bycatch in the Federal fisheries off of Alaska in 2020 decreased dramatically from 2019, and was among the lowest estimate in the 10 year time series. While several unique situations presented themselves in 2020 that may have affected seabird bycatch, they themselves likely do not fully explain the reason for the observed trend.

The first reported interaction between a fishing vessel from the BSAI groundfish fishery with threatened spectacled eider may be a direct result of ecological change in the EBS. Recent changes in ocean temperatures in the BSAI and the resulting ecological response of commercially valuable fish species, mainly Pacific cod, has led to an increase in the amount of fishing vessel traffic in areas near spectacled eider designated critical habitat. NMFS has observed a corresponding northward shift in fishing vessel activity and an increased harvest of Pacific cod, primarily in the northern areas of regulatory zones 514 and 524 from 2016 through 2020. In the analysis completed for the 2021 seabird Biological Opinion (USFWS, 2021), the authors note that compared to the number of fishing vessels present in the northern areas of the Bering Sea in 2015 (the baseline for that analysis), 2016 through 2019 show a substantial increase in the number of vessels, especially north of 61°N (as described in Section 7.9.2). How this fleet response to new ecological conditions will affect other species of seabirds remains to be seen.

However, it can be difficult to determine how seabird bycatch estimates and trends in some fisheries are linked to changes in ecosystem components because seabird mitigation gear is used in the longline fleet. There does appear to be a link between poor ocean conditions and the peak bycatch years, on a species-group basis. Fishermen have noted in some years that the birds appear starved and attack baited longline gear more aggressively. This probably indicates changes in food availability rather than distinct changes in how well the fleet employs mitigation gear. A focused investigation of this aspect of seabird bycatch is needed and could inform management of poor ocean conditions if seabird bycatch rates (reported in real time) were substantially higher than normal.

Maintaining and Restoring Fish Habitats

Area Disturbed by Trawl Fishing Gear in the Eastern Bering Sea

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Last updated: September 2021

Description of indicator: Fishing gear can impact habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. This indicator uses output from the Fishing Effects (FE) model to estimate the area of geological and biological features disturbed over the Bering Sea domain, utilizing spatially-explicit VMS data summarized to 25km^2 grid cells in fishable depths (<1000m). The time series for this indicator is available since 2003, when widespread VMS data became available. In 2021, methods developed by the Alaska Regional Office of NMFS were used to incorporate unobserved fishing events over the entire time series (2003–2021) into FE analysis. Unobserved fishing events typically account for 7-12% of total effort in the VMS data set.

Status and trends: The percent of area disturbed due to commercial fishing interactions (pelagic and non-pelagic trawl, longline, and pot) decreased from about 10% prior to 2008 to approximately 8% currently.

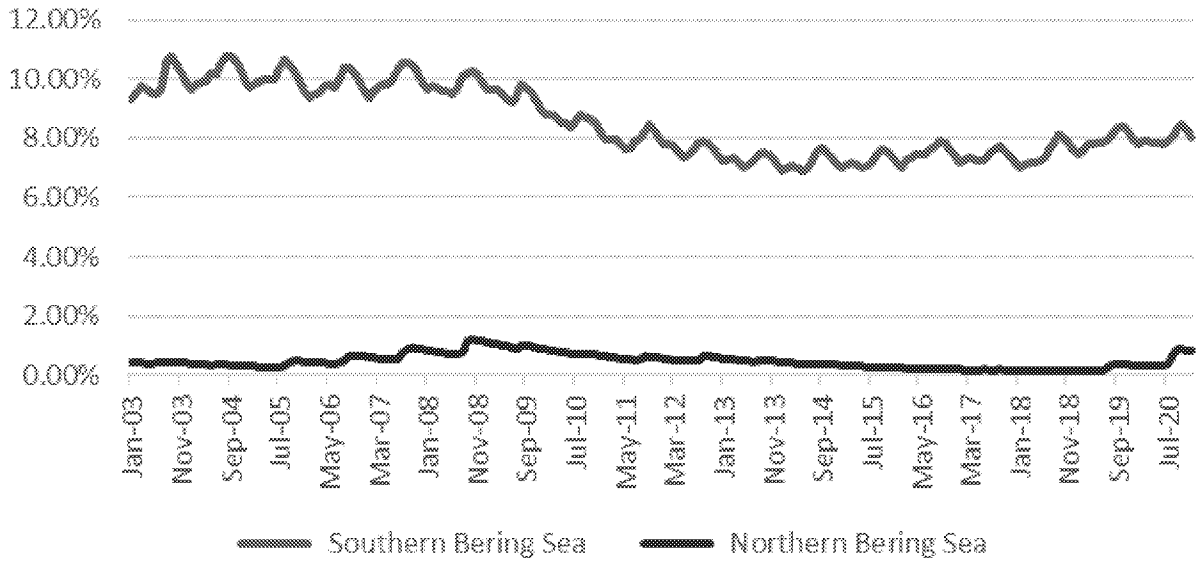

Figure 118: Percent area disturbed by commercial fishing gear, all gear types combined, from 2003 through 2020.

Factors influencing observed trends: Trends in seafloor area disturbed can be affected by numerous variables, such as fish abundance and distribution, management actions (e.g., closed areas), changes in the structure of the fisheries due to rationalization, improved technology (e.g., increased ability to find fish, acoustics to fish near the bottom without contact), markets for fish products, and changes in vessel horsepower and fishing gear. Intensive fishing in an area can result

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in a change in species diversity by attracting opportunistic fish species which feed on animals that have been disturbed by fishing activity, or by reducing the suitability of habitat used by some species. It is possible that increased effort in fisheries that interact with both living and non-living bottom substrates could result in increased habitat loss/degradation due to fishing gear effects. The footprint of habitat damage varies with gear (type, weight, towing speed, depth of penetration), the physical and biological characteristics of the areas fished, recovery rates of living substrates in the areas fished, and management or economic changes that result in spatial redistribution of fishing effort.

Between 2003 and 2008, variability in area disturbed was driven largely by the seasonality of fishing in the Bering Sea, and this pattern continues in 2020 but to a lesser degree. In 2008, Amendment 80 was implemented, which allocated BSAI Yellowfin sole, Flathead sole, Rock sole, Atka mackerel, and Aleutian Islands Pacific ocean perch to the head and gut trawl catcher processor sector, and allowed qualified vessels to form cooperatives. The formation of cooperatives reduced overall effort in the fleet while maintaining catch levels. In 2010, trawl sweep gear modifications were implemented on non-pelagic trawls in the Bering Sea, resulting in less gear contacting the seafloor and less habitat impact.

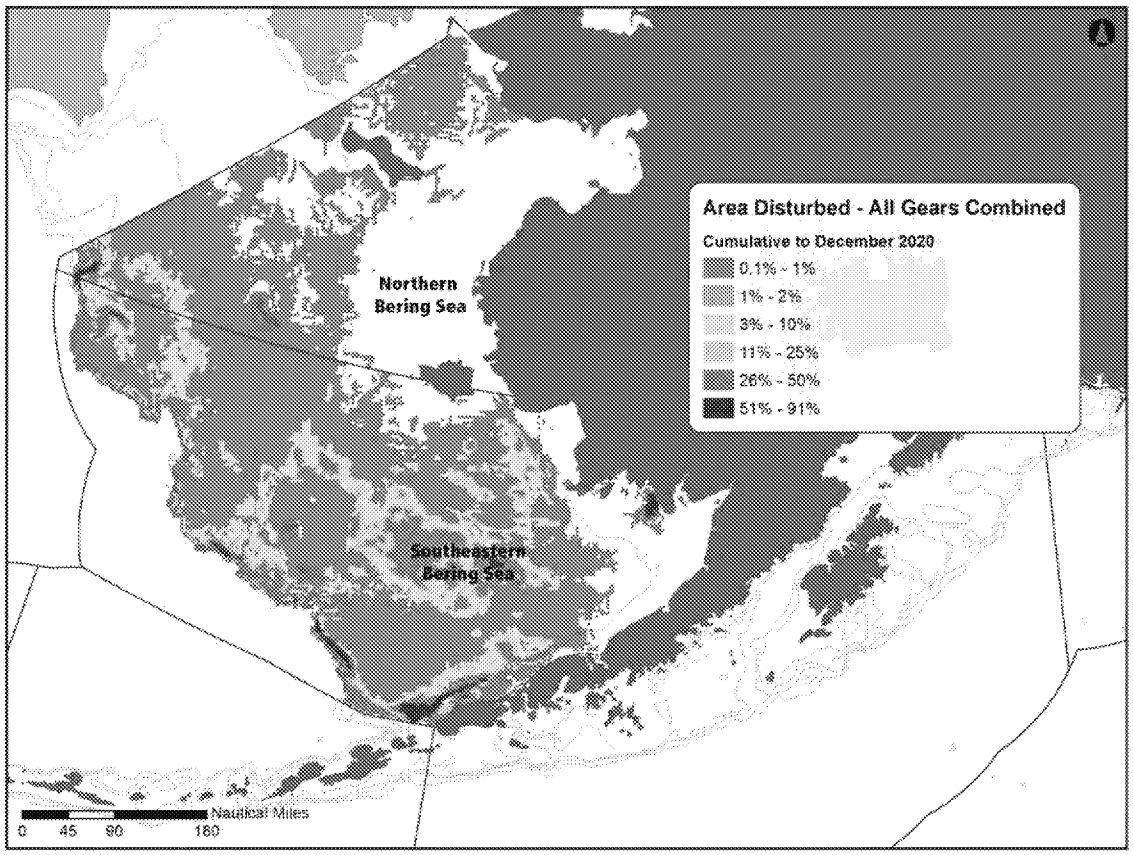

Figure 119: Map of percentage area disturbed per grid cell for all gear types. Effects are cumulative and consider impacts and recovery of features from 2003 to 2020.

Implications: The effects of changes in fishing effort on habitat are difficult to assess, although our ability to quantify those effects has increased greatly with the development of the Fishing Effects model as a part of the 2017 EFH 5-year Review[23]. The 2005 EFH FEIS and 2010 EFH 5-year Review concluded that commercial fisheries can have long term effects on habitat; however, those impacts were determined to be minimal and not detrimental to fish populations or their habitats. These previous EFH analyses indicated the need for an improved fishing effects assessment methodology. With the development and implementation of the FE model, many of the shortcomings of previous fishing effects methods were addressed. Vessel Monitoring System data provides a much more detailed treatment of fishing intensity, allowing better assessments of the effects of overlapping effort and distribution of effort between and within grid cells. The development of literature-derived fishing effects database has increased our ability to estimate gear-specific susceptibility and recovery parameters. The distribution of habitat types, derived from increased sediment data availability, has improved. The combination of these parameters has greatly enhanced our ability to estimate fishing impacts.

New methods and criteria were developed to evaluate whether the effects of fishing on EFH are more than minimal and not temporary on managed fish stocks in Alaska. These criteria were developed and reviewed by the Council and its advisory committees in 2016, and stock assessment authors in 2017. In April 2017, the Council concurred with the Plan Team consensus that the effects of fishing on EFH do not currently meet the threshold of more than minimal and not temporary, and mitigation action is not needed at this time.

Although the impacts of fishing across the domain are very low, it is possible that localized impacts may be occurring. The issue of local impacts is an area of active research.

Areas Closed to Bottom Trawling in the BSAI and GOA

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Last updated: September 2021

Description of indicator: Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Figure 120, Table 5). Some of the trawl closures are in effect year-round while others are seasonal. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat or vulnerable species life stages. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high.

Status and trends: Additional measures to protect the declining western stocks of the Steller sea lion began in 1991 with some simple restrictions based on rookery and haulout locations; in 2000 and 2001 more specific fishery restrictions were implemented. In 2001, over 90,000 nm^2 of the Exclusive Economic Zone (EEZ) of Alaska was closed to trawling year-round. Additionally, 40,000 nm^2 were closed on a seasonal basis. State waters (0-3 nmi) are also closed to bottom trawling in many areas. A motion passed the North Pacific Management Council in February 2009 which

[23] ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/TM_NMFS_AFKR/TM_NMFS_FAKR_15.pdf

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closed all waters north of the Bering Strait to commercial fishing as part of the development of an Arctic Fishery management plan. This additional closure added 148,300 nm^2 to the area closed year-round to bottom trawling.

Implications: With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling. For additional background on fishery closures in the U.S. EEZ off Alaska, see Witherell and Woodby (2005).

Steller Sea Lion closure maps are available on NOAA Fisheries[24].

[24] https://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones

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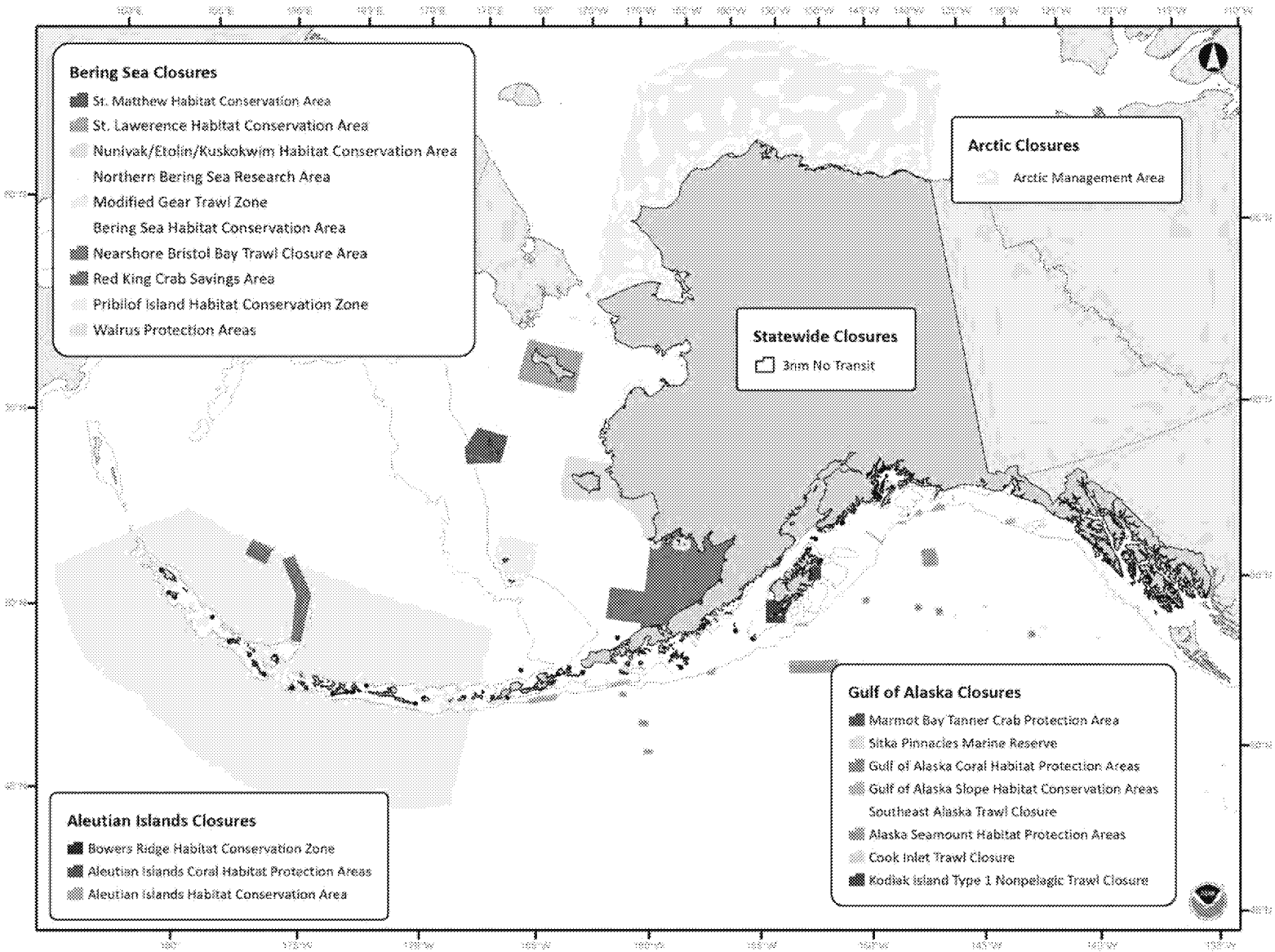

Figure 120: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

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Table 5: Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2020. LLP = License Limitation Program; HCA = Habitat Conservation Area; HCZ = Habitat Conservation Zone.

Area	Year	Location	Season	Area size	Notes
BSAI	1995	Area 512	Year-round	8,000 nm^2	Closure in place since 1987
		Area 516	3/15-6/15	4,000 nm^2	Closure in place since 1987
		Chum Salmon Savings Area	8/1-8/31	5,000 nm^2	Re-closed at 42,000 chum salmon
		Chinook Salmon Savings Area	Trigger	9,000 nm^2	Closed at 48,000 Chinook salmon
		Herring Savings Area	Trigger	30,000 nm^2	Trigger closure
		Zone 1	Trigger	30,000 nm^2	Trigger closure
		Zone 2	Trigger	50,000 nm^2	Trigger closure
		Pribilofs HCA	Year-round	7,000 nm^2	
		Red King Crab Savings Area	Year-round	4,000 nm^2	Pelagic trawling allowed
		Walrus Islands	5/1-9/30	900 nm^2	12 mile no-fishing zones
		SSL Rookeries	Seasonal ext.	5,100 nm^2	20 mile extensions at 8 rookeries
	1996	Nearshore Bristol Bay Trawl Closure	Year-round	19,000 nm^2	Expanded area 512 closure
		C. opilio bycatch limitation zone	Trigger	90,000 nm^2	Trigger closure
	2000	Steller Sea Lion protections			
		Pollock haulout trawl exclusion zones for EBS, AI * areas include GOA	* No trawl all year	11,900 nm^2	
			No trawl (Jan–Jun)*	14,800 nm^2	
			No Trawl Atka Mackerel restrictions	29,000 nm^2	
	2006	Essential Fish Habitat			
		AI Habitat Conservation Area	No bottom trawl all year	279,114 nm^2	
		AI Coral Habitat Protection Areas	No bottom contact gear all year	110 nm^2	
		Bowers Ridge Habitat Conservation Zone	No mobile bottom tending fishing gear	5,286 nm^2	
	2008	Northern Bering Sea Research Area	No bottom trawl all year	66,000 nm^2	
		Bering Sea HCA	No bottom trawl all year	47,100 nm^2	
		St. Matthews HCA	No bottom trawl all year	4,000 nm^2	
		St. Lawrence HCA	No bottom trawl all year	7,000 nm^2	
		Nunivak/Kuskokwim Closure Area	No bottom trawl all year	9,700 nm^2	
Arctic	2009	Arctic Closure Area	No Commercial Fishing	148,393 nm^2	
GOA	1995	Kodiak King Crab Protection Zone Type 1	Year-round	1,000 nm^2	Red king crab closures, 1987
		Kodiak King Crab Protection Zone Type 2	2/15-6/15	500 nm^2	Red king crab closures, 1987
		SSL Rookeries	Year-round	3,000 nm^2	10 mile no-trawl zones
	1998	Southeast Trawl Closure	Year-round	52,600 nm^2	Adopted as part of the LLP
		Sitka Pinnacles Marine reserve	Year-round	3.1 nm^2	
	2000	Pollock haulout trawl exclusion zones for GOA* areas include EBS, AI	No trawl all year	11,900 nm^2*	
			No trawl (Jan–Jun)	14,800 nm^2	
	2006	Essential Fish Habitat			
		GOA Slope Habitat Conservation Area	No bottom trawl all year	2,100 nm^2	
		GOA Coral Habitat Protection Measures	No bottom tending gear all year	13.5 nm^2	
		Alaska Seamount Habitat Protection Measures	No bottom tending gear all year	5,329 nm^2	
	2010	Marmot Bay Tanner Crab Protection Area	No bottom trawl all year	112 nm^2	

Sustainability (for consumptive and non-consumptive uses)

Fish Stock Sustainability Index – Bering Sea and Aleutian Islands

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Last updated: July 2021

Description of indicator: The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of fish stocks selected for their importance to commercial and recreational fisheries[25]. The FSSI will increase as overfishing is ended and stocks rebuild to the level that provides maximum sustainable yield. The FSSI is calculated by awarding points for each fish stock based on the following rules:

1. Stock has known status determinations:
   (a) overfishing level is defined = 0.5
   (b) overfished biomass level is defined = 0.5
2. Fishing mortality rate is below the "overfishing" level defined for the stock = 1.0
3. Biomass is above the "overfished" level defined for the stock = 1.0
4. Biomass is at or above 80% of the biomass that produces maximum sustainable yield (B_{MSY}) = 1.0 (this point is in addition to the point awarded for being above the "overfished" level)

The maximum score for each stock is 4.

In the Alaska Region, there are 35 FSSI stocks and an overall FSSI of 140 would be achieved if every stock scored the maximum value, 4. Over time, the number of stocks included in the FSSI has changed as stocks have been added and removed from Fishery Management Plans (FMPs). To keep FSSI scores for Alaska comparable across years we report the FSSI as a percentage of the maximum possible score (i.e., 100%).

The list of stocks included in the FSSI was revised in 2020 to focus on stocks of heightened commercial and recreational importance[26]. In the BSAI, the Pribilof Islands blue king crab, Saint Matthew Island blue king crab, Pribilof Islands red king crab, and the black-spotted/rougheye rockfish stocks were removed from the FSSI and added to the group of non-FSSI stocks. The BSAI stock of Kamchatka flounder, the AI Pacific cod stock, and the Bogoslof stock of walleye pollock were added to the BSAI FSSI. These changes resulted in a net reduction from 22 to 21 FSSI stocks in the BSAI. With few exceptions, groundfish species (or species complex) in the BSAI are managed as single stocks and not separately for the Bering Sea and Aleutian Islands. As such, the FSSI scores are reported for the BSAI as a whole.

[25] https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates
[26] https://www.fisheries.noaa.gov/national/population-assessments/status-us-fisheries#fish-stock-sustainability-index

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Table 6: Summary of status for the 21 FSSI stocks in the BSAI, updated through June 2021.

BSAI FSSI (21 stocks)	Yes	No	*Unknown*	*Undefined*	N/A
Overfishing	0	21	0	0	0
Overfished	0	19	2	0	0
Approaching Overfished Condition	0	19	2	0	0

Additionally, there are 28 non-FSSI stocks in Alaska, three ecosystem component species complexes, and Pacific halibut which are managed under an international agreement. Two of the non-FSSI crab stocks are overfished but are not subject to overfishing. The Pribilof Islands blue king crab stock is in year seven of a rebuilding plan, and the Saint Matthews Island blue king crab stock is in year one of a 26-year rebuilding plan. None of the other non-FSSI stocks are known to be subject to overfishing, are overfished, or are approaching an overfished condition. For more information on non-FSSI stocks see the Status of U.S. Fisheries webpage (`https://www.fisheries.noaa.gov/national/population-assessments/status-us-fisheries`).

Status and trends: The overall Alaska FSSI generally trended upwards from 80% in 2006 to a high of 94% in 2018 (Figure 121). The FSSI decreased in 2019 and 2020 to 88.9% but increased in 2021 to 89.6%.

As of June 30, 2021, no BSAI groundfish stock or stock complex is subject to overfishing, is known to be overfished, or known to be approaching an overfished condition (Table 6). The BSAI groundfish FSSI score is 59 out of a maximum possible 64. The AI Pacific cod stock and the walleye pollock Bogoslof stock both have FSSI scores of 1.5 due to not having known overfished status or known biomass relative to their overfished levels or to B_{MSY}. All other BSAI groundfish FSSI stocks received the maximum possible score of four points.

The BSAI king and tanner crab FSSI is 19 out of a possible 20. One point was deducted for the Bristol Bay red king crab stock's biomass decreasing to below the B/B_{MSY} threshold.

The overall BSAI FSSI score is 78 out of a maximum possible score of 84 (Table 7) and has generally trended upward from 74% in 2006 to 93% in 2021 (Figure 122).

Factors influencing observed trends: The overall trend in Alaska FSSI has been positive over the duration examined here (2006–2021). The one point increase in the overall score from 2020 to 2021 was due to an increase in the biomass of sablefish above 80% of B_{MSY}. One point was lost for the Bristol Bay red king crab stock biomass dropping to below 80% B_{MSY}. However, one point was gained for the biomass of the Norton Sound red king crab stock increasing to above 80% of B_{MSY}.

Implications: The majority of Alaska groundfish and crab fisheries appear to be sustainably managed. None of the FSSI stocks in the BSAI are subject to overfishing or known to be overfished.

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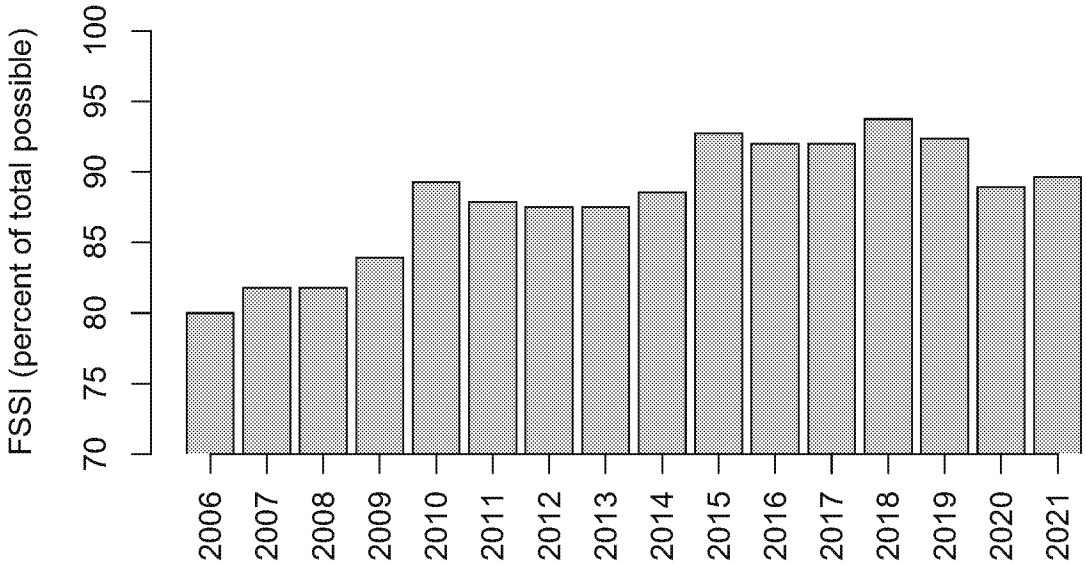

Figure 121: The trend in overall Alaska FSSI from 2006 through 2021 as a percentage of the maximum possible FSSI. The maximum possible FSSI is 140 from 2006 to 2014, 144 from 2015 to 2019, and 140 in 2020 and 2021. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

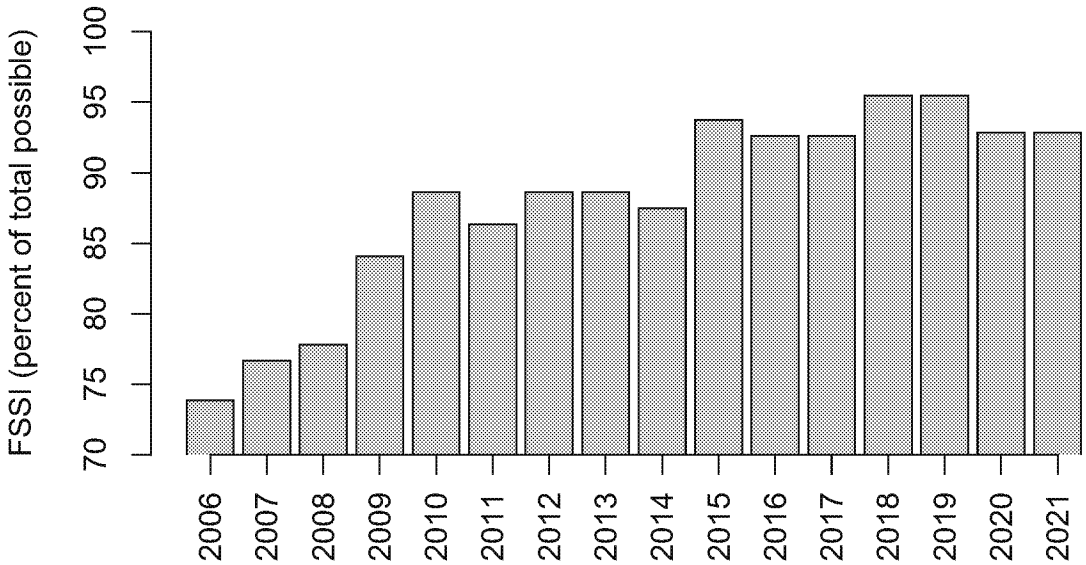

Figure 122: The trend in BSAI FSSI from 2006 through 2021 as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

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Table 7: BSAI FSSI stocks under NPFMC jurisdiction updated through June 2021 adapted from the NOAA Fishery Stock Status Updates webpage: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`. *See FSSI and Non-FSSI Stock Status Table on the Fishery Stock Status Updates webpage for definition of stocks and stock complexes.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/B_{MSY}	FSSI Score
Golden king crab - Aleutian Islands*	No	No	No	N/A	N/A	1.55/1.11	4
Red king crab - Bristol Bay	No	No	No	N/A	N/A	0.76	3
Red king crab - Norton Sound	No	No	No	N/A	N/A	0.80	4
Snow crab - Bering Sea	No	No	No	N/A	N/A	1.33	4
Southern Tanner crab - Bering Sea	No	No	No	N/A	N/A	0.96	4
BSAI Alaska plaice	No	No	No	N/A	N/A	1.84	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.24	4
BSAI Arrowtooth Flounder	No	No	No	N/A	N/A	2.35	4
BSAI Kamchatka flounder	No	No	No	N/A	N/A	1.4	4
BSAI Flathead Sole Complex*	No	No	No	N/A	N/A	2.08	4
BSAI Rock Sole Complex*	No	No	No	N/A	N/A	2.47	4
BSAI Skate Complex*	No	No	No	N/A	N/A	1.7	4
BSAI Greenland halibut	No	No	No	N/A	N/A	1.59	4
BSAI Northern rockfish	No	No	No	N/A	N/A	1.89	4
BS Pacific cod	No	No	No	N/A	N/A	1.32	4
AI Pacific cod	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.81	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	1.26	4
Walleye pollock - Bogoslof	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.56	4
BSAI Yellowfin sole	No	No	No	N/A	N/A	1.86	4

Total Annual Surplus Production of Groundfish and Crab

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Last updated: August 2021

Description of indicator: Total annual surplus production (ASP) of 17 groundfish and crab stocks on the eastern Bering Sea (EBS) shelf from 1979–2017 was estimated by summing annual production across major commercial stocks for which assessment data were available over this time period from NOAA Fisheries (2021) (Table 8). Annual surplus production in year t can be estimated as the change in total adult biomass across species from year t(B_t) to year t+1 (B_{t+1}) plus total catches in year t(C_t):

$$ASP_t = \Delta B_t + C_t = B_{t+1} - B_t + C_t$$

All estimates of B and C are based on the most recent stock assessments. An index of total exploitation rate within each region was obtained by dividing the total catch across the major commercial species by the estimated combined biomass at the beginning of the year:

$$u_t = \mathrm{C}_t \ / \ \mathrm{B}_t$$

Table 8: Species included in computing annual surplus production in the BSAI management area. Data retrieved from NOAA Fisheries on September 24, 2020 (`www.st.nmfs.noaa.gov/stocksmart`).

Stock (BSAI unless otherwise indicated)
EBS walleye pollock (*Gadus chalcogrammus*)
AI walleye pollock (*Gadus chalcogrammus*)
EBS Pacific cod (*Gadus macrocephalus*)
Yellowfin sole (*Limanda aspera*)
Arrowtooth flounder (*Atheresthes stomias*)
Greenland turbot (*Reinhardtius hippoglossoides*)
Flathead sole (*Hippoglossoides elassodon*)
Northern rock sole (*Lepidopsetta polyxystra*)
Alaska plaice (*Pleuronectes quadrituberculatus*)
Pacific Ocean Perch (*Sebastes alutus*)
Northern rockfish (*Sebastes polyspinus*)
Rougheye/Blackspotted rockfish (*Sebastes aleutianus*, *S. melanostictus*)
Atka mackerel (*Pleurogrammus monopterygius*)
Bristol Bay, Pribilof Islands, and Norton Sound Red King crab (*Paralithodes platypus*)
Pribilof Islands Blue King Crab (*Paralithodes camtschaticus*)

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Status and trends: The resulting indices suggest high variability in production in the eastern Bering Sea with multi-year periods of below- and above-average surplus production. ASP was lowest in the late 1980s, mid-1990s, from 2004–2007, and in 2017. Total exploitation rates (catch/mature biomass) for the combined species ranged from 9.5–24.7% (Figure 123). Overall exploitation rates were highest following periods of low surplus production in the late 1980s and mid-2000s. Trends in annual surplus production in the eastern Bering Sea are largely driven by variability in Walleye pollock (Figure 124). Therefore, ASP for the Bering Sea was also computed after excluding Walleye pollock (Figure 125). The results suggest variable aggregate surplus production of all non-pollock species ranging from a high of more than 800,000 tons in 1980, due to strong recruitment of a number of species, to a low of less than 300,000 t in the late 2000s. Annual non-pollock surplus production has decreased on average over the full time period, although the trend was not significant (p=0.20) and showed large periodic fluctuations. Besides Walleye pollock, stocks that contribute most to mean surplus production, and to its variability (not shown), include Pacific cod and Yellowfin sole, with neither species dominating the trends in Figure 125.

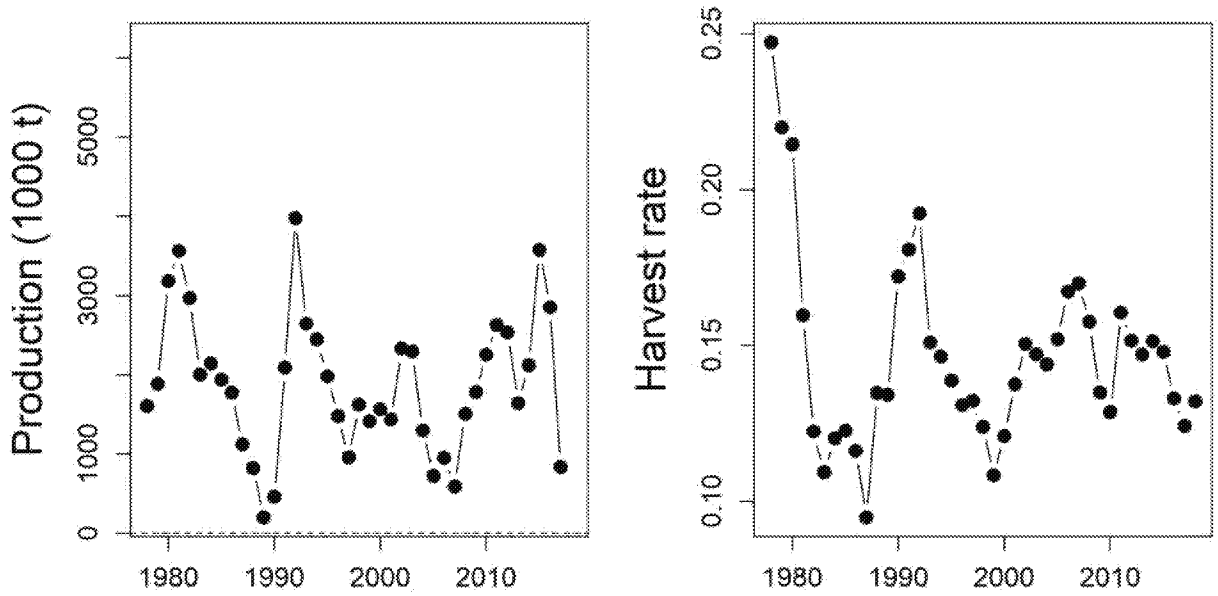

Figure 123: Total annual surplus production (change in biomass plus catch) across all major groundfish and crab stocks in the Bering Sea/Aleutian Islands (left) and total harvest rate (total catch/beginning-of-year biomass, each summed across the major stocks in Table 8).

Factors influencing observed trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e., mortality from all non-fishery sources) during a given year. It is highest during periods of increasing total biomass and lowest during periods of decreasing biomass (e.g., 2004–2007). In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Theory suggests that surplus production of a population will decrease as biomass increases much above B_{MSY}, which is the case for many species in the BSAI management area. Exploitation rates are primarily determined by management and reflect a relatively precautionary management regime with rates that have averaged about 15% of adult (mature) biomass for the species in Table 8 combined.

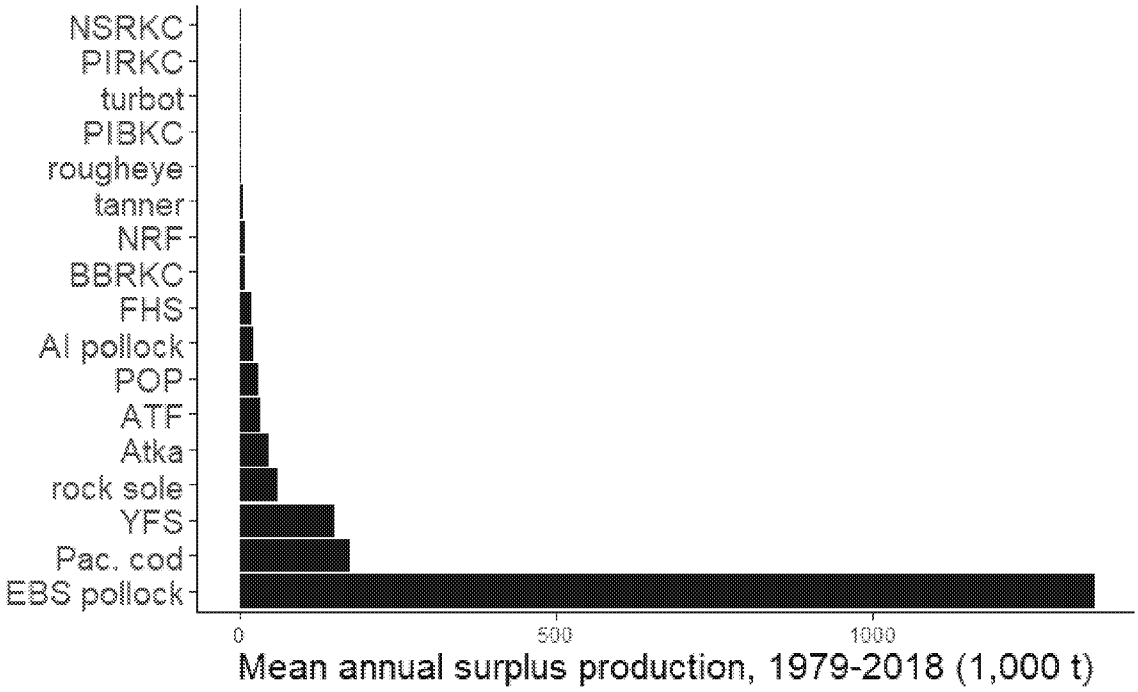

Figure 124: Contributions of each stock to mean annual surplus production.

Implications: Under certain assumptions, aggregate surplus production can provide an estimate of the long-term maximum sustainable yield of these groundfish complexes (Mueter and Megrey (2006), Figure 126). Although there is relatively little contrast in total biomass over time, it appears that biomass was generally above the level that would be expected to yield maximum surplus production under a Graham-Schaefer model fit to aggregate ASP (Figure 126). The estimated maximum sustainable yield for the complex encompassing the 17 stocks in Table 8 was close to 2.0 million tons.

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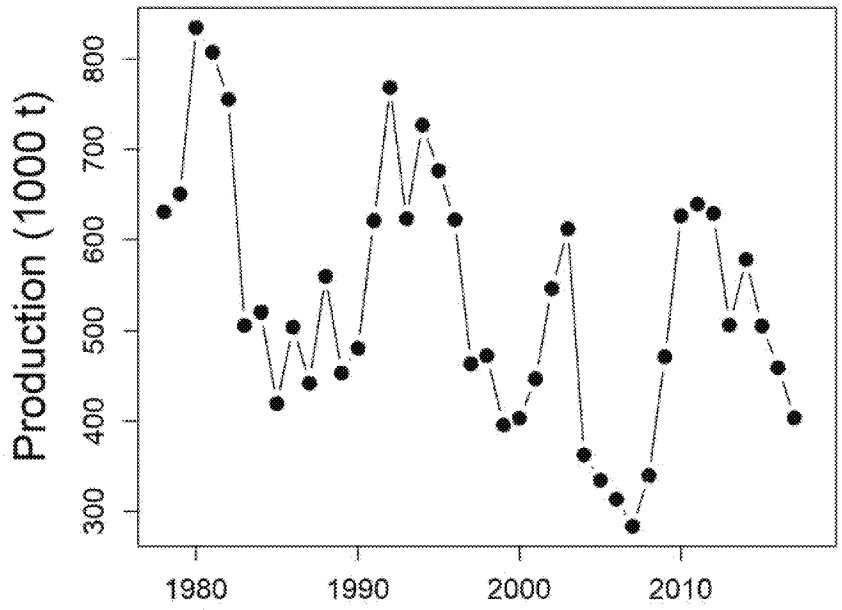

Figure 125: Total annual surplus production (change in biomass plus catch) in the Bering Sea across the major commercial stocks in Table 8, excluding Walleye pollock.

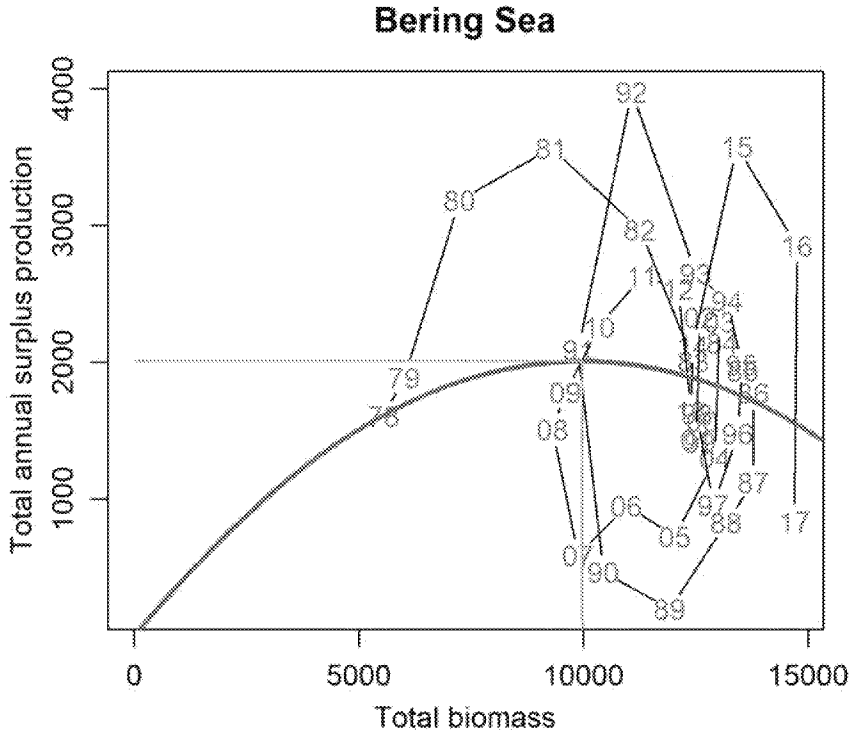

Figure 126: Estimated annual aggregated surplus production against total biomass of major commercial species with fitted Graham-Schaefer curve. Units on both axes are in 1000 t.

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Appendix

History of the ESRs

Since 1995, staff at the Alaska Fisheries Science Center have prepared a separate Ecosystem Status (formerly Considerations) Report within the annual Stock Assessment and Fishery Evaluation (SAFE) report. Each new Ecosystem Status Report provides updates and new information to supplement the original report. The original 1995 report presented a compendium of general information on the Gulf of Alaska, Bering Sea, and Aleutian Island ecosystems as well as a general discussion of ecosystem-based management. The 1996 edition provided additional information on biological features of the North Pacific, and highlighted the effects of bycatch and discards on the ecosystem. The 1997 edition provided a review of ecosystem-based management literature and ongoing ecosystem research, and provided supplemental information on seabirds and marine mammals. The 1998 edition provided information on the precautionary approach, essential fish habitat, effects of fishing gear on habitat, El Niño, local knowledge, and other ecosystem information. The 1999 edition again gave updates on new trends in ecosystem-based management, essential fish habitat, research on effects of fishing gear on seafloor habitat, marine protected areas, seabirds and marine mammals, oceanographic changes in 1997/98, and local knowledge.

In 1999, a proposal came forward to enhance the Ecosystem Status Report by including more information on indicators of ecosystem status and trends and more ecosystem-based management performance measures. The purpose of this enhancement was to accomplish several goals:

1. Track ecosystem-based management efforts and their efficacy
2. Track changes in the ecosystem that are not easily incorporated into single-species assessments
3. Bring results from ecosystem research efforts to the attention of stock assessment scientists and fishery managers
4. Provide a stronger link between ecosystem research and fishery management
5. Provide an assessment of the past, present, and future role of climate and humans in influencing ecosystem status and trends

Each year since 1999, the Ecosystem Status Reports have included some new contributions and will continue to evolve as new information becomes available. Evaluation of the meaning of observed changes should be in the context of how each indicator relates to a particular ecosystem component.

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For example, particular oceanographic conditions, such as bottom temperature increases, might be favorable to some species but not for others. Evaluations should follow an analysis framework such as that provided in the draft Programmatic Groundfish Fishery Environmental Impact Statement that links indicators to particular effects on ecosystem components.

In 2002, stock assessment scientists began using indicators contained in this report to systematically assess ecosystem factors such as climate, predators, prey, and habitat that might affect a particular stock. Information regarding a particular fishery's catch, bycatch, and temporal/spatial distribution can be used to assess possible impacts of that fishery on the ecosystem. Indicators of concern can be highlighted within each assessment and can be used by the Groundfish Plan Teams and the Council to justify modification of allowable biological catch (ABC) recommendations or time/space allocations of catch.

We initiated a regional approach to the ESR in 2010 and presented a new ecosystem assessment for the eastern Bering Sea. In 2011, we followed the same approach and presented a new assessment for the Aleutian Islands based on a similar format to that of the eastern Bering Sea. In 2012, we provided a preliminary ecosystem assessment on the Arctic. Our intent was to provide an overview of general Arctic ecosystem information that may form the basis for more comprehensive future Arctic ecosystem assessments. In 2015, we presented a new Gulf of Alaska report card and assessment, which was further divided into Western and Eastern Gulf of Alaska report cards beginning in 2016. This was also the year that the previous Alaska-wide ESR was split into four separate report, one for the Gulf of Alaska, Aleutian Islands, eastern Bering Sea, and the Arctic[27].

The eastern Bering Sea and Aleutian Islands ecosystem assessments were based on additional refinements contributed by Ecosystem Synthesis Teams. For these assessments, the teams focused on a subset of broad, community-level indicators to determine the current state and likely future trends of ecosystem productivity in the EBS and ecosystem variability in the Aleutian Islands. The teams also selected indicators that reflect trends in non-fishery apex predators and maintaining a sustainable species mix in the harvest as well as changes to catch diversity and variability. Indicators for the Gulf of Alaska report card and assessment were also selected by a team of experts, via an online survey first, then refined in an in-person workshop.

Originally, contributors to the Ecosystem Status Reports were asked to provide a description of their contributed indicator, summarize the historical trends and current status of the indicator, and identify potential factors causing those trends. Beginning in 2009, contributors were also asked to describe why the indicator is important to groundfish fishery management and implications of indicator trends. In particular, contributors were asked to briefly address implications or impacts of the observed trends on the ecosystem or ecosystem components, what the trends mean and why are they important, and how the information can be used to inform groundfish management decisions. Answers to these types of questions will help provide a "heads-up" for developing management responses and research priorities. In 2018, a risk table framework was developed for individual stock assessments as a means of documenting concerns external to the stock assessment model, but relevant to setting the Acceptable Biological Catch (ABC) value. These concerns could be categorized as those reflecting the assessment model, the population dynamics of the stock, and environmental and ecosystem concerns—including those based on information from Ecosystem Status Reports. In the past, concerns used to justify an ABC below the maximum calculated by the assessment model were documented in an ad hoc manner in the stock assessment report

[27] The Arctic report is under development

or in the minutes of the groundfish Plan Teams or Scientific and Statistical Committee reviews. With the risk table, formal consideration of concerns—including ecosystem—are documented and ranked, and the stock assessment author presents a recommendation for the maximum ABC or a value lower. Five risk tables were completed in 2018 as a test case. After review, the Council requested risk tables to be included in all stock assessments in 2019.

In Briefs were started in 2018 for the Eastern Bering Sea, 2019 for the Gulf of Alaska, and 2020 for the Aleutian Islands. These more public-friendly succinct versions of the full ESRs are now planned to be produced in tandem with the ESRs.

In 2019, risk tables were completed for all full assessments. Ecosystem scientists collaborated with stock assessment scientists to use the Ecosystem Status Reports to help inform the ecosystem concerns in the risk tables.

Ecosystem and Socioeconomic Profiles (ESPs) were initiated in 2017 (Sablefish) and ESR editors began working closely with ESP teams in 2019 (starting with GOA walleye pollock). These complimentary annual status reports inform groundfish management and alignment in research that feeds these reports increases efficiency and collaboration between ecosystem and stock assessment scientists.

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 127). The primary stakeholders in this case are the North Pacific Fishery Management Council. Research and development of risk analyses and management strategies is ongoing and will be referenced or included as possible.

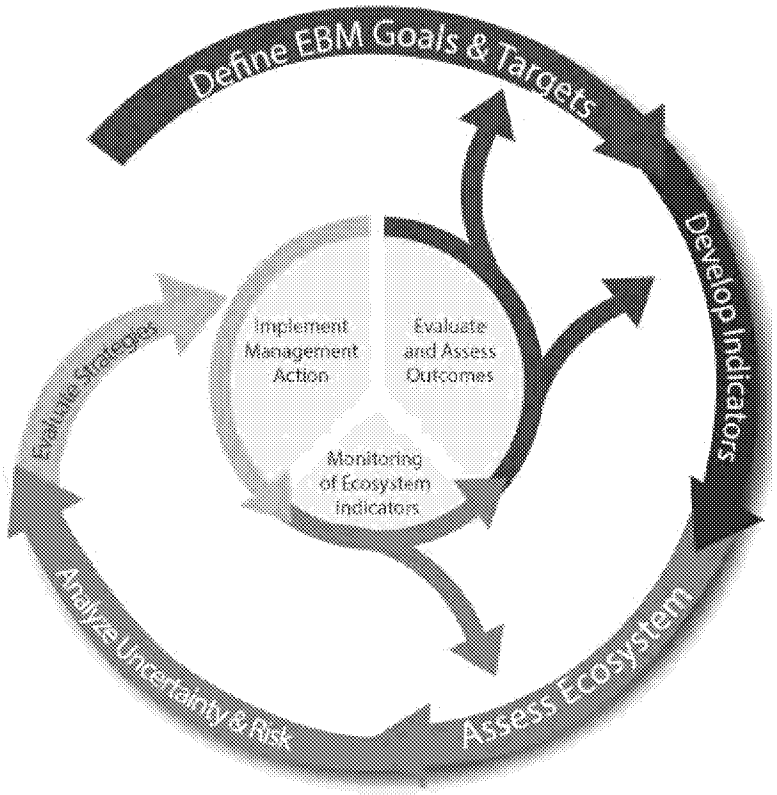

Figure 127: The IEA (integrated ecosystem assessment) process.

It was requested that contributors to the Ecosystem Status Reports provide actual time series data or make them available electronically. The Ecosystem Status Reports and data for many of the time series presented within are available online at: `http://access.afsc.noaa.gov/reem/ecoweb/`. These reports and data are also available through the NOAA-wide IEA website at: `https://www.integratedecosystemassessment.noaa.gov/regions/alaska`.

Past reports and all groundfish stock assessments are available at: `https://www.fisheries.noaa.gov/alaska/population-assessments/north-pacific-groundfish-stock-assessment-and-fishery-evaluation`.

If you wish to obtain a copy of an Ecosystem Considerations Report version prior to 2000, please contact the Council office (907) 271-2809.

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Responses to SSC comments from October and December 2020 and October 2021

October 2020: C-1/C-2 Ecosystem Status Report Preview

The SSC received a preview of the Ecosystem Status Reports (ESR) on the Gulf of Alaska (GOA) by Bridgett Ferriss (NOAA-AFSC), the Aleutian Islands (AI) by Yvonne Ortiz (NOAA-AFSC), and the eastern Bering Sea (EBS) by Elizabeth Siddon (NOAA-AFSC). There was no public testimony. The SSC greatly appreciates the clear and informative presentations, which were all the more impressive given the restrictions on data gathering and in-person meetings due to the COVID-19 pandemic.

One issue, common to all three areas, was the lack of surveys and a significant loss in related environmental data. *This issue was least acute in the GOA, as 2020 was a year in which bottom trawl surveys were not scheduled to occur. The problem was most acute in the AI region, as there has not been a bottom trawl survey in three years. Missing too were the zooplankton surveys in the GOA and the EBS. In some cases, these losses were in part mitigated by data from partner organizations, but in others, there was no way to make up for the missing data.*

A second issue common to two of the three areas was the continued presence of elevated SSTs. *These concerns were moderate in the SE Bering Sea, especially in autumn 2019 and summer 2020, and most severe in summer 2020 in the GOA, where temperatures periodically exceeded the Hobday heatwave threshold. There were no data on sub-surface temperatures in the AI or the EBS, but ROMS model estimates were presented. In the GOA, sub-surface temperatures were sufficiently elevated to raise concerns about their effects on larval and juvenile fish.*

Southeastern Bering Sea Report

There was almost no collection of fishery-independent data on either commercially important fish stocks, or environmental data that might have been used to indicate probable year-class strength, or fish distribution. Remote-sensing data on sea-ice cover was available and, for 2020, it appears that ice cover was about average in aerial extent, though perhaps thinner than usual for an average year, and with an early retreat in mid-March. It is unclear how well this thin ice and early retreat will support the 2020 year-classes of pollock and Pacific cod. Reduced levels of chlorophyll-a concentrations (an estimate of phytoplankton biomass), typical of the last five years, may affect fish recruitment, though the connections are not well established. ***The SSC suggested that the authors examine indices of region-wide chlorophyll-a rather than focusing solely on the middle shelf.*** *The unexplained mortality event (UME) of grey whale die-offs continued in 2020. The SSC raised questions as to whether the beaching of grey whales was confined to the Bering Sea.* ***There were apparently beachings of these whales quite far south along the west coast of the United States, and the SSC requested that more information on this topic be provided in the December ESR.*** *If starvation is found to be the most likely cause, it may indicate that the whales have reached or exceeded the carrying capacity of their foraging grounds under current environmental conditions in the northern Bering and Chukchi seas.*

In the full 2020 Ecosystem Status Report, and in the December 2020 presentation to the SSC, a complete suite of chlorophyll-a information was provided. This included time series of chlorophyll-a biomass for 8 regions over the southeastern and northern shelf and time series of bloom timing for 3 regions over the southeastern shelf (bloom timing cannot be determined in the northern portion of the shelf due to sea ice coverage in early spring).

We were unable to acquire additional information on specific causes of gray whale mortalities connected to the UME. When possible, trained and authorized members of the NMFS Alaska Marine Mammal Stranding Network respond and collect life history data and samples as part of a partial or full necropsy; those efforts have been greatly curtailed during the on-going COVID-19 pandemic.

Considerable time was devoted to new modeling of ocean acidification and the spatial distribution of aragonite concentrations over the eastern Bering Sea shelf. From 15 July through August 2020, waters over the outer shelf were likely corrosive. ***The SSC requested that there be an effort to model aragonite concentrations at those times of year and locations where commercially important species of crabs would be most vulnerable and to compare these estimates to threshold levels for deleterious effects for Bristol Bay Red King crab, northern rock sole, and pteropods.***

In the full 2020 Ecosystem Status Report, a "Noteworthy" contribution on Ocean Acidification information available from the ROMS model was presented. The contribution highlighted the type of information that is available to researchers and stock assessment authors and can be tailored, both spatially and temporally, to stock-specific vulnerabilities or known thresholds.

In addition to the "In Brief" handouts developed by ESR authors for public outreach, the ESR authors have been preparing other public outreach materials. Story Maps were developed for the 2019 ESRs and will be produced for the 2020 ESRs, and educational outreach videos based on the ESRs are planned for 2020 to enable additional public engagement. The SSC was pleased to hear how the outreach efforts are being expanded and looks forward to hearing updates on their progress. ***The SSC also recommends that the ESR authors pursue the systematic and consistent incorporation of local knowledge (LK) and traditional knowledge (TK) as relevant to ecosystem status updates and reports.*** *This would be beneficial in the short-term for the identification of potential ecosystem "red flags" especially in a time when researchers do not have timely access to the typical full suite of survey data and over the long-term as the Council moves toward a greater focus on ecosystem-based management. The SSC recognizes that the systematic, methodologically sound, and culturally appropriate collection of all forms of LK and TK is beyond the purview of ESR authors, but sees the benefits of ESR use of these types of data as one more reason for moving forward in building relationships and exploring partnerships with the fishing industry, coastal communities, and regional entities, including tribal entities, in a coordinated manner with ESP authors, SAFE authors, and the Bering Sea LK/TK/Subsistence Task Force, among others.*

The ESR editors agree wholeheartedly in continuing to explore partnerships with the fishing industry, coastal communities, and regional entities, including tribal entities. Such partners have pertinent and relevant knowledge to inform the ESRs, both to help identify "red flags" and provide perspective and context to ecosystem trends. We continue to explore and invite partners to contribute to the ESRs while also awaiting advice on the systematic and consistent incorporation of local knowledge (LK) and traditional knowledge (TK) through the Bering Sea LK/TK/Subsistence Task Force.

The authors questioned the SSC as to whether the SSC would like to continue the practice of having brief ecosystem status updates at the October Council meeting. ***The SSC expressed appreciation for these valuable reports and requested that they be continued annually****, even if there is no pending crisis.*

The ESR authors will continue to provide brief ecosystem status updates at October Council meetings.

December 2020: C-3 BSAI and C-4 GOA Ecosystem Status Reports
The SSC received a review of the marine ecosystems of the Bering Sea (BS) from Elizabeth Siddon (NOAA-AFSC), the Aleutian Islands (AI) from Ivonne Ortiz (University of Washington), and the Gulf of Alaska (GOA) from Bridget Ferris (NOAA-AFSC). There were no public comments.

This year, as in the past, the Ecosystem Status Reports (ESRs) are insightful, well-written, and well-edited. They represent an enormous amount of work accomplished under very tight time constraints. All three chapters were helpful in providing a context within which to assess the stocks of commercially harvested fish in the federal waters of Alaska. As usual, the editors and authors have been responsive to the comments and suggestions provided by the SSC in 2019. The process this year, from the gathering of data to the analysis and presentation of the ESRs, has been affected by the necessary reduction in close personal interactions, whether they be in the laboratory or on a ship. The resulting deficit of new information on the status of the marine ecosystems that the Council manages was apparent to the SSC as it conducted its review of the ESRs for 2020. ***The SSC appreciates the extraordinary efforts made to provide quality ESRs under such difficult circumstances.***

The SSC noted that information from the EBS/AI ESRs were incorporated into the risk tables for 21 BSAI stock assessments (16 recommended ecosystem risk level of 1 and 5 recommended ecosystem risk level of >1). The GOA ESR information was incorporated into the risk tables for 8 stock assessments (7 recommended ecosystem risk level of 1, and sablefish (statewide) was the only assessment with an ecosystem risk level of 2).

Issues of Concern: Southeastern Bering Sea
There were four issues of concern in the EBS that the SSC wished to highlight for the Council:

- *There was an unusually high Prohibited Species Catch (PSC) of herring in the 2020 A season directed pollock fishery. The 2020 PSC of herring exceeded the 2020 herring PSC limit and the Summer Herring Savings Areas (HSA) 1 and Winter HSA were therefore closed. The SSC appreciated the efforts by the pollock fleet to provide information as to why this PSC overage occurred. The pollock fishermen suggested that the increased PSC was not due to a change in spatial or temporal overlap between pollock and herring, but due to an increased abundance of herring. The authors of the report in the ESR provided suggestions for research that could help explain why this high PSC occurred and how to avoid repeating similar high PSC in the future. They suggest a re-evaluation of herring spawning migration by stock, and a re-evaluation of HSAs with respect to their effectiveness for protecting herring. It could also be valuable to retain PSC herring for genetic analysis of the stock of origin.* ***The SSC recommends that efforts be made to address these issues quickly and agrees that the areas of research identified could inform the hypotheses surrounding the increase in herring PSC and the degree of concern about this PSC, depending on the stock of origin.***

- *Starting in late July 2020 and continuing through at least October, communities in the Bering Strait region, and eventually along the Chukchi Sea coast began reporting increased amounts of marine debris, which was predominantly foreign in manufacture, with Russian and Korean characters being readily identifiable. This debris has a potential for disrupting local fishing*

efforts and increasing the potential for ingestion of plastics by marine life (both initially, or in the future, as items degrade). ***The SSC suggests that the Council may want to collaborate with U.S. and international agencies to determine the origin of the debris, and work toward eliminating future debris discharges.***

- *A new indicator of ocean acidification based on aragonite saturation states suggests that seasonal bottom water corrosive conditions peaked in 2013. Modeled output from a ROMS hindcast for summer 2020 indicated a more strongly corrosive outer shelf domain compared to the 2003–2019 average. The authors concluded that these corrosive conditions likely resulted from bacterial respiration of organic carbon produced by phytoplankton that had sunk below the mixed layer. Increased corrosivity of bottom waters is of concern, particularly for crab stocks. There seems to be little that the Council can do to ameliorate this problem.*

- *Starting in January 2019, and persisting into 2020, elevated numbers of North Pacific gray whales (*Eschrichtius robustus*) died along the west coast of North America, resulting in the declaration of an Unusual Mortality Event (UME). These deaths apparently occurred on the return migration of the whales to Alaska from their breeding grounds along the coast of Baja California, Mexico; reports suggest that they may have died of starvation. Gray whales feed in the northern Bering and Chukchi seas and are benthic feeders (e.g., amphipods, crab larvae). The 2019 mortality events may reflect 2018 feeding conditions in the Bering Sea, conditions experienced during migrations to the south, or a lack of available prey to complete the return migration to the Bering Sea in 2019 (Siddon 2019). The 2019 gray whale UME may also reflect a population approaching carrying capacity. Moore et al. 2001 first suggested that gray whales might be reaching the carrying capacity of their NBS and Chukchi Sea foraging grounds. At that time, there were an estimated 26,635 gray whales. The estimated population as of 2019 was 27,000*[28]*. The carrying capacity, as estimated in 2002, was between 19,830 and 28,470 individuals (Wade et al. 2002). Thus, the deaths of emaciated individuals in 2019, might have been expected. There is little the Council can do to address these mortalities. A survey of the amphipod beds in the NBS and the southern Chukchi Sea could provide information on the condition of food resources compared to what was there in the 1970s and 1980s.*

Ecosystem Trends: Southeastern Bering Sea

Indicators for the prey field (zooplankton and forage fish), seabirds, marine mammals, and holistic ecosystem indicators were missing for 2020 due to the COVID-19 pandemic. Data loss was partially mitigated by participation of citizen scientists, communities, and tribal governments who contributed observations and data. For example, when USFWS seabird monitoring was canceled, coastal community members, tribal governments, and state/university partners provided information on seabird dynamics, which were then synthesized with help from the USFWS. ***The SSC commends and greatly appreciates these efforts and supports development of similar activities that incorporate local and traditional knowledge (LK/TK) and collaborations where possible.***

The ESR editors are equally appreciative to the efforts of partners who have, and continue to, provide local and traditional knowledge (LK/TK) that better our understanding of ecosystem dynamics in the region.

The ESR editors and contributors continue to make strides at improving collaborations with many LK and TK holders. However, at this time, systematic incorporation of LK and TK into the ESR

[28] `https://www.wbur.org/hereandnow/2019/05/27/gray-whales-wash-up-record-levels`

is outside the scope of these individual contributions and specifically the tasking and objectives of the LKTKS Task Force, and additional efforts focused on incorporating LK and TK into the ESR will be done in coordination with the LKTKS Task Force.

The combined climate section and the combined seabird section were both excellent and much easier to digest. ***The SSC greatly appreciates these efforts to streamline the ESR without losing important information.***

In this year's 2021 Ecosystem Status Report for the Eastern Bering Sea, we again present synthesized sections for (1) Physical Environment Information and (2) Integrated Seabird Information. We hope these sections continue to enhance the utility of the ESRs and the uptake of ecosystem information into the management process.

The use of data on seabirds, salmon and ice conditions to infer zooplankton abundance showed the power of annually gathering multiple, interrelated indices on ecosystem conditions.

We agree that by sampling and understanding the ecosystem holistically, we are better able to infer changes in conditions.

The 2019–2020 daily mean sea ice extent was within one standard deviation of the long-term mean. Sea ice cover exceeded the median extent in February and March of 2020, but had reduced thickness and retreated quickly. The cold pool extent and temperatures (as output from the ROMS hindcast model) were average. ***The SSC suggests that the use of the ROMS model for predicting specific indices in 2020, such as the extent of the cold pool or measures of mean bottom temperatures, continue to be validated with appropriate comparisons of hindcasts with data available from the bottom trawl surveys.***

In this year's 2021 Ecosystem Status Report for the Eastern Bering Sea we include a "Noteworthy" contribution focused on ROMS bottom temperature output, including information and references on model skill and validation.

Both the northern Bering Sea (NBS) and the southeastern Bering Sea (SEBS) have been in a persistent stanza of warm surface waters that has been greater in magnitude and duration than that of the early 2000s. A new metric of sea surface temperature (SST) that indicates when a marine heatwave (MHW) has occurred shows that the threshold for defining a MHW has been persistently exceeded in both the SEBS and NBS for much of the last five years. To date, this warming has not resulted in a major die off of a commercially important species in the EBS. However, there have been considerable re-distributions of stocks in the SEBS and NBS. Projections are for delayed sea ice formation, and moderately warm conditions over the shelf in 2021. ***The SSC urges the Council to seek comprehensive annual surveys of the NBS and collaborations with Russia to ascertain the implications of changing climate on the distribution and health of commercially important stocks.***

Information on primary production indicates that the spring bloom was early in 2020 in the SEBS, and that chlorophyll-a biomass was below average in 2020 in the NBS.

The use of the remotely controlled an Unmanned Surface Vehicle (USV) was superb and provided essential data on pollock distribution and abundance. The SSC suggests that these data be also used to extract information on the distribution and abundance of euphausiids, if possible.

Estimates for euphausiids from the 2020 Saildrone mission are being developed and AFSC staff

hope they will be available in 2022. The acoustic equipment on the Saildrone was different from standard ship-based acoustic equipment and therefore further analysis is needed to ensure data are accurate and comparable.

Editorial Comments: all regions

1) ***SSC appreciates the efforts made to standardize and stabilize the formats and methods applied to the ESRs.*** *The ESRs for the EBS and GOA are already well aligned, and it would be good to put the AI ESR into a similar format, where possible. Standardized methodologies across ESRs would not have to be re-reviewed annually and changes to methods could be introduced in such a way that they could be quickly identified as new and then be evaluated. The SSC also continues to encourage the editors of the ESRs to work to reduce redundancy.*

The format of the AI ESR has been updated this year to be more cohesive across all ESRs. Some formatting differences between ESRs will remain as we try to portray the information in a way that highlights particular features of an ecosystem (e.g., regional report cards in the AI). With regards to standardized methodologies, contributors follow the same guidelines for all ESRs. However, sometimes using the same methodology is not possible or suitable, even when using the same kind of data. To help track changes in the ESR, any contribution that is either new or has updated methodology is marked by a dagger in the table of contents; updated contributions (new information, same methodology) are marked with an asterisk. Lastly, in an effort to reduce redundancy, we are removing the executive summary in the front matter of the ESR. Instead, we will focus on the ecosystem assessment and include links to the contributions as they are mentioned. The report card will continue to be included.

2) It would be useful to determine which of the sections of the ESRs are of greatest use to the intended audience.

The ecosystem information in this report is integrated into the annual harvest recommendations through inclusion in stock assessment-specific risk tables, presentations to the Groundfish and Crab plan teams in annual September and November meetings, presentations to the Council in their annual October and December meetings, and submission of the final report to the Council in December. However, the SSC is the primary audience for this report, as the final ABCs are determined by the SSC, based on "biological and environmental scientific information through the stock assessment and Tier process".

The Ecosystem Assessment section of the ESRs are likely to be of greatest use to the SSC in this regard. The assessments are based on a synthesis of myriad data in the reports, but are not necessarily reflective of all the information available. Instead, the authors strive to pull together the 'story' for the ecosystem in the current and previous year based on apparent connections and mechanisms supported by recent trends. Some indicators may be more influential than others in any particular year due to changing environmental conditions or food web interactions. These are highlighted in the Ecosystem Assessment, as well as common trends that may inform unobserved parts of the ecosystem.

Within each standard contribution, the last section is intended to highlight any implications of the indicator trends that could be informative for fisheries managers.

3) ***The SSC recommends that the ESR authors pursue the systematic and consistent incorporation of LK and TK as relevant to ESR.*** *As noted before, we recognize that the systematic, methodologically sound, and culturally appropriate collection of all forms of LK and*

TK is beyond the purview of the ESR authors, but see the benefits of the ESRs incorporating these types of data when available. As demonstrated in the EBS ESR, in light of recent disruptions to surveys due to the pandemic, established protocols for incorporation of LK and TK can be useful for avoiding data gaps.

The Ecosystem Status Report (ESR) team agrees wholeheartedly in continuing to explore partnerships with the fishing industry, coastal communities, and regional entities, including tribal entities. Such partners have pertinent and relevant knowledge to inform the ESRs, both to help identify "red flags" and provide perspective and context to ecosystem trends. We continue to explore and invite partners to contribute to the ESRs while also awaiting advice on the systematic and consistent incorporation of local knowledge (LK) and traditional knowledge (TK) through the Bering Sea LK/TK/Subsistence Task Force.

NOAA's Alaska Fisheries Science Center's Economic and Social Science Research department has stated the following–The social science contributors to the ESR agree that it is important to include LK and TK in the ESRs when this information is available, but caution against its inclusion when there are recognized limitations in the methodological approaches (at present they are neither systematic nor consistent) as well as their limits on representativeness across regions, species, and communities. We recommend continuing additional efforts focused on incorporating LK and TK into the ESR to be done in coordination with the LKTKS Task Force.

4) In addition to the ESR Chapters, the SSC is pleased to see the continued development of the "In Brief" for the EBS and GOA, the addition of a new "In Brief" for the Aleutian Islands, and updated storymaps. We also look forward to seeing the new videos being developed. These resources are essential for efficiently and clearly communicating the main ecosystem patterns to stakeholders and the public, and the ***SSC supports their continued development****.*

In 2020 we produced "In Brief" 4 page summaries for the EBS, GOA, and AI. We also produced an outreach video for the first time, summarizing the GOA 2020 ESR. In 2021 we plan to produce "In Briefs" for the EBS, GOA, and AI and a second outreach video summarizing the ESR products and process.

We have been examining the effort and resources required to produce these various outreach products ("In Brief", storymap, video) with the AFSC communications team and have settled on a strategy that includes the annual production of "In Briefs", intermittent production of storymaps focused on specific ecosystem stories, and no additional videos at this time.

5) The SSC suggests that the use of terms like "normal" is somewhat problematic given that what is "normal" seems to be changing rapidly. Some extremes are becoming normal. Regarding climate issues in particular, and perhaps for other areas in general, it might be better to use "average" and to indicate the years for which the average is calculated. It could also be appropriate to give departures from "average" in terms of standard deviations.

The ESR team agrees with the SSC and is working with our contributors to shift away from the term "normal" and to the term "average", with specified years and standard deviations, where appropriate. In certain contributions that are qualitative or a synthesis of multiple datasets and observations, we are exploring the appropriate terminology that describes the concept of average conditions without using the quantitative term. This is an evolving conversation that reaches beyond the ESRs, particularly in the context of social science and local and traditional knowledge.

6) The MHW index provides a relative value for each season in each year in comparison to a long-term mean. However, it is likely the absolute value that drives ecosystem responses to heat waves via metabolic rates. In this regard, it would be useful if the authors can provide an index that captures the relative metabolic stress.

Metabolic stress, especially when talking about "absolute" temperature values, is highly dependent on species. Bioenergetics indices, incorporating temperature-specific respiration, foraging rates, and varying prey quality, are being or have been incorporated into several stock-specific ESPs as requested by each stock's ESP development team. However, on an ecosystem scale, it would be difficult to develop an absolute stress measure that is meaningful across a wide range of species; rather, a relative index provides a view of how unusual current conditions are compared to past observation, thus indicating greater potential for broad species shifts that may include less stress for warmer-water preferring species alongside decreases in colder-water species. As ESPs expand to include more per-species bioenergetics rates, we are considering future reporting of a "meta-index" to indicate which/how many stocks are experiencing metabolic stress in any given year.

Additionally, the MHW does not seem to be reflected in the stability index. Is this because the index is averaged over 10 years? If so, this index may not be very sensitive to major perturbations of the ecosystem.

The lead contributor has provided a response to this comment: There is a certain amount of inertia built into these indicators. While they are responsive to and reflect change, they are not designed to show immediate and highly sensitive responses to small amounts of change, or change that is acutely felt by a single species. These community level indicators are intended to show when there is community-wide systemic change occurring, that integrate across species-specific responses. The changes in community indicator values during the heatwave may not have been as pronounced as one might have expected, perhaps due to variation in the magnitude and timing of the species-specific responses. While they may all ultimately end up having a similar trajectory in response to the heatwave (e.g., what may be happening with mean length and mean lifespan), it takes some time for the entire community to integrate those environmental changes. In summary, the inertia in these community indicators is intentional and they are designed to indicate systemic community-wide change.

Detailed response reflecting the 2014–2016 marine heatwave: The 10-year average dampens the effect of the survey index dip in 2017 (not 2016). While the survey biomass index dropped in 2017, the drop in the 10-year mean of the survey index was not remarkable. However, this indicator integrates information on both the mean and the variation in the index. In 2017, the survey biomass index was the second lowest over the time series (1999 was the lowest), the 10-year mean was the lowest over the time series, and the SD was the highest over the time-series. What is important to note about the indicator in 2017 is that the 10 [survey] year window included the two lowest survey index values (1999 and 2017) and the four highest index values, over the survey index time series. This led to the high standard deviation in 2017 and thus the low indicator value.

7) How meaningful is the index of mean lifespan of the community if so many species, and especially long-lived species such as rockfish, are excluded?

The lead contributor has provided a response to this comment: The mean lifespan indicator is specific to the portion of the groundfish community that is consistently sampled by the bottom-trawl survey gear. Rockfish are long-lived and would have an impact on the indicator value,

particularly if they have high biomass in the survey area. Rockfish have previously been excluded from the bottom-trawl survey index, and thus the mean lifespan indicator, because the bottom-trawl surveys may not adequately sample the habitat or depths where rockfish are frequently found in order to represent their trends in abundance. The eastern Bering Sea shelf bottom-trawl survey is limited to depths less than 200 m and rockfish are routinely caught at only a small number of the standard stations, and in some years, some rockfish species are entirely absent from the survey catch.

Furthermore, the topography of the eastern Bering Sea, with a very large shelf area compared to slope, means that the rockfish contribution would have a minimal effect on the lifespan indicator, even when weighted by age. Therefore, we continue to exclude rockfish from the eastern Bering Sea shelf survey index and related indicators, while noting the need to develop indicators specifically targeted towards the eastern Bering Sea slope region using slope survey data. The Gulf of Alaska bottom-trawl survey samples to much greater depths than in the eastern Bering Sea as part of the standard survey design, the slope represents a larger proportion of the overall Gulf of Alaska survey area, and rockfish species are consistently encountered across all years in the time series. We have reviewed the catch of rockfish in the GOA bottom-trawl survey time series and the relevant stock assessment documents and now include several rockfish species in the Gulf of Alaska bottom-trawl survey index and related indicators.

8) The absolute takes of seabirds in some years, and for some species, are of conservation concern. While a standardized index, such as birds caught per line or net set may be useful for some management purposes, the number of dead birds are more useful from a conservation and ecosystem perspective.

The lead contributor has provided a response to this comment: In general, yes, providing only extrapolated numbers does generate a biased downward depiction of the take of seabirds. For example, the sablefish IFQ fishery has about 15% observer coverage. If we only provided observed takes of seabirds we would theoretically underestimate the seabird bycatch by 85%. We provide observed takes of ESA-listed seabirds (short-tailed albatross, Steller's eider, and spectacled eider), but I think it is less useful for something like northern fulmars whose populations number in the hundreds of thousands. In addition, we provide extrapolated and not extrapolated takes to the SSC when we present our annual bycatch report.

9) There have been suggestions that fluctuations in seabird bycatch possibly reflect prey availability; however, patterns differ among species or species groups. This may be an interesting area to investigate as the time series get longer and the methods of bycatch reduction stabilize. It may also be possible to relate seabird bycatch to die-off events, which also likely reflect a lack of available prey.

We agree with the SSC. We are hoping to include diet data of seabird bycatch in future ESRs to inform seabird bycatch trends and potentially prey availability. Currently, these food habits data exist but are in the process of being centralized into a searchable AFSC database. At that point, they will be available for further analyses to better understand these relationships of interest. We look forward to discussing these data in future ESRs.

10) In the description of fishing and human dimension indicators, it would seem useful to separate landings and price. Ex-vessel value may be what is of concern to economists or the industry, but when the two are multiplied together, the underlying driver behind the final number – whether the amount of fish has gone up or if the price has gone up – is unknown.

The AFSC Economic and Social Science Research Director has provided a response to this comment: The authors are unsure exactly to which area this comment applies. There are ESR contributions both for landings and value by functional group, as well as unit value (price) to make the distinction as suggested by the SSC.

11) Regarding the human dimension indicator of population and population change by community, the SSC recommends that the analysts consider flagging those communities that are currently directly engaged in the harvesting and/or processing sectors of federally managed fisheries.

The AFSC Economic and Social Science Research Director has provided a response to this comment: The social and economic conditions surrounding community participation in federal managed groundfish and crab species are more appropriately covered in the Annual Community Engagement and Participation Overview (ACEPO), which is its primary focus.

12) The addition of new data on HABs is excellent. Should there also be an effort to report on other pollutants and heavy metals?

Unfortunately, there are no yearly or periodic surveys for pollutants and heavy metals. We have included mercury in the food webs in the Aleutian Islands as a Noteworthy contribution as that is an ongoing project and also because levels of concern have been identified for mercury in several species. Threshold levels are not available for a lot of other pollutants (e.g., PCBs) but we will try to incorporate them as Noteworthy contributions as they become available.

13) ***The SSC reiterates that authors who wish to include figures make certain that these figures are readable when reduced to page or half-page size.*** *This has been an issue of concern for a number of years. Perhaps the editors can scan contributions from authors when they are first submitted and return them to the authors if the included figures are unreadable. Fonts within figures are a particular problem; and figures that show long-term trends might benefit from zooming in on more recent years to show current trends.*

The ESR authors continue to work with contributors to improve the readability and utility of submitted figures.

October 2021: D3 October Preview of Ecosystem Status Reports

The SSC received presentations by Elizabeth Siddon (NOAA-AFSC), Bridget Ferriss (NOAA-AFSC), and Ivonne Ortiz (UW-CICOES) on the Ecosystem Status Reports (ESR) for the EBS, the GOA, and the AI. Overall, data loss due to COVID in 2021 was limited in the GOA and AI, and moderate in the EBS with most loss due to survey cancellations, survey reductions (smaller footprints), and lab/data processing delays. Though preliminary, the presentations were informative and highlighted the great strides that the authors and editors of the ESRs have made in producing documents that are insightful and of benefit to the management of Federal fisheries off Alaska. The SSC appreciates the consistent high quality of the ESR presentations and looks forward to seeing the final products in December. Public testimony was provided by Chris Tran (Aleut Corporation of St. Paul).

The NPI was strongly positive in winter 2020–2021, the AO was negative in winter and positive in spring and summer 2021, while the PDO was negative. Water temperatures were warmer than average offshore and cooler inshore.

Eastern Bering Sea

In 2021, there was a decoupling of the winds in the NBS (strong winds from the north) and the southeastern Bering Sea (moderate to strong winds from the south). As a result, there was widespread and thick sea ice in the northern Bering, and reduced sea-ice extent and thickness in the southeast. Over the southeastern shelf, the advancement of sea ice stalled at the end of January, resulting in a relatively small cold pool, similar in size to those occurring in the warm years of the early 2000s. In 2021, air temperatures, as measured at St. Paul Island, were again quite warm, continuing the period of temperatures above the 100-year mean observed since 2012. This period of above average air temperatures is also reflected in total annual cumulative SSTs being high since 2012, particularly in the southeastern Bering Sea. The winter SSTs in 2021 were slightly below the long-term mean in the north, and somewhat above the long-term mean in the southeastern Bering Sea. Summer SSTs were above average throughout the eastern Bering Sea, though less warm than in 2019. The inner shelf south of St. Matthew Island was closer to the long-term mean than were the middle or outer shelf regions. There was no indication of a marine heatwave in the NBS, but in the southeastern Bering Sea, temperatures briefly achieved heatwave status.

Red Flags

The presentation noted several red flags related to population declines or die-offs occurring in the EBS. In 2021, there was a 25% decline in BBRKC mature female biomass and a sharp, 69% decrease in legal male snow crab in the survey. There were also seabird die-offs in the NBS and the AYK Chinook and chum salmon returns were low. There is apparently no "smoking gun" as to the causes of the precipitous declines in snow crab and sustained period of low production of BBRKC, but several hypotheses related to changing ocean environmental conditions will be explored and presented by the ESR authors at the December Council meeting including: cumulative impacts of thermal exposure and metabolic demands, changes in stratification and vertical distribution of prey resources, and prey switching and lack of functional redundancy. ***The SSC looks forward to the synthesis of more indicators in the full ESR in December and emphasizes the need for mechanistic studies, especially as they relate to the benthos in the EBS, to understand the impacts of climate change.***

Please see the Ecosystem Assessment (p. 8) for the full synthesis and discussion of ecosystem indicators and status of 2021.

Description of the Report Card Indicators

1. The North Pacific Index (NPI) winter average (Nov-Mar): The NPI index (Trenberth and Hurrell, 1994) was selected as the single most appropriate index for characterizing the climate forcing of the Bering Sea. The NPI is a measure of the strength of the Aleutian Low, specifically the area-weighted sea level pressure (SLP) for the region of 30°N to 65°N, 160°E to 140°W. Above (below) average winter (November–March) NPI values imply a weak (strong) Aleutian Low and generally calmer (stormier) conditions.

The advantage of the NPI include its systematic relationship to the primary causes of climate variability in the Northern Hemisphere, especially the El Niño-Southern Oscillation (ENSO) phenomenon, and to a lesser extent the Arctic Oscillation (AO). It may also respond to North Pacific SST and high-latitude snow and ice cover anomalies, but it is difficult to separate cause and effect.

The NPI also has some drawbacks: (1) it is relevant mostly to the atmospheric forcing in winter, (2) it relates mainly to the strength of the Aleutian Low rather than its position, which has also been shown to be important to the seasonal weather of the Bering Sea (Rodionov et al., 2007), and (3) it is more appropriate for the North Pacific basin as a whole than for a specific region (i.e., Bering Sea shelf).

Implications: For the Bering Sea, the strength of the Aleutian Low relates to wintertime temperatures, with a deeper low (negative SLP anomalies) associated with a greater preponderance of maritime air masses and hence warmer conditions.

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2. Bering Sea ice extent: The Bering Sea ice year is defined as 1 August–31 July. Bering Sea ice extent data are from the National Snow and Ice Center's Sea Ice Index, version 3 (Fetterer et al., 2017), and use the Sea Ice Index definition of the Bering Sea, effectively south of the line from Cape Prince of Wales to East Cape, Russia (i.e., this index includes ice extent in both the western and eastern Bering Sea). The daily mean annual ice extent integrates the full ice season into a single value. *Implications:* Seasonal sea ice coverage impacts, for example, the extent of the cold pool, bloom strength and timing, and bottom-up productivity.

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3. Cold pool extent: Area of the cold pool in the eastern Bering Sea (EBS) shelf bottom trawl survey area (including strata 82 and 90) from 1982–2021. The cold pool is defined as the area of the southeastern Bering Sea continental shelf with bottom temperature <2°C, in square kilometers (km^2). *Implications:* The cold pool has a strong influence on the thermal stratification and influences the spatial structure of the demersal community (Spencer, 2008; Kotwicki and Lauth, 2013; Thorson et al., 2020), trophic structure of the eastern Bering Sea food web (Mueter and Litzow, 2008; Spencer et al., 2016), and demographic processes of fish populations (Grüss et al., 2021).

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4. Aggregate forage fish: This index aggregates survey biomass estimates for key forage fish species in the eastern Bering Sea. The constituents are members of the "forage fish" group included as Ecosystem Components in the BSAI Fishery Management Plan: eulachon, Pacific capelin, sand lance species, rainbow smelt, Pacific sandfish, and a group of minor smelt species. This aggregate does not include important forage species such as age-0 Walleye pollock or Pacific herring. The biomass estimates are from the eastern Bering Sea shelf bottom trawl survey including the northwestern survey strata 82 and 90. Because this survey is not optimized for small pelagic fishes, the data should be viewed with caution. *Implications:* Forage fish fill an important trophic niche in the food web of the eastern Bering Sea. When this index is higher, there is more food available to upper trophic predators (including fish, seabirds, and mammals), and vice versa.

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5., 6., 7., 8. Description of the Fish and Invertebrate Biomass Indices: We present four guilds to indicate the status and trends for fish and invertebrates in the eastern Bering Sea: motile epifauna, benthic foragers, pelagic foragers, and apex predators. Each is described in detail below. The full guild analysis involved aggregating all eastern Bering Sea species included in a food web model (Aydin and Mueter, 2007) into 18 guilds by trophic role, habitat, and physiological status (Table 9). For the four guilds included here, time trends of biomass are presented for 1982–2021. Foraging guild biomass is based on catch data from the NMFS-AFSC annual summer bottom trawl survey of the EBS shelf (<200 m), modified by an Ecopath-estimated catchability coefficient that takes into account the minimum biomass required to support predator consumption (see Appendix 1 in (Boldt, 2007) for complete details). This survey index is specific to the standard bottom trawl survey area in the southeastern Bering Sea (does not include strata 82 and 90) and does not include the northern Bering Sea. New this year, foraging guild biomass is weighted by strata area (km^2) which has resulted in a minor shift in the biomass values from reporting in previous years but the trends and patterns remain the same. Also, we no longer include species that lack time series and were previously represented by a constant biomass equal to the mid-1990s mass balance level estimated in (Aydin and Mueter, 2007).

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5. Motile epifauna (fish and benthic invertebrates): This guild includes both commercial and non-commercial crabs, sea stars, snails, octopuses, other mobile benthic invertebrates, and eelpouts. There are ten commercial crab stocks in the current Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs; we include seven on the eastern Bering Sea shelf: two red king crab *Paralithodes camtschaticus* (Bristol Bay, Pribilof Islands), two blue king crab *P. platypus* (Pribilof District and St. Matthew Island), one golden king crab *Lithodes aequispinus* (Pribilof Islands), and two Tanner crab stocks (southern Tanner crab *Chionoecetes bairdi* and snow crab *C. opilio*). The three dominant species comprising the eelpout group are marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*), and shortfin eelpout (*L. brevipes*). The composition of seastars in shelf trawl catches is dominated by the purple-orange seastar (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. *Implications:* Trends in

Table 9: Composition of foraging guilds in the eastern Bering Sea.

Motile Epifauna	Benthic Foragers	Pelagic Foragers	Apex Predators
Eelpouts	Yellowfin sole	W. pollock	P. cod
Octopuses	Flathead sole	P. herring	Arrowtooth
Tanner crab	N. rock sole	Atka mackerel	Kamchatka fl.
King crab	Alaska plaice	Misc. fish shallow	Greenland turbot
Snow crab	Dover sole	Salmon returning	P. halibut
Sea stars	Rex sole	Capelin	Alaska skate
Brittle stars	Misc. flatfish	Eulachon	Other skates
Other echinoderms	Greenlings	Sandlance	Sablefish
Snails	Other sculpins	Other pelagic smelts	Large sculpins
Hermit crabs		Other managed forage	
Misc. crabs		Scyphozoid jellies	

the biomass of motile epifauna indicate benthic productivity and/or predation pressure, although individual species and/or taxa may reflect shorter or longer time scales of integrated impacts of bottom-up or top-down control.

6. Benthic foragers (fish only): The species which comprise the benthic foragers group are the Bering Sea shelf flatfish species, greenlings, and small sculpins. *Implications:* Trends in the biomass of benthic foragers indirectly indicate availability of infauna (i.e., prey of these species).

7. Pelagic foragers (fish and Scyphozoid jellies only): This guild includes adult and juvenile Walleye pollock (*Gadus chalcogrammus*), other forage fish such as Pacific herring (*Clupea pallasi*), Capelin (*Mallotus villosus*), Eulachon (*Thaleichthys pacificus*), and Sandlance, salmon, Atka mackerel (*Pleurogrammus monopterygius*), and Scyphozoid jellies. *Implications:* Trends in the biomass of pelagic foragers largely track Walleye pollock which is an important component of the Bering Sea ecosystem, both as forage and as a predator.

8. Apex predators (shelf fish only): This guild includes Pacific cod (*Gadus macrocephalus*), Arrowtooth flounder, Kamchatka flounder (*Atheresthes evermanni*), Pacific halibut (*Hippoglossus stenolepis*), Greenland turbot (*Reinhardtius hippoglossoides*), Sablefish (*Anoplopoma fimbria*), Alaska skate, and large sculpins. *Implications:* Trends in the biomass of apex predators indicate relative predation pressure on zooplankton and juvenile fishes within the ecosystem.

9. Habitat impacted by trawls: Fishing gear can affect habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. This indicator uses output from the Fishing Effects (FE) model to estimate the habitat reduction of geological and biological features over the Bering Sea domain, utilizing spatially-explicit VMS data. The indicator reflects an estimate of time that gear is in contact with the substrate; disturbance is assumed cumulative over the year, therefore the December value of each year is plotted. Further detail on this index is reported on p. 202. *Implications:* An estimate of the area of seafloor disturbed by trawl gear provides an indication of habitat disturbance.

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Methods Description for the Report Card Indicators

For each plot, the mean (green dashed line) and ±1 standard deviation (SD; green solid lines) are shown as calculated for the entire time series. Time periods for which the time series was outside of this ±1 SD range are shown in yellow (for high values) and blue (for low values).

The shaded green window shows the most recent 5 years prior to the date of the current report. The symbols on the right side of the graph are all calculated from data inside this 5-year moving window (maximum of 5 data points). The first symbol represents the "2016–2020 Mean" as follows: '+ or -' if the recent mean is outside of the ±1 SD long-term range, '.' if the recent mean is within this long-term range, or 'x' if there are fewer than 2 data points in the moving window. The symbol choice does not take into account statistical significance of the difference between the recent mean and long-term range. The second symbol represents the "2016–2020 Trend" as follows: if the magnitude of the linear slope of the recent trend is greater than 1 SD/time window (a linear trend of >1 SD in 5 years), then a directional arrow is shown in the direction of the trend (up or down), if the change is <1 SD in 5 years, then a double horizontal arrow is shown, or 'x' if there are fewer than 3 data points in the moving window. Again, the statistical significance of the recent trend is not taken into account in the plotting.

The intention of the figure is to flag ecosystem features and the magnitude of fluctuations within a generalized "fisheries management" time frame (i.e., trends that, if continued linearly, would go from the mean to ±1 SD from the mean within 5 years or less) for further consideration, rather than serving as a full statistical analysis of recent patterns.

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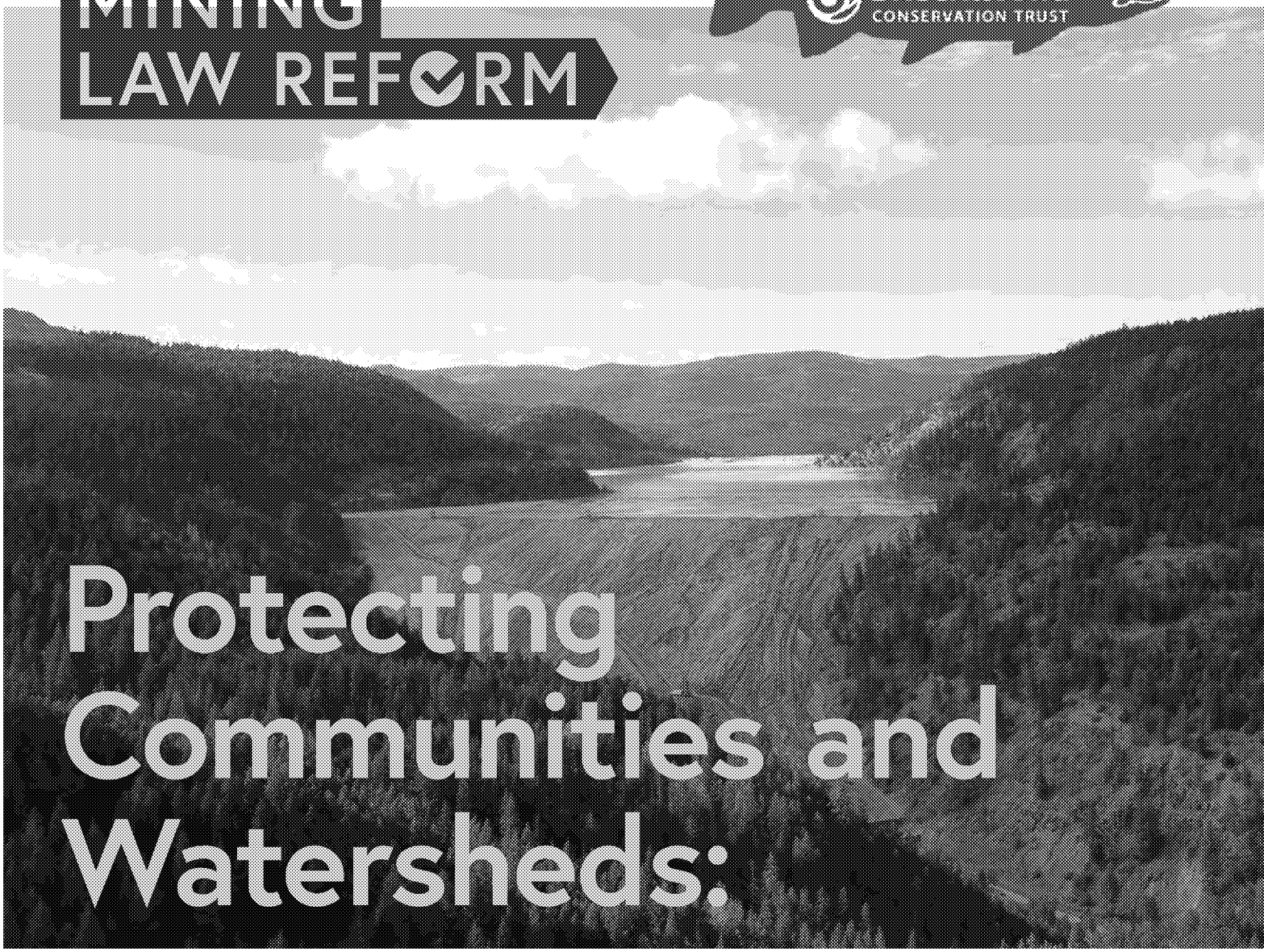
BC MINING LAW REFORM

SkeenaWild CONSERVATION TRUST



Protecting Communities and Watersheds:

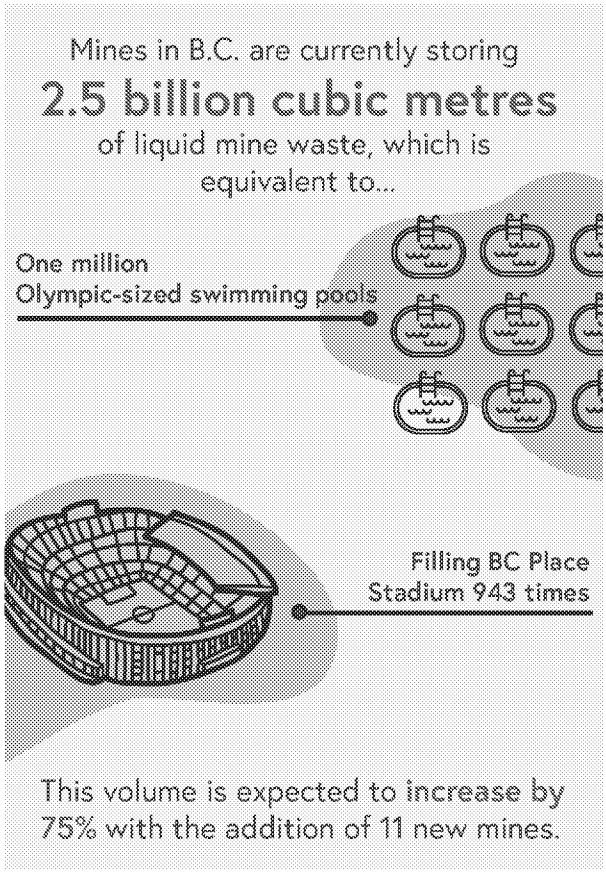
Risks of Tailings Dam Failures in the Face of Climate Change

July 2022

ABOVE: COPPER MOUNTAIN / PHOTO: ANDREW ROBERTS

A new expert analysis evaluating current and proposed mines in British Columbia shows the growing cumulative impacts of the province's mining boom at a time of increasingly extreme weather events driven by climate change. The analysis, *The Risk of Tailings Dam Failure in British Columbia: An Analysis of the British Columbia Existing and Future Tailings Storage Database*, looks at the risks of a failure at the 172 dams holding back mine processing waste, called tailings.[1] [2] The analysis also looks at the total volume of tailings currently being stored at B.C. mines, conservatively estimated to be 2.5 billion cubic metres, based on government and mining industry data. This amount of tailings is equivalent to one million Olympic-sized swimming pools and would fill B.C. Place stadium 943 times. With the addition of 11 proposed new mines, this volume is expected to increase by 75%.

According to the expert analysis, the height and volume of tailings storage facilities (TSFs) in B.C. have been increasing exponentially over time, meaning they are getting increasingly riskier. In fact, B.C. is contemplating new mines that would include TSFs among the tallest in the world. As tailings facilities have grown in height and volume, there has been a corresponding increase in the potential severity of consequences of tailings dams' failures, including the potential for loss of human life. Nearly half of B.C.'s existing mine sites with TSFs are officially rated as likely to have High, Very High, or Extreme consequences in the event of a tailings dam failure. Finally, the analysis found that one in four mine sites with tailings dams use a riskier construction type, upstream dam construction, which has twice as many stability issues than downstream constructed tailings dams. Upstream dams are banned in other jurisdictions but still permitted in B.C.



British Columbia is already at high risk for some of the primary drivers of tailings dam failures globally —earthquake risks and high precipitation, which cause flooding. Climate change will compound risks of flooding, bringing in more frequent, severe rainstorms, like the atmospheric rivers already experienced in B.C. in 2021.

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Mine Tailings Storage and New Risks from Climate Change

Tailings, which can include trace heavy metals, selenium, and other toxins such as arsenic and cyanide, are typically stored permanently in aboveground facilities that are retained by dams. If these dams fail, as happened with the Mount Polley mine waste disaster in 2014, large volumes of tailings can be released to the surrounding environment. The potential risks associated with even a single tailings storage facility (TSF) failure are serious, including loss of human life, catastrophic damage to roads and infrastructure, and total losses to ecosystems, including salmon watersheds. Dozens of communities and thousands of people across B.C. live downstream of mines with tailings dams.[3] Today, there are 75 mine sites in B.C. that contain at least one TSF. At these mine sites there are at least 172 dams holding back tailings mine waste.[4]

Meanwhile, British Columbians find themselves on the front lines of climate change, facing more extreme weather. In the fall of 2021, the province experienced 'atmospheric rivers' that caused severe flooding, loss of homes and infrastructure, and billions of dollars of damage.

Climate change is rapidly compounding precipitation risks, and British Columbia is experiencing more severe and frequent storms as a result. Extreme rainfall driven by climate change adds stress to the structures holding mine tailings. Even tailings facilities designed for today's most extreme weather events may not be able to withstand future extremes under the influence of climate change, or multiple events such as heat domes, atmospheric rivers, and recurring flooding.

The Fraser River Basin, where atmospheric river events are predicted to increase in strength and frequency due to climate change,[5] is home to 27 current and future mine sites hosting at least one tailings storage facility—over one-third of the total number of mine sites across B.C.[6]

The B.C. government has stated an urgent need for action to prepare and adapt to the changing climate, including a critical need for climate-ready infrastructure.[7] The mining industry and mining experts acknowledge the growing risks of climate change, especially in light of a growing volume of tailings globally.[8]

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A Current Assessment of B.C. Mines with Current or Future Tailings

Following the Mount Polley tailings disaster in 2014, the Mount Polley Independent Expert Engineering Investigation and Review Panel found that to get on a path to zero failures, the province needed to reduce its tailings facility inventory by half and use Best Available Technology (BAT) for the remaining facilities.[9] As a follow up to this recommendation, the BC Mining Law Reform network and SkeenaWild Conservation Trust created a database of mines with TSFs across the province. The database comprises 86 mine sites that currently, or are proposed to, contain at least one TSF, and informed the creation of a publicly available online British Columbia Mine Tailings Map as well as an expert report.[10] The expert report, *The Risk of Tailings Dam Failure in British Columbia: An Analysis of the British Columbia Existing and Future Tailings Storage Database*, authored by Dr. Steven Emerman, evaluates this database and the risks of a tailings dam failure (based on assessing the combination of the probability of failure and consequence of failure).[11] Dr. Emerman is an internationally recognized expert who has evaluated proposed and existing TSFs in North America, South America, Europe, Africa, Asia, and Oceania.[12]

Key Findings from the Expert Report

B.C.'s Mining Growth Will Create Some of the Largest Tailings Facilities in the World

The height and storage capacity of tailings facilities in B.C. have been increasing exponentially over time, meaning they are getting increasingly riskier. In fact, B.C. is contemplating new mines that would include tailings storage facilities among the tallest in the world.

Tailings dam height and tailings storage volume are risk factors that can increase the economic, environmental, or human consequences in the event of a tailings dam failure. According to the expert report, operating TSFs are on average nearly twice as high as facilities in closed and care and maintenance status and proposed facilities on average would be again twice as high as operating facilities. Operating facilities hold on average five times more tailings than facilities in closed and care and maintenance status and proposed facilities would hold on average three times more than operating facilities.[13] In fact, B.C. is pursuing mines with tailings dams among the tallest in the world, including one taller than Vancouver's tallest building, the Shangri-la tower.[14]

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Dam Failure Consequences are also Increasing

As B.C.'s tailings facilities have grown in height and volume, there has been a corresponding increase in the potential severity of consequences of tailings dams' failures, including the potential for loss of human life. Nearly half of B.C.'s existing mine sites with tailings storage facilities are officially rated as likely to have High, Very High, or Extreme consequences to humans and the environment in the event of a tailings dam failure.[15]

Tailings dams are rated under a system established by the Canadian Dam Association, where ratings are based on the consequences of failure, including loss of human life, loss of critical fish or wildlife habitat, and economic losses to infrastructure, public transportation, or commercial facilities. A review of these ratings in B.C. suggests consequences are increasingly severe at newer tailings facilities. While the potential for loss of human life or significant to major economic or environmental damage exists at 46% of older sites (closed or under care and maintenance), that potential jumps to 83% for mines that are currently in operation. At proposed sites where consequence ratings have been established, nearly all (5 out of 6) would result in Very High or even Extreme consequences, including anywhere from 10 to over 100 human lives lost or irreparable loss of critical fish or wildlife habitats.[16] Failure consequence ratings at existing and proposed sites suggest thousands of lives could be at risk across B.C. from tailings dam failure.[17]

Figure 1: Percentage of mine sites with tailings storage facilities (TSFs) according to status and dam failure consequence classification

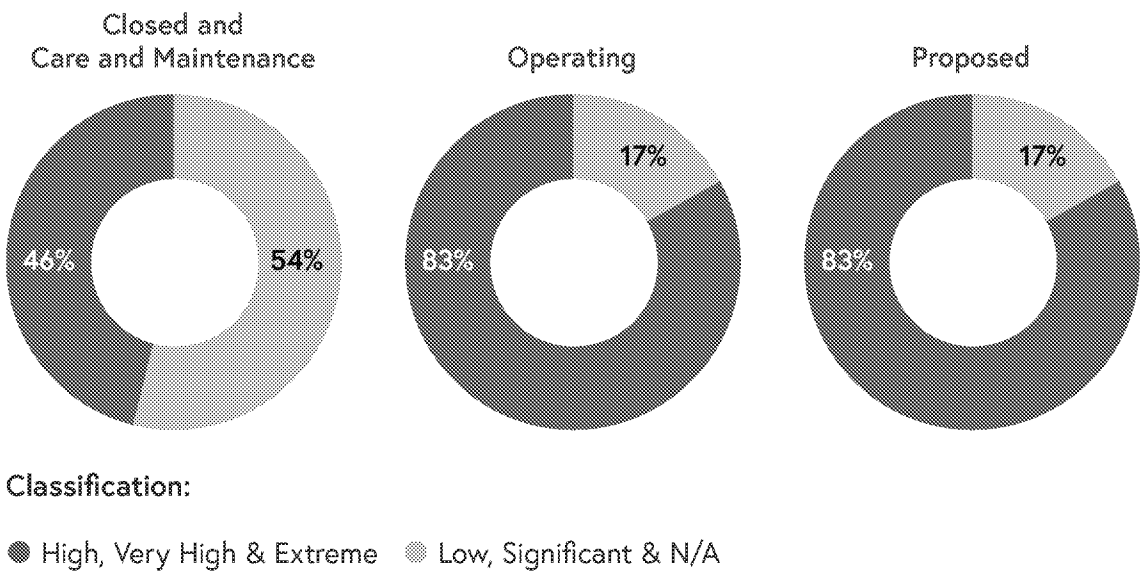

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Table 1: B.C. mine sites with tailings storage facilities (TSFs) according to dam failure consequence classification

Dam Failure Consequence Classification*	Failure Consequence Description**	Percent & Number of Sites	
Low	• No loss of life • Minimal/short-term loss of environmental or cultural values • Minimal economic losses	19%	14
Significant	• Low potential for multiple losses of life • No significant loss of environmental/cultural values • Low economic losses	18%	13
High	• Loss of fewer than 10 lives • Significant loss of environmental/cultural values, where restoration is possible • High economic losses	22%	16
Very High	• Loss of fewer than 100 lives • Significant loss of environmental/cultural values, where restoration is impractical • Very high economic losses	26%	19
Extreme	• Loss of greater than 100 lives • Major loss of environmental/cultural values, where restoration is impossible • Extremely high economic losses	10%	7
N/A	No dam failure consequence assigned because TSF does not have dams	4%	3

* Dam Consequence Classifications are based on B.C. Dam Safety Regulations, which are adopted from Canadian Dam Association Guidelines.

** Consequence descriptions are adapted from the B.C. Ministry of Forests, Lands and Natural Resources "Downstream Consequence of Failure Classification Interpretation Guideline", Appendix A. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/dam-safety/con_class_guidelines_for_owners-2017.pdf

Note: There are also 14 sites with TSFs where Dam Consequence Classification is not publicly available (9 Closed or under Care and Maintenance, and 5 Proposed). These sites have been excluded from Table 1 and Figure 1.

Note: Percentages have been rounded to the nearest whole number.

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Nearly two-thirds of the sites in B.C. with tailings facilities—54 out of 86—are located in salmon habitat. A major tailings failure at any of these facilities could significantly harm salmon and salmon habitat.

Seismic and Climate Factors Add to the Risk of Failures

British Columbia is at high risk for some of the primary drivers of tailings dams failure globally—earthquake risks and high precipitation. Climate change will compound the risks of flooding, bringing in more frequent and severe rainstorms, like the atmospheric rivers already experienced in B.C. in 2021.

Two of the primary drivers of tailings dams failure globally are earthquakes and overtopping by floods, both of which are major risks in British Columbia. The province's western coast is on a major earthquake fault line and experts believe the province has a one in five chance of going through a major earthquake in the next 50 years, increasing the risk of a tailings dam failure. Portions of B.C. also receive extensive rainfall and flooding, which contribute to an increased risk of tailings facility dam failure.[18] Tailings facilities designed for today's most extreme weather events may not be able to withstand future extremes that will occur under the influence of climate change.

B.C. Allows Risky Construction Types

One in four B.C. mine sites with tailings dams use a riskier construction type—upstream dam construction—which has twice as many stability issues than downstream constructed tailings dams. Upstream dams are banned in other jurisdictions but still permitted in B.C.

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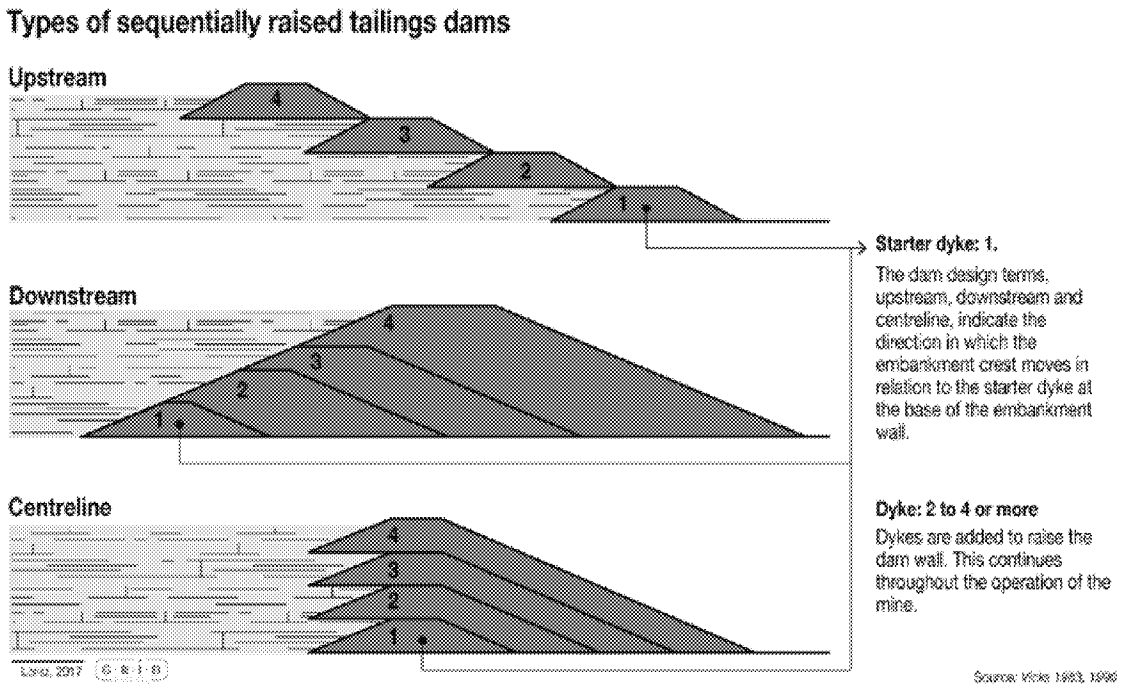
One quarter of the currently existing mine sites with TSFs in the province—19 of them—have tailings dams constructed using the upstream method, which has a greater rate of instability issues compared to other dam construction methods.[19] Upstream construction involves progressively raising the dam on top of the existing tailings in the facility.
The expert analysis notes the risk of tailings dam failure is likely underestimated in B.C. because of the way mining companies often classify their dams.[20] Increasingly, dams are classified as 'modified centreline' construction instead of 'upstream.' Modified centreline is a lesser known construction type that also involves building on top of uncompacted tailings, giving these dams similar risks of stability as upstream dams.[21]

Figure 2: Types of sequentially raised tailings dams



The expert review indicated that certain communities in the Fraser River watershed would be more vulnerable. The watershed contains 27 existing and proposed mine sites with TSFs. One of those mine sites is the Highland Valley Copper mine, which stores 1.2 billion cubic metres of tailings at one of its storage facilities, or the equivalent to 480,000 Olympic-sized swimming pools. In the event of a complete facility failure, these tailings could be released into the lower Fraser River, potentially impacting communities downstream such as Abbotsford, Burnaby, Coquitlam, Delta, Richmond, Surrey, and Vancouver.[22]

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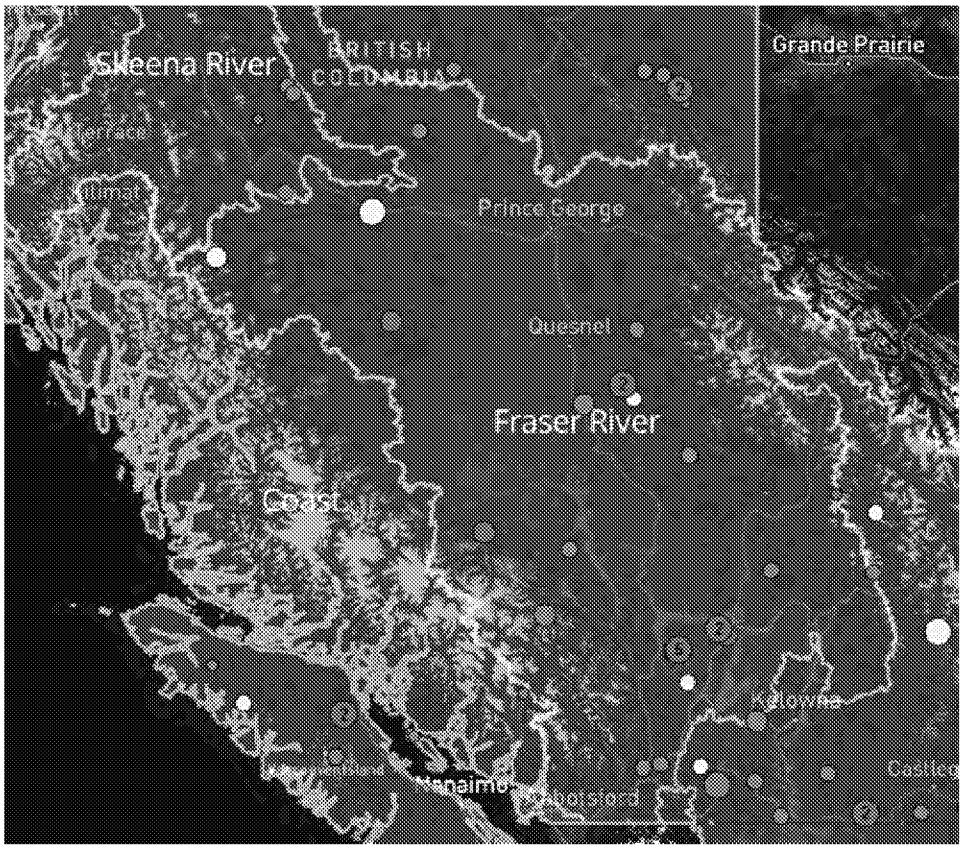

SCREENSHOT FROM THE INTERACTIVE ONLINE MAP SHOWING THE NUMBER OF MINE SITES IN THE FRASER RIVER WATERSHED WITH AT LEAST ONE TSF.

57 Closed Mines with 'Legacy' Tailings Facilities Require Ongoing Attention

Mines that are currently closed or in care and maintenance may present higher risks if they do not receive ongoing inspection, monitoring, and maintenance. There are currently 57 sites with tailings storage facilities in B.C. that are closed or in care and maintenance.

According to the expert report, mines that are closed or in care and maintenance may not be receiving the sufficient and ongoing inspection, monitoring, and maintenance that are critical to preventing tailings failure. Tailings facilities are often expected to remain on the landscape forever. The only ways of avoiding facility failure over this timeframe are a) eliminating all possible failure modes (i.e., via decommissioning and reclamation) or b) perpetual monitoring, inspection, and maintenance.[23]

Nearly two-thirds of the sites in B.C. with tailings facilities—54 out of 86—are located in salmon habitat. A major tailings failure at any of these facilities could significantly harm salmon and salmon habitat.

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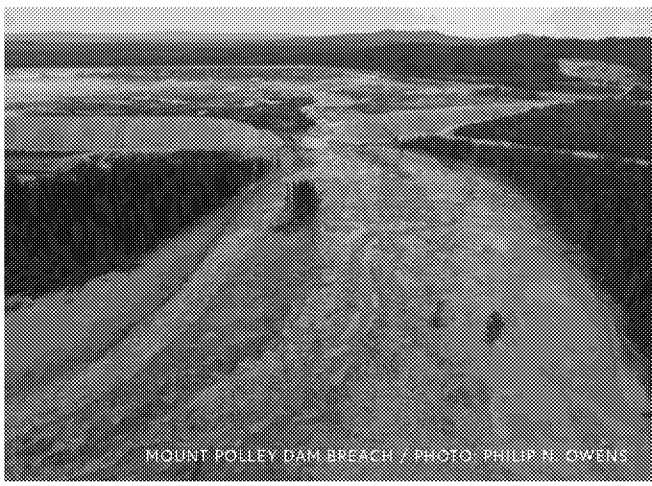
Multiple Risk Factors to Mitigate as Tailings Increase by 75%

The expert report reveals that there are a number of overlapping risk factors at TSFs in British Columbia, including dam construction method, status, dam height, storage volume, and dam consequence rating. Over time, the growth and location of TSFs is cumulatively increasing the risk of tailings dam failure by increasing the consequences from a failure. Experts, including the Mount Polley Independent Expert Engineering Investigation and Review Panel, have observed that the sheer number of active tailings sites on the landscape increases risk by increasing the probability that any one of them will fail.[24]

As new, larger mines are built, introducing a substantial increase in the number of TSFs and overall volume of tailings on the B.C. landscape, these new mines, in combination with the legacy of tailings already present, will increase the overall cumulative risk.

Building on progress made and continuous improvement

The B.C. government has taken steps to evaluate the regulatory framework at mines with individual TSFs. In June 2021, the government released its first audit from the new Mine Audits & Effectiveness Unit of B.C. entitled *Audit of Code Requirements for Tailings Storage Facilities*. This audit looked at the regulatory framework governing health, safety, and reclamation of mines in B.C. and made a number of recommendations calling on the government to update its regulatory framework to reflect best standards, practices, and regulations. An additional analysis of B.C.'s tailings standards and the audit was completed by the BC Mining Law Reform network and MiningWatch Canada in January 2022.[25] B.C.'s Auditor General also recently released a progress audit showing some improvements to policies, procedures, and plans for monitoring and compliance at mine sites since the Mount Polley disaster.[26]



MOUNT POLLEY DAM BREACH / PHOTO: PHILIP B. OWENS

While it is important that B.C. continues to make progress on its regulatory oversight at individual tailing storage facilities (see box: Building on progress made and continuous improvement), it is equally important that B.C. understand and evaluate the cumulative risk presented by the 75 mines with TSFs and the potential addition of 11 new mines with TSFs. This is especially imperative as B.C. faces more extreme weather events due to climate change.

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HIGHLAND VALLEY COPPER MINE TAILINGS RESERVOIR / PHOTO: JEREMY SEAN WILLIAMS/WILDERNESS COMMITTEE. PHOTO PROVIDED BY JOE FOY

Recommendations

As B.C. pursues the growth of its mining sector, there are concrete steps that the government should take to reduce the likelihood and consequence of tailings dam failures, thereby preventing serious human, economic, and ecological impacts. Any one of these steps would act to lessen the cumulative risk of a tailings dam failure. Together, taking multiple actions would have an additive effect to confront new risks, including those presented by climate change.

Existing Mines

#1: Commit to a plan to reclaim or otherwise seek safe closure of tailings storage facilities in B.C.

As mentioned, the presence of more TSFs on the landscape increases risk. B.C. should address this by committing to a plan to implement a nearly decade old recommendation outlined in the 2015 Mount Polley Expert Panel report to reduce B.C.'s tailings storage facilities by half, and require Best Available Technology and Practices for the remaining TSFs.[27] According to *Safety First: Guidelines for Responsible Mine Tailings Management*, "A tailings facility is safely closed when deposition of tailings has ceased and all closure activities have been completed so that the facility requires only routine monitoring, inspection and maintenance in perpetuity or until there are no credible failure modes."[28]

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#2: Clarify treatment of tailings storage facilities in 'care and maintenance' and provide clear guidance for management of facilities in this status

The expert report identifies 23 mines with TSFs in care and maintenance which may present higher risks if they do not receive ongoing inspection, monitoring, and maintenance.[29] By clearly defining the stages of mine life where a 'care and maintenance' status is permitted, long delays to closure and reclamation of tailings facilities could be avoided, thereby ensuring all credible failure modes are eliminated at TSFs that are no longer operational, so they can be removed from B.C.'s inventory.[30]

Future Mines

#3: Align with international best practices and implement a ban on risky upstream tailings dam construction methods

Globally, there is a trend away from upstream tailings dam construction. Banning upstream dam construction would put B.C. in line with best practices. This also aligns with industry trends—none of the proposed dams evaluated in the expert report contemplate use of the 'upstream' construction type. Any new provincial policy should include banning what are referred to as 'modified centreline' dams, which are still constructed on top of uncompacted tailings in the manner of an upstream dam.[31]

#4: Reverse the trend of more severe consequence ratings at new tailings storage facilities

The expert analysis reveals that tailings facilities are increasingly being designed with failure consequences in the High, Very High, and Extreme categories. Experts suggest that over hundreds of years, the required oversight to prevent failure at tailings facilities is not realistic, and facility failure should be considered a 100% likelihood. Reducing the consequences of failure at all new tailings facilities or, alternatively, denying permitting for those that cannot be more safely designed and/or located, puts safety as a top priority. This is especially important for mines located upstream from communities, and those in high seismic and/or high precipitation zones where climate change risks may make failure an even greater and more pressing likelihood.

Existing and Future Mines

#5: Factor in seismic and climate change risks at all tailings facilities, especially when evaluating proposed mines

B.C. should update its guidelines to require that all tailings dams be built to withstand the most extreme flooding and earthquake events.[32] For proposed tailings facilities, the B.C. government should factor local seismic risk and the risks of future climate impacts, such as more extreme and/or frequent precipitation events, into all environmental impact

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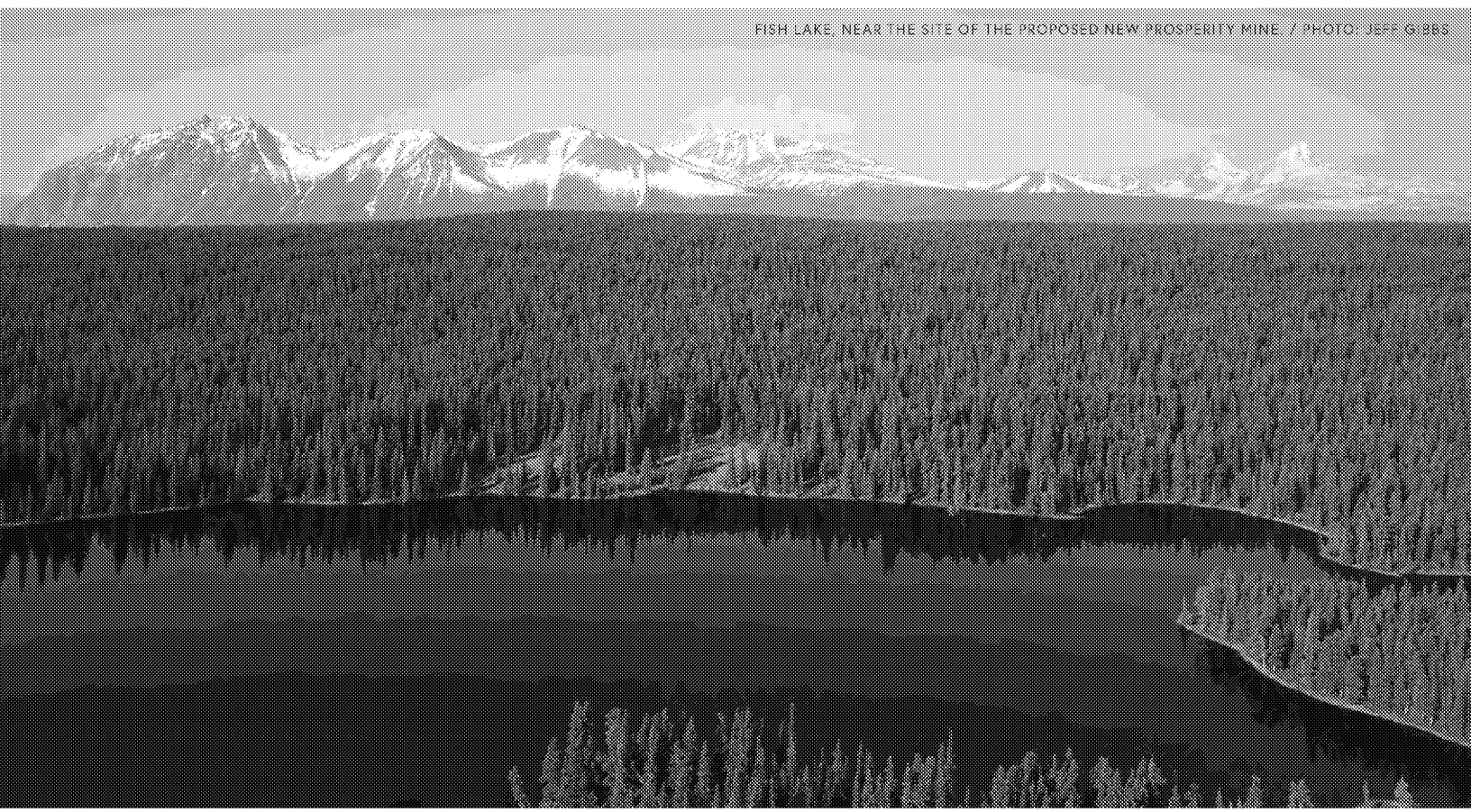
assessments. With respect to existing tailings facilities, climate change considerations should be incorporated into the regulatory oversight of all facilities to inform emergency preparedness and implement more resilient design modifications wherever possible.

#6: Pursue strategies to reduce the volume of tailings, especially at new mines

The total volume of tailings on the provincial landscape is growing. B.C. should investigate and then implement technologies and more stringent policies and requirements for dewatered tailings. Technologies to investigate would include filtered tailings as well as paste or thickened tailings, and dry closure methods (as opposed to permanent water covers). Adopting these strategies at proposed sites is particularly critical, given the greater opportunity to incorporate safer technology into the design for facilities that have not yet been built.[33]

#7: Improve accessibility and transparency of information on risk factors for all tailings facilities

Most of the risk factors identified by the expert report (e.g., storage volume, dam heights) are not required by B.C. to be publicly reported in a consistent manner. For example, current tailings storage volumes are missing for one third of all sites and tailings dam heights are not reported for about 10% of sites. The province's incomplete record of health and environmental risk at tailings dams points to the need for more transparency and disclosure in relation to all sites—past, present, and future.[34]



FISH LAKE, NEAR THE SITE OF THE PROPOSED NEW PROSPERITY MINE. / PHOTO: JEFF GIBBS

Endnotes

1 Emerman, Steven, *The Risk of Tailings Dam Failure in British Columbia: An Analysis of the British Columbia Existing and Future Tailings Storage Database*, July 2022. https://reformbcmining.ca/wp-content/uploads/2022/06/BC_TSF_Database_Analysis_Emerman_Revised2.pdf
(hereinafter "Emerman, Risk of Tailings Dam Failure"). This expert report is based on a database created by the BC Mining Law Reform network and SkeenaWild Conservation Trust, sourcing B.C. government and industry data.

2 Tailings are only one type of mine processing waste. Tailings are the wet and crushed rock particles that remain after the commodity of value has been removed from the ore body.

3 See, for example, BC First Nations Energy and Mining Council, *Uncertainty Upstream: Potential Threats from Tailings Facility Failure in Northern British Columbia*, 2015. https://fnemc.ca/wp-content/uploads/2015/07/Uncertainty-Upstream-2015-compressed.pdf

4 TSFs in the province are typically constructed using dams, often multiple dams. As of June 4, 2022, the database on which the expert report is based identified a total of at least 172 dams currently retaining tailings across B.C., and another at least 21 tailings dams proposed. This is a minimum number, as the number of tailings dams was not publicly reported for all sites.

5 Government of Canada, *Canada in a Changing Climate: Regional Perspectives Report, British Columbia*, 2022, Section 5.3, p. 24. https://changingclimate.ca/site/assets/uploads/sites/4/2020/11/British-Columbia-Regional-Perspective-Report-.pdf

6 Emerman, Risk of Tailings Dam Failure, p. 31–32.

7 Government of British Columbia and Clean BC, *Climate Preparedness and Adaptation Strategy for 2022–2025*, June 2022. https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/cpas.pdf

8 Global Tailings Review, *Towards Zero Harm: A Compendium of Papers Prepared for the Global Tailings Review*, August 2020. https://globaltailingsreview.org/wp-content/uploads/2020/08/towards-zero-harm.pdf (which identified climate change as a key factor influencing tailings failure outcomes throughout the report)

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9 For example, the review panel stated: "Reducing the number of active dams can also be considered as a means for meeting the same safety goals. …Reducing the current inventory of active tailings dams can be brought about from attrition by eliminating surface water at closure. Restricting future growth of the inventory can be achieved through tailings technologies that avoid water storage in the first place." Mount Polley Independent Expert Engineering Investigation and Review Panel, *Report on Mountain Polley Tailings Storage Facility Breach*, January 30, 2015. https://www.mountpolleyreviewpanel.ca/sites/default/files/report/Appendixl_BCTDFFrequencyandPortfolioRisk.pdf (hereinafter, "Mount Polley Independent Expert Engineering Investigation and Review Panel Report"). Appendix I, Section 5.3, p. 10–12.

10 As of June 4, 2022, the database includes 86 sites in total: 75 mine sites in British Columbia currently containing at least one TSF holding tailings mine waste, and 11 future mine sites, many of which are advanced in the regulatory process, that would contain a TSF and create at least 19 additional tailings dams if built. Many of these sites contain more than one TSF. The database and map do not list every single TSF, nor do they provide a count on the total number of TSFs across B.C. The database and map highlight the tallest tailings dam at each site, the design storage capacity for the largest TSF on site, the current tailings storage volume across all TSFs on site, and the highest consequence classification assigned to any tailings dam on site.

11 See generally Emerman, Risk of Tailings Dam Failure. While the expert report did not look singularly at the risk of a tailings dam failure of any one mine site, it looked at multiple risk factors that can collectively increase the probability and/or consequence of failure of a tailings facility across the province. These risk factors include: high runoff (high precipitation), high seismicity, the use of upstream dam construction method, the status of sites (such as closed or in care and maintenance), dam height, and storage volume.

12 Dr. Emerman has testified before the U.S. Congress, the European Parliament, the UN Permanent Forum on Indigenous Issues, and the UN Environment Assembly. He is Chair of the Body of Knowledge Subcommittee for the U.S. Society on Dams and a co-author of *Safety First: Guidelines for Responsible Mine Tailings Management*.

13 Based on the tallest tailings dams at each site, operating TSFs on average (65.5 m) are nearly twice as high (or 1.8 times higher) as closed and care and maintenance facilities (36.8 m), and proposed facilities on average (123.9 m) will be again twice as high (or 1.9 times higher) as operating facilities. Based on current tailings storage at existing sites and design capacity at proposed sites, operating facilities hold on average (121.5 million m3) five times more than closed and care and maintenance sites (22.7 million m3), and proposed facilities would hold on average (362.3 million m3) three times more than operating facilities. See Emerman, Risk of Tailings Dam Failure, p. 15.

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14 A comparison with the Global Tailings Portal (an international tailings database built from direct mine company disclosures) indicates that if built, the future KSM mine would have the seventh tallest tailings dam in the world at 239 m, which would be far taller than Vancouver's tallest building, the Shangri-la tower (201 m). See Klohn Crippen Berger's report to Seabridge Gold Inc., *2012 Engineering Design Update of Tailing Management Facility*, p. 33. https://projects.eao.gov.bc.ca/api/public/document/5887de449b566a12e7f69c83/download/Appendix%204C%20Appendix%20H8%20%20TMF%20Engineering%20Design%202012%2010f6.pdf. Additionally, B.C. currently has at least six dams, and at least two more proposed (KSM and Galore Creek) in the top 30 dam heights in the world according to the Global Tailings Portal. To be one of the top 30, based on the tallest tailings dam at each mine site, the dam would need to be greater than 126 m.

15 See Emerman, Risk of Tailings Dam Failure, p. 19. 37 out of 75 existing mine sites with tailings facilities have dam consequence ratings of High, Very High, or Extreme, which mean dam failure would likely involve loss of life and/or serious damage to environmental and cultural values.

16 There are another five proposed sites where consequence ratings have not yet been established.

17 The expert report calculates potential loss of life based on the dam consequence classification rating system established by the Canadian Dam Association. Based on a review of the official consequence ratings, the expert report found that 42 sites, including proposed sites, had dam failure consequence ratings of High (1–10 lives), Very High (11–100), and Extreme (more than 100 lives). Assuming 10 lives, 100 lives, and 101 lives lost at sites rated High, Very High, and Extreme, respectively, the potential loss of life could be as much as 2,767 lives at these 42 sites. This estimate, however, may be several orders of magnitude too low because there are sites for which the dam failure consequence is unknown, where there is more than one dam or TSF, or where the loss of life would exceed 101 lives. See Emerman, Risk of Tailings Dam Failure, p. 30.

18 According to the expert report, 12 mine sites located within areas with high seismic risk and/or areas with high annual runoff already also have other high risk factors for tailings dam failure. These sites, primarily along B.C.'s coastal region, are of significant concern.

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19 Upstream dams are considered to be more risky because they have a nearly 20% greater incidence of stability issues as other types of tailings dams, including having 200% more (or twice as many) stability issues than downstream-constructed tailings dams. See Franks, D., et al. *Tailings facility disclosures reveal stability risks*, March 2021. https://www.nature.com/articles/s41598-021-84897-0. The 19 sites with upstream dams in B.C. include: Copper Mountain, Elkview-West Fork, Endako, Gibraltar, and Mount Polley mines, among others. In two cases, at Copper Mountain and Gibraltar, the TSF with the upstream dam also has an Extreme failure consequence rating (potential loss of >100 lives), which is a disturbing combination of unacceptable probability of failure and unacceptable consequences of failure.

20 See Emerman, Risk of Tailings Failure, p. 34.

21 To stay consistent with public reporting on B.C. tailings dams, the database on which the expert report is based did not treat modified centreline dams as upstream dams. See Emerman, Risk of Tailings Failure, p. 34–35 and 81–84.

22 See Emerman, Risk of Tailings Failure, p. 31–32.

23 See Emerman, Risk of Tailings Failure, p. 9–11.

24 Mount Polley Independent Expert Engineering Investigation and Review Panel Report, Appendix I.

25 Emerman, Steven, *Bridging the Gap: Toward the Best International Standards on Mine Waste Safety in British Columbia*, January 2022, https://miningwatch.ca/sites/default/files/bcmlr-bridging-the-gap-report_0.pdf (produced by BC Mining Law Reform and MiningWatch Canada; hereinafter referred to as "Emerman, Bridging the Gap").

26 Office of the Auditor General of British Columbia, *Oversight of Major Mines: Policies and Procedures to Address Environmental Risks*, June 2022. https://www.bcauditor.com/sites/default/files/publications/reports/BCOAG-Oversight-Major-Mines-Report-June-2022.pdf

27 See Mount Polley Independent Engineering Investigation and Review Panel Report, Section 9.3 and Appendix I. Section 9.3.4 states that BAT principles would apply "to the closure of active impoundments so that they are progressively removed from the inventory by attrition."

28 Morrill, J., Chambers, D., Emerman, S., Harkinson, R., Kneen, J., Lapointe, U., Maest, A., Milanez, B., Personius, P., Sampat, P., and Turgeon, R., *Safety First: Guidelines for Responsible Mine Tailings Management*, Earthworks, MiningWatch Canada and London Mining Network, 2022. https://earthworks.org/wp-content/uploads/2022/05/Safety-First-Safe-Tailings-Management-V2.0-final.pdf, Guideline 11, p. 32.

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29 See Emerman, Risk of Tailings Failure, p. 12.

30 While many mines in B.C. are reported to be in 'care and maintenance,' this term is not defined anywhere in B.C.'s mining regulations or guidance documents. It often applies to mines that are not operational, but are not moving towards closure and reclamation either. While putting a mine into care and maintenance may make sense for short term reasons, any delay in moving a TSF towards safe closure prolongs the risk of tailings facility failure, so these delays must be transparent and well regulated.

31 While none of the 11 new sites with tailings facilities currently proposed by B.C. mining companies are identified as using upstream dams, the province must determine whether any of them have been labeled 'modified centreline' and regulate them as upstream dams if they are, given they use similar construction methods and pose similar risks as upstream dams. See Emerman, Risk of Tailings Failure, p. 34–35, 39 and 81–84.

32 Emerman, Bridging the Gap, p. 14.

33 All new mines that create tailings must begin with an analysis of the Best Available Technology (BAT) for tailings disposal. BAT and practices in tailings management will continue to change, but tailings BAT was specified by the Mount Polley Independent Expert Engineering Investigation and Review Panel. According to Morrill et al., "The goal of BAT for tailings management is to assure physical stability of the tailings deposit. This is achieved by preventing release of impoundment contents, independent of the integrity of any containment structures. In accomplishing this objective, BAT has three components that derive from first principles of soil mechanics: 1. Eliminate surface water from the impoundment. 2. Promote unsaturated conditions in the tailings with drainage provisions. 3. Achieve dilatant conditions throughout the tailings deposit by compaction." (p. 25)

34 Specific actions the province could take include: 1) Require standardized reporting by mining companies of the information highlighted in the database and map on which the expert report is based, including tailings dam construction methods, dam heights (current and planned), current storage volumes, and design storage volumes; and 2) Monitor and accelerate the B.C. Code Review Committee's progress on implementation of the 2021 TSF audit recommendations, that included providing clarity, consistency, and guidance on TSF data systems, reports, and inspections.

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ADVANCING THE STATE OF PRACTICE FOR TAILINGS DAM BREACH ASSESSMENT USING EMPIRICAL CORRELATIONS

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The Extractive Industries and Society 8 (2021) 100962

Contents lists available at ScienceDirect

The Extractive Industries and Society

journal homepage: www.elsevier.com/locate/exis

Original article

Participation or frustration? Local stakeholders and the National Environmental Policy Act (NEPA): Donlin gold project, Western Alaska

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ARTICLE INFO

Keywords:
Mine permitting
National Environmental Policy Act
Alaska
Donlin mine
Alaskan natives

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https://doi.org/10.1016/j.exis.2021.100962
Received 21 March 2021; Received in revised form 27 June 2021; Accepted 28 June 2021
Available online 14 July 2021
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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF ALASKA

UNITED STATES OF AMERICA, Plaintiff, and KUSKOKWIM RIVER INTER-TRIBAL FISH COMMISSION, Intervenor-Plaintiff, v. THE STATE OF ALASKA, THE ALASKA DEPARTMENT OF FISH & GAME, and DOUG VINCENT-LANG, in his official capacity as Commissioner of the Alaska Department of Fish & Game, Defendants.	Case No. 1:22-cv-00054-SLG

ORDER REGARDING PLAINTIFF'S MOTION FOR PRELIMINARY INJUNCTION

Before the Court at Docket 5 is Plaintiff United States of America's Motion for Preliminary Injunction. Intervenor-Plaintiff Kuskokwim River Inter-Tribal Fish Commission ("the Commission") joined Plaintiff's motion at Docket 14.[1] Defendants State of Alaska; Alaska Department of Fish & Game (ADF&G); and

[1] The case caption has been amended to include Intervenor-Plaintiff. *See* Docket 29 (Order Regarding Kuskokwim River Inter-Tribal Fish Commission's Motion to Intervene).

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Doug Vincent-Lang, Commissioner of ADF&G, responded in opposition at Docket 17. Plaintiff replied at Docket 21, and Intervenor-Plaintiff joined Plaintiff's reply at Docket 24. Defendants responded in opposition to Intervenor-Plaintiff's joinder at Docket 30. The Court heard oral argument on June 21, 2022.[2]

Plaintiff seeks a preliminary injunction "to prohibit Defendants from continuing to authorize or implement actions that contravene the rural Alaskan subsistence priority and are preempted by federal law."[3] The state action at issue is Defendants' Emergency Order #3-S-WR-02-22, which Plaintiff describes as "purport[ing] to open the Kuskokwim River within the Yukon Delta National Wildlife Refuge to gillnet fishing by all Alaskans in violation of federal orders issued to effectuate the ANILCA Title VIII rural subsistence priority."[4] Defendants respond that Plaintiff has not met its burden to justify the issuance of a preliminary injunction.

I. Background

The Court set forth the factual background relevant to the instant motion in its May 31, 2022 Order Denying Plaintiff's Motion for Temporary Restraining Order and assumes familiarity here.[5] On June 17, 2022, the Court allowed the

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[2] As the Court indicated at oral argument, it will not consolidate a ruling on the instant motion for preliminary injunction with a determination of the case on its merits.

[3] Docket 5 at 2.

[4] Docket 6 at 2–3.

[5] Docket 11 at 2–11. The Court denied the Motion for Temporary Restraining Order because

Commission to intervene as a plaintiff.[6] As explained by Intervenor-Plaintiff, it "represents the Federally Recognized Indian Tribes of the Kuskokwim River watershed concerning fisheries management matters, including the management of the Kuskokwim River Chinook and chum salmon populations."[7]

II. Legal Standard

The standard for obtaining a preliminary injunction was articulated in *Winter v. Natural Resources Defense Council, Inc.*, where the United States Supreme Court held that plaintiffs seeking preliminary injunctive relief must establish that (1) they are likely to succeed on the merits;[8] (2) they are likely to suffer irreparable harm in the absence of preliminary relief; (3) the balance of equities tips in their favor; and (4) a preliminary injunction is in the public interest.[9] *Winter* places the

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Plaintiff had not made a showing that irreparable harm would occur in the short time before the Court determined whether a preliminary injunction should issue.

[6] Docket 29.

[7] Docket 14 at 2.

[8] Following *Winter*, the Ninth Circuit addressed the first element—the likelihood of success on the merits—and held that the Circuit's "serious questions" approach to preliminary injunctions was still valid "when applied as a part of the four-element Winter test." *All. for the Wild Rockies v. Cottrell*, 632 F.3d 1127, 1131–35 (9th Cir. 2011). Accordingly, if a plaintiff shows "that there are 'serious questions going to the merits'—a lesser showing than likelihood of success on the merits—then a preliminary injunction may still issue if the 'balance of hardships tips *sharply* in the plaintiff's favor.'" *Friends of the Wild Swan v. Weber*, 767 F.3d 936, 942 (9th Cir. 2014) (quoting *Shell Offshore, Inc. v. Greenpeace, Inc.*, 709 F.3d 1281, 1291 (9th Cir. 2013)). "Serious questions are 'substantial, difficult, and doubtful, as to make them a fair ground for litigation and thus for more deliberative investigation.'" *Gilder v. PGA Tour, Inc.*, 936 F.2d 417, 422 (9th Cir. 1991) (quoting *Republic of the Philippines v. Marcos*, 862 F.2d 1355, 1362 (9th Cir. 1988)). They "need not promise a certainty of success, nor even present a probability of success, but must involve a 'fair chance on the merits.'" *Id.* (quoting *Marcos*, 862 F.2d at 1362). All of the *Winter* elements must still be satisfied under this approach for injunctive relief to issue.

[9] 555 U.S. 7, 20 (2008). When the government is a party to the action, such as here, "the

burden on a plaintiff to make a showing on all of the *Winter* factors before a court will issue a preliminary injunction.[10]

Injunctive relief is an equitable remedy, and "[t]he essence of equity jurisdiction is the power of the court to fashion a remedy depending upon the necessities of the particular case."[11]

III. Discussion

Plaintiff and Intervenor-Plaintiff assert that all four *Winter* elements—likelihood of success on the merits, irreparable harm, the balance of the equities, and public interest—weigh in favor of a preliminary injunction. Defendants respond that Plaintiff has not shown that any of the *Winter* elements support the issuance of a preliminary injunction.

A. Plaintiff has shown a likelihood of success on the merits.

The Alaska National Interest Lands Conservation Act (ANILCA) provides that rural subsistence users are given priority to hunt and fish on federal land and waters within Alaska: "[N]onwasteful subsistence uses of fish and wildlife and other renewable resources shall be the priority consumptive uses of all such resources on the public lands of Alaska when it is necessary to restrict taking in order to

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balance of equities factor and the public interest factor merge." *Jones v. Bonta*, 34 F.4th 704, 713 (9th Cir. 2022) (citing *Drakes Bay Oyster Co. v. Jewell*, 747 F.3d 1073, 1092 (9th Cir. 2014)).

[10] *See All. for the Wild Rockies*, 632 F.3d at 1135.

[11] *United States v. Odessa Union Warehouse Co-op*, 833 F.2d 172, 175 (9th Cir. 1987).

assure the continued viability of a fish or wildlife population or the continuation of subsistence uses of such population, the taking of such population for nonwasteful subsistence uses shall be given preference on the public lands over other consumptive uses."[12]

Plaintiff construes the relevant question as one of conflict preemption governed by the Supremacy Clause of the United States Constitution.[13] Plaintiff maintains that "the State's management actions on the Kuskokwim River within the [Yukon Delta National Wildlife] Refuge contradict federal management efforts and create an obstacle to ANILCA's federal purposes and objectives of prioritizing the subsistence use of Chinook and chum salmon within the Refuge over all other uses."[14] Plaintiff asserts that ANILCA's express policy of protecting and prioritizing rural subsistence users' ability to harvest fish preempts any state action that conflicts with federal law or a federal emergency order.[15] Plaintiff contends that ANILCA "not only contemplates, but also prescribes that outcome of 'a clash of lifestyles and a dispute over who gets to fish. Congress, using clear language, has resolved this dispute in favor of [federally qualified users] . . . by giving them priority'" in waters located within federal lands.[16]

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[12] 16 U.S.C. § 3112(2).

[13] Docket 5 at 12 (citing U.S. Const. art. VI, cl. 2).

[14] Docket 5 at 13.

[15] Docket 5 at 13–14.

[16] Docket 5 at 14 (quoting *Kenaitze Indian Tribe v. State of Alaska*, 860 F.2d 312, 318 (9th Cir.

Defendants first respond that federal preemption fails here because the Federal Subsistence Board (FSB) is not validly constituted and thus cannot legally manage Kuskokwim River fisheries. Specifically, Defendants contend that the make-up of the FSB violates the Appointments Clause of the federal Constitution because the FSB members "exercise[] significant authority pursuant to the laws of the United States"[17] and thus are "principal officers of the United States" but have not been appointed by the President with the consent of the Senate.[18] And Defendants maintain that the FSB further violated the Appointments Clause when it delegated what they describe as "unreviewable executive power" to the Refuge Manager, "giv[ing] the Refuge Manager 'significant authority pursuant to the laws of the United States.'"[19] Defendants also respond that the Refuge Manager's

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1988)). In *Kenaitze Indian Tribe*, the Ninth Circuit stated that ANILCA gives priority to rural subsistence users in "federal waters." 860 F.2d at 313, 318. In *Sturgeon v. Frost*, 139 S. Ct. 1066, 1080 n.2 (2019), the Supreme Court did "not disturb the Ninth Circuit's holdings that the Park Service may regulate subsistence fishing on navigable waters." (Citing *Alaska v. Babbitt*, 72 F.3d 698 (1995); *John v. United States*, 247 F.3d 1032 (2001) (en banc); and *John v. United States*, 720 F.3d 1214 (2013)).

[17] Docket 17 at 12–19 (citing U.S. Const. art. II, § 2, cl. 2). According to Defendants, "the Board surely 'exercises significant authority pursuant to the laws of the United States'—the secretaries have assigned to it the responsibility for implementing the rural subsistence priority, which is the primary focus of an entire title of an important federal statute." Docket 17 at 14 (footnote omitted).

[18] Docket 17 at 12–19; *see* U.S. Const. art. II, § 2, cl. 2 ("The President . . . shall nominate, and by and with the Advice and Consent of the Senate, shall appoint Ambassadors, other public Ministers and Consuls, Judges of the supreme Court, and all other Officers of the United States, whose Appointments are not herein otherwise provided for, and which shall be established by Law: but the Congress may by Law vest the Appointment of such inferior Officers, as they think proper, in the President alone, in the Courts of Law, or in the Heads of Departments.").

[19] Docket 17 at 19–23; *see* U.S. Const. art. II, § 2, cl. 2.

emergency actions were arbitrary and capricious in violation of the Administrative Procedure Act (APA) because he improperly entered into a Memorandum of Understanding with the Commission[20] and because his emergency actions lacked scientific justification or support.[21]

Plaintiff replies by first noting that "Defendants continue to forego any response to Plaintiff's preemption claim" that "federal action taken pursuant to ANILCA Title VIII preempts contradictory state action within the Refuge."[22] As to Defendants' APA arguments, Plaintiff replies that Defendants have "not yet invoked the APA's right of action" and thus "any such claims are not yet before the Court, so their assertion here is premature."[23] Regarding Defendants' Appointment Clause arguments, Plaintiff replies that Defendants are "unlikely able to demonstrate standing" and that claim preclusion prevents Defendants from maintaining these Appointment Clause claims.[24] Plaintiff also contends that, even

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[20] Specifically, Defendants contend that, in issuing the emergency orders, "the Refuge Manager has relied on factors which Congress has not intended him to consider by participating in a co-management relationship with [the Commission] that is not authorized by ANILCA or by the FSB's delegation of authority." Docket 17 at 23.

[21] Docket 17 at 23–34. Defendants specifically contend that the Refuge Manager's "order does not contain any analyses explaining why the action was necessary or appropriate. . . . [T]he order fails to explain how restricting the fishery to federally qualified users only, then providing significant opportunity to take fish from the purportedly depleted stock, is 'necessary for the conservation of healthy populations of fish or wildlife,' a justification required by the Board's own regulations." Docket 17 at 31 (citing 50 C.F.R. § 100.10(d)(4)(vi)).

[22] Docket 21 at 4.

[23] Docket 21 at 5.

[24] Docket 21 at 6. Specifically, Plaintiff contends that Defendants could have raised their Appointments Clause claims in *Dep't Fish & Game v. Fed. Subsistence Board*, __ F. Supp. 3d

if Defendants had standing and had timely brought their arguments, Defendants are making a collateral attack on the validity of the federal action and "Plaintiff has amply demonstrated that the federal actions at issue here are within the scope of congressionally delegated authority, and the State's Appointments Clause arguments to the contrary have no merit."[25] Intervenor-Plaintiff agrees that "federal law clearly establishes that ANILCA preempts the State's asserted authority; and the State's arguments raising issues of constitutional authority and administrative law are both meritless and misplaced."[26]

The Court finds that, on the current record, Plaintiff has shown a likelihood of success on the merits. Defendants have not contested ANILCA's rural subsistence priority nor explained how the State's emergency order does not "both violate the federal orders and stand as an obstacle" to the congressional intent of ANILCA.[27] Instead, Defendants assert that the federal action is constitutionally flawed but do not offer sufficient support for those assertions. Defendants acknowledge that additional discovery "may be necessary" to develop their

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__, Case No. 3:20-cv-00195-SLG, 2021 WL 5756381 (D. Alaska Dec. 3, 2021), a case in which the State of Alaska and ADF&G "challenged the authority of the FSB in a context where it could have presented the same claims." Docket 21 at 6.

[25] Docket 21 at 7.

[26] Docket 24 at 2.

[27] Docket 5 at 17.

Appointments Clause arguments,[28] which implicitly acknowledges the current gaps in those arguments. Regarding Defendants' yet-unpled APA claims as to the FSB's actions, Defendants have not properly raised an APA claim nor rebutted the presumption of regularity that attaches to the FSB's actions.[29] In contrast, Plaintiff has established that ANILCA's rural subsistence use priority preempts the State's regulatory authority when Plaintiff has determined that restrictions are "necessary to meet tributary and drainage-wide escapement goals while allowing for some harvest by federally qualified subsistence users."[30]

B. Plaintiff and Intervenor-Plaintiff have shown that irreparable harm is likely to occur before the Court determines the case on its merits.

Plaintiff and Intervenor-Plaintiff contend that irreparable harm will occur in three ways, each of which Defendants dispute.

1. Irreparable harm to ANILCA's rural subsistence user priority.

Plaintiff's first and primary argument stresses ANILCA's federal subsistence user priority and asserts that the State's "interference with the FSB's ability to

[28] Docket 17 at 11.

[29] *San Luis & Delta-Mendota Water Auth. v. Jewell*, 747 F.3d 581, 601 (9th Cir. 2014).

[30] Docket 1-1 at 12; *see Gov't of Guam v. Guerrero*, 11 F.4th 1052, 1058 (9th Cir. 2021) ("We have held that a public actor is entitled to the presumption of regularity where there is some evidence that the public actor properly discharged the relevant official duties, which an opposing party must rebut with clear, affirmative evidence to the contrary.").

provide for federally qualified subsistence use constitutes irreparable injury to affected rural Alaskans."[31]

Intervenor-Plaintiff similarly contends that Defendants' "actions directly impact the Commission's co-management authority and interfere with its ability to carry out its responsibilities under the [Memorandum of Understanding]. This in itself constitutes an irreparable harm, as it directly threatens the sovereignty of the Commission's Member Tribes . . . ."[32]

Defendants respond that "ANILCA's rural subsistence use priority does not allow—much less require—the closure or restriction of fisheries in times of abundance when there is enough fish for everyone."[33] According to Defendants, Plaintiff has not shown that the State's fishing openers will result in the harvest of salmon, and thus ANILCA's rural subsistence use priority cannot be threatened by the State openers.[34] Defendants also respond that the State's openers help, not harm, the subsistence values and cultural identity of federally qualified subsistence users because "the involvement of . . . non-federally qualified users provides vital assistance for rural residents" who are federally qualified subsistence users.[35] As

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[31] Docket 5 at 18.

[32] Docket 14 at 3 (footnote omitted).

[33] Docket 17 at 35.

[34] Docket 17 at 35–36.

[35] Docket 17 at 37–38.

to Intervenor-Plaintiff, Defendants again point to alleged APA violations and also assert that Intervenor-Plaintiff has not presented evidence as to how tribal sovereignty is threatened by the State's actions.[36]

The Court finds that Plaintiff and Intervenor-Plaintiff have shown that irreparable harm will occur to the enforcement of ANILCA's rural subsistence user priority if the State's emergency order is not enjoined. Plaintiff and Intervenor-Plaintiff have shown "that enforcement of the [State's emergency order] in fact conflicts with federal . . . law and its objectives."[37] Promulgating a State emergency order that contradicts ANILCA's rural subsistence use priority violates the Supremacy Clause, and "an alleged constitutional infringement will often alone constitute irreparable harm"[38] even when the constitutional injury is structural, such as a Supremacy Clause violation.[39] Here, irreparable harm would necessarily result from the enforcement of a State emergency order that is likely preempted and in violation of the Supremacy Clause.

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[36] Docket 30 at 2–3.

[37] *Arizona v. United States*, 567 U.S. 387, 416 (2012).

[38] *United States v. Arizona*, 641 F.3d 339, 366 (9th Cir. 2011) (quoting *Associated Gen. Contractors v. Coal. for Econ. Equity*, 950 F.3d 1401, 1412 (9th Cir. 1991)), *rev'd in part on other grounds*, 567 U.S. 387 (2012); *accord Nelson v. Nat'l Aeronautics & Space Admin.*, 530 F.3d 865, 882 (9th Cir. 2008) ("Unlike monetary injuries, constitutional violations cannot be adequately remedied through damages and therefore generally constitute irreparable harm."), *rev'd on other grounds*, 562 U.S. 134 (2011).

[39] *Am. Trucking Ass'ns, Inc. v. City of Los Angeles*, 559 F.3d 1046, 1058 (9th Cir. 2009).

2. Uncertainty as to the legality of conflicting emergency orders will cause irreparable harm to federally qualified users.

Plaintiff next asserts that federally qualified users will be harmed by "uncertainty and confusion" if the State openers are not immediately enjoined.[40] According to Plaintiff, "Kuskokwim rural residents face the dilemma of coming closer to their historical subsistence harvest of salmon by capitalizing on the possibility of additional harvest under the State's openings, while facing possible enforcement action or other consequences of being found in violation of federal orders prohibiting such harvest."[41] Plaintiff also contends that the State's 2022 emergency orders "create a practical risk that large numbers of Alaskans will arrive at the State-appointed times to set gillnets on the Kuskokwim, resulting in unpredictable and extensive harvest of the depleted fisheries."[42]

Intervenor-Plaintiff has submitted considerable evidence that demonstrates how Defendants' emergency order has "sowed confusion."[43] Intervenor-Plaintiff points to the 2021 fishing season, when similar conflicting federal and state orders

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[40] Docket 5 at 18.

[41] Docket 5 at 19. The Court's Order Denying Plaintiff's Motion for Temporary Restraining Order acknowledged the confusion created by conflicting emergency orders but concluded that in the short time prior to the Court's determination of the preliminary injunction motion, that short-term confusion did not warrant a temporary restraining order. Rather, the Court determined "that the competing perspectives of the United States and the State of Alaska warrant the careful consideration by this Court that can only occur after full briefing on the preliminary injunction motion has been accorded to both parties." Docket 11 at 14.

[42] Docket 5 at 18–19.

[43] Docket 14 at 3.

were promulgated. The 2021 orders "caused widespread confusion for federally qualified subsistence fishers" who both needed to harvest salmon for subsistence but also worried about fishing illegally.[44]

Defendants respond that Plaintiff "has not presented any evidence to support [the] claim [that confusion and uncertainty will occur], much less that any harm resulted, even though . . . the same situation prevailed on the River" in summer 2021.[45] Defendants respond to Intervenor-Plaintiff's evidence of confusion by construing the 220 boats that were observed fishing on June 28, 2021, as evidence "that local residents ignored the Commission's message[,] . . . not evidence that they were confused."[46]

The Court finds that there is an irreparable harm to federally qualified subsistence users caused by the conflicting terms of the federal and state emergency orders, which may dissuade a federally qualified user from legal fishing opportunities or may cause a non-federally qualified user to harvest fish in violation

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[44] Docket 14 at 8 (quoting Docket 14-1 at 6, ¶ 12 (Decl. of Mike Williams, Sr.)). Mike Williams, Sr., the Chairman of the Commission, has averred that the language in the State's emergency order was confusing, "especially for rural subsistence fishers who may speak English as a second language." Docket 14-1 at 6, ¶ 12 (Decl. of Mike Williams, Sr.). Intervenor-Plaintiff maintains that it "received numerous phone calls from users who were confused by the State's announcement of a purported opening, and the Commission was forced to undertake significant outreach efforts . . . in an attempt to clarify the confusion. Docket 14 at 8. Outreach efforts included "the Commission's webpage and email newsletter, social media posting, radio talk show announcements, and extensive word-of-mouth communications. Docket 14-1 at 7, ¶14 (Decl. of Mike Williams, Sr.).

[45] Docket 17 at 39.

[46] Docket 30 at 5.

of federal law. Once confusion has prevented a federally qualified subsistence user from fishing—and thus working toward harvesting subsistence goals—or has prompted a non-federally qualified user to harvest salmon in violation of federal closures, neither the Court nor the parties can go back in time to remedy the harm financially. As emphasized by Intervenor-Plaintiff at oral argument, it is irrelevant whether the confusion causes one salmon or 10,000 salmon to be harvested by a non-federally qualified user, because "[y]ou can't give a fish back to the federally qualified users that was taken by a non-federally qualified user. We're not going to somehow compensate or be able to compensate the members of the federally recognized tribes along this portion of the [Kuskokwim River]."[47]

3. Kuskokwim River salmon populations.

Third, Plaintiff asserts that irreparable harm will occur because "Kuskokwim Chinook and chum salmon populations are in decline, and face risk of overharvest."[48] According to Plaintiff, the environmental injury to the Kuskokwim Chinook and chum salmon alone is a sufficient basis for a preliminary injunction.[49]

Intervenor-Plaintiff agrees that Defendants' actions "detrimentally impacted the Chinook and chum populations on which tribal members and other rural

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[47] Docket 34 at 4–5.

[48] Docket 5 at 20; *accord* Docket 5 at 17–18 (citing "threats to declining fisheries resources").

[49] Docket 5 at 19.

residents depend for their subsistence."[50] Intervenor-Plaintiff points to a single day during the 2021 season—June 28—when the State announced an opening despite the federal closure and "at least 220 boats fished and harvested salmon within the Refuge in reliance on the State's announced opening."[51] According to Intervenor-Plaintiff, "the events of last summer show that it is highly likely that users will rely on the State-announced openings and will harvest salmon in contravention of the federal closure. That is sufficient for preliminary injunction purposes . . . ."[52] Intervenor-Plaintiff also emphasizes that even a small amount of harvest by non-federally qualified users would cause irreparable harm: "Against the backdrop of the 'food security crisis' happening on the Kuskokwim, each additional salmon taken by non-federally qualified users directly threatens the ability of families along the Kuskokwim" to meet their subsistence needs.[53]

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[50] Docket 14 at 3–4.

[51] Docket 14 at 4; *accord* Docket 14-1 at 5, ¶ 10 (Decl. of Mike Williams, Sr.). Intervenor-Plaintiff contends that "no data exists regarding exactly how many Chinook and chum salmon were harvested within Refuge waters during the unlawful [State] opening" because ADF&G does not measure harvest numbers "despite being statutorily required to do so." Docket 14 at 4–5 (citing Alaska Stat. § 16.05.330(c)). Defendant responds that it is the Board of Fisheries' responsibility to comply with the cited Alaska statute, not the responsibility of ADF&G. Docket 30 at 4.

[52] Docket 14 at 5.

[53] Docket 14 at 7 (footnote omitted) (citing *Native Village of Quinhagak v. United States*, 35 F.3d 388 (9th Cir. 1994)); *see Native Village of Quinhagak*, 35 F.3d at 394 (holding that the plaintiff "needed to prove nothing more" than that the disputed waterway was a source of subsistence fishing and that the contested regulations interfered with their way of life and culture "in light of the clear congressional directive to protect the cultural aspects of subsistence living").

Defendants respond that Plaintiff and Intervenor-Plaintiff have presented insufficient evidence to demonstrate "that the State's actions in allowing limited openers on the Kuskokwim River will have a negative effect on the sustainability of the Chinook or chum runs."[54] Defendants point to Plaintiff's own actions of announcing "two drift[net] openers for June, with larger gear that more easily targets Chinook and purposefully removes salmon . . . from the allegedly critically depressed stock" as evidence that the State's "limited non-salmon openers" will not cause irreparable harm to the Kuskokwim River salmon runs.[55]

The Court acknowledges the parties' conflicting positions regarding whether there will be irreparable harm to the Kuskokwim River salmon populations if the State's emergency order remains in effect. However, because the Court finds that Plaintiff and Intervenor-Plaintiff have shown irreparable harm to the federal government's ability to enforce ANILCA's rural subsistence priority and irreparable harm to federally qualified subsistence users, it need not determine whether there would be irreparable harm to the salmon populations during the duration of this case if the State's emergency order remained in effect.

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[54] Docket 17 at 35; *see also* Docket 30 at 3.

[55] Docket 17 at 36.

C. Plaintiff has shown that the balance of equities tips in its favor, and a preliminary injunction is in the public interest.

Plaintiff submits that a preliminary injunction barring implementation of Defendants' emergency order would support Congress's "determination of equities—that on public lands, conservation and subsistence uses by rural Alaskans be given priority over other consumptive uses."[56] Plaintiff maintains that the Alaska Constitution cannot "authorize any state official to contravene a national policy expressed through a federal statute."[57]

Defendants respond that Plaintiff's position "assumes the outcome of the litigation—in effect, merging not just the equities and public interest, but also the probability of success on the merits."[58] According to Defendants, it they are "correct that the Board lacks jurisdiction, or was invalidly appointed, or invalidly delegated its authority, or that the Refuge Manager's orders are arbitrary and capricious, the national policy expressed in ANILCA has not been contravened and neither the equities nor the public interest support an injunction."[59]

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[56] Docket 5 at 21.

[57] Docket 5 at 21.

[58] Docket 17 at 40. Defendants also contend that "because both the plaintiff and the defendant in this action are 'governments,' the rule [that the balance of equities factor and the public interest factor merge] is not especially helpful here." Docket 17 at 40.

[59] Docket 17 at 40–41.

Plaintiff replies by reasserting that "[a]llowing a state to enforce a state law in violation of the Supremacy Clause is neither equitable nor in the public interest."[60]

Plaintiff and Intervenor-Plaintiff have met their burden of establishing that the balance of equities tips in their favor and that a preliminary injunction is in the public interest. Plaintiff is correct that the Ninth Circuit has held that allowing a state to enforce a regulation that violates a federal rule in violation of the Supremacy Clause is neither equitable nor in the public interest.[61] Moreover, if the State emergency order—for which the Court has found a likelihood of preemption—is in effect, the State's fishing openers would interfere with ANILCA's stated policy of prioritizing rural subsistence uses and would likely cause confusion to both federally qualified subsistence users and non-federally qualified subsistence users. The issuance of a preliminary injunction will allow Plaintiff to pursue federal priorities, which is inherently in the public interest, until a final decision on the merits is reached in this case.

CONCLUSION

In light of the foregoing, IT IS ORDERED that Plaintiff's Motion for Preliminary Injunction at Docket 5 is GRANTED. Defendants are hereby

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[60] Docket 21 at 16 (quoting *United States v. Arizona*, 703 F. Supp. 2d 980, 1007 (D. Ariz. 2010)).

[61] *Cal. Pharmacists Ass'n v. Maxwell–Jolly*, 563 F.3d 847, 852–53 (9th Cir. 2009); *Am. Trucking Ass'ns*, 559 F.3d at 1059–60.

ENJOINED, pending a final ruling by this Court, from implementing ADF&G Emergency Order #3-S-WR-02-22 and are further ENJOINED from taking similar actions that authorize gillnet fishing by all Alaskans on the Kuskokwim River within the Yukon Delta National Wildlife Refuge when such action(s) would be contrary to federal orders issued pursuant to Title VIII of the ANILCA.

DATED this 23rd day of June, 2022, at Anchorage, Alaska.

/s/ Sharon L. Gleason
UNITED STATES DISTRICT JUDGE

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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF ALASKA

THE UNITED STATES OF AMERICA, Plaintiff, v. THE STATE OF ALASKA, THE ALASKA DEPARTMENT OF FISH & GAME, and DOUG VINCENT-LANG, in his official capacity as Commissioner of the Alaska Department of Fish & Game, Defendants,	Case No. 1:22-cv-00054-SLG

PLAINTIFF'S MOTION FOR PRELIMINARY INJUNCTION
AND COMBINED MEMORANDUM IN SUPPORT

INTRODUCTION

The United States brings this suit to address Defendants' repeated actions that

contradict and interfere with federal orders taken to implement the rural subsistence priority established by Title VIII of the Alaska National Interest Lands Conservation Act, Pub. L. No. 96-487, 94 Stat. 2371, 2371-2551 (1980) (codified at 16 U.S.C. §§ 3111-3126) ("ANILCA"). This dispute focuses on gillnet harvest of salmon for subsistence use from the lower 180 miles of the Kuskokwim River located within the Yukon Delta National Wildlife Refuge ("Refuge"). Local rural residents depend on these salmon for their physical, economic, traditional, and cultural existence. However, in recent years it has become necessary to impose gillnet harvest restrictions to address conservation concerns for Kuskokwim River Chinook and chum salmon. ANILCA makes clear that any conflict between different uses of scarce or finite resources must be resolved in favor of the federal subsistence priority, which explicitly prioritizes rural Alaskans' use. Defendants, however, continue to authorize harvest in conflict with ANILCA, refusing to limit such harvest to local rural residents as required by federal orders effectuating that legally required priority. The United States hereby moves under Fed. R. Civ. P. 65 for a preliminary injunction, and separately for a temporary restraining order, to prohibit Defendants from continuing to authorize or implement actions that contravene the rural Alaskan subsistence priority and are preempted by federal law.

LEGAL BACKGROUND

Through ANILCA, Congress sought "to preserve Alaska's natural resources, historic sites, and ecosystems, while also providing the continued opportunity for rural residents to engage in a subsistence way of life." *Dep't of Fish & Game v. Fed.*

Subsistence Bd., No. 3:20-cv-00195-SLG, 2020 WL 5625897, at *5 (D. Alaska Sept. 18, 2020) (citing *Alaska v. Fed. Subsistence Bd.*, 544 F.3d 1089, 1091 (9th Cir. 2008)).

The Federal Subsistence Board ("FSB") administers the federal subsistence program in accordance with Title VIII of ANILCA, to preserve a way of life "essential to Native physical, economic, traditional, and cultural existence and to non-Native physical, economic, traditional, and social existence." 16 U.S.C. § 3111(1). Congress directed that "nonwasteful subsistence uses of fish and wildlife . . . shall be the priority consumptive uses of all such resources on the public lands of Alaska" and that, when it is necessary to restrict taking of fish and wildlife for enumerated reasons, "the taking of such population for nonwasteful subsistence uses shall be given preference on the public lands over other consumptive uses." 16 U.S.C. § 3112(2). While establishing the rural subsistence priority, Congress made it clear that even subsistence uses must yield to conservation of healthy populations of fish and wildlife. *See* 16 U.S.C. § 3125(1).

ANILCA defines "subsistence uses" to mean:

> the customary and traditional uses by rural Alaska residents of wild, renewable resources for direct personal or family consumption as food, shelter, fuel, clothing, tools, or transportation; for the making and selling of handicraft articles out of nonedible byproducts of fish and wildlife . . . ; for barter, or sharing for personal or family consumption; and for customary trade.

16 U.S.C. § 3113. This definition specifies that the priority applies only to *rural* Alaskans. Also, the term "customary and traditional uses" carries significant weight, because "[i]n the course of its administration, the FSB '[d]etermine[s] which rural Alaska areas or communities have customary and traditional subsistence uses of specific fish and

wildlife populations.'" *Alaska*, 544 F.3d at 1092 (quoting 50 C.F.R. § 100.10(d)(4)(iii)). The term "federally qualified users" typically describes users meeting these criteria.

"Congress authorized the Secretary of the Interior and the Secretary of Agriculture to promulgate regulations in furtherance of its directives; they created the FSB and charged it with 'administering the subsistence taking and uses of fish and wildlife on public lands.'" *Dep't of Fish & Game v. Fed. Subsistence Bd.*, 501 F. Supp. 3d 671, 683 (D. Alaska 2020) (quoting *Fed. Subsistence Bd.*, 544 F.3d at 1092 n.1); *see* 50 C.F.R. Part 100.[1] These regulations empower the FSB and federal officials to implement the federal subsistence priority, and otherwise manage subsistence taking and uses on public lands as required by ANILCA. *See* 50 C.F.R § 100.10(d)(4).

FACTUAL BACKGROUND

A. The Kuskokwim River and Salmon Conservation

At over 700 miles long, the Kuskokwim River is the longest free-flowing river in the United States. It drains a remote area of the Alaska interior on the north and west side of the Alaska Range and flows generally westward into Kuskokwim Bay on the Bering Sea. There are numerous subsistence-dependent rural villages along the river and its tributaries, comprised primarily of members of the 33 different federally recognized Tribes located in the Kuskokwim drainage area. The lower 180 river miles are within the

[1] Identical regulations promulgated by the Department of Agriculture are found at 36 C.F.R. Part 242. Citations here are to the Department of the Interior regulations at Title 50 of the Code of Federal Regulations.

boundaries of the Refuge. *See* Decl. of Boyd Blihovde ¶¶ 3, 7, ECF No. 5-1.

The Kuskokwim River supports stocks of Chinook (or king), chum (dog), sockeye (red), humpback (pink), and coho (silver) salmon. To conserve healthy populations of salmon, the State of Alaska, through its Department of Fish & Game ("ADF&G"), sets minimum goals for escapement of the five species of salmon to allow them to spawn.[2] For instance, the State's escapement goal for Chinook on the Kuskokwim is a range of between 65,000 and 120,000 fish. *Id.* ¶ 4. However, both the federal in-season manager and the Kuskokwim River Inter-Tribal Fish Commission ("Inter-Tribal Fish Commission"), comprised of local residents with traditional ecological knowledge of salmon fisheries as well as a former federal biologist, have concluded that the escapement goal for Chinook must be set at a minimum of 110,000 to preserve and enhance future run strength.[3] *Id.* ¶¶ 10, 11. While the 25-year average escapement is 243,000 Chinook, even the minimum State escapement goal was unmet in 2010, 2011, 2012, and 2013, and

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[2] Escapement refers to the number of fish allowed to escape the active fishery and reach traditional spawning areas. Blihovde Decl. ¶ 4. Fish counts occur using sonar transducers on the river bottom that allow for imaging and logging the numbers and species of passing fish, through visual counts at weirs on several tributaries, through an established test gillnet fishery, and through aerial surveys throughout the lower, middle, and headwater tributaries.

[3] The 33 Kuskokwim area tribes formed the Inter-Tribal Fish Commission (often referred to as "KRITFC") to provide traditional knowledge and input to federal fisheries managers. Blihovde Decl. ¶ 7. While federal regulations do not prescribe escapement numbers, the federal in-season manager concurs with the Inter-Tribal Fish Commission that managing for escapement of 110,000 Chinook is appropriate to ensure long-term conservation. *Id.* ¶ 10.

was just barely met in several other recent years, despite conservation efforts. *Id.* ¶ 5. In 2020, roughly 116,000 Chinook salmon returned, with escapement estimated at 88,000. *See* https://www.adfg.alaska.gov/static/applications/dcfnewsrelease/1229575804.pdf at 4 (last visited May 24, 2022) ("2020 Report"). In 2021, the total Chinook return numbered about 129,000 Chinook, with escapement estimated by roughly 101,000 of them. *See* https://www.adfg.alaska.gov/static/applications/dcfnewsrelease/1345527186.pdf at 4 (last visited May 24, 2022) ("2021 Report").

As for chum salmon, estimated 2020 escapement of 19,032 – described as "weak but adequate" – fell towards the bottom range of ADFG's goal of 15,000-49,000 fish. 2020 Report at 4. And in 2021, chum salmon escapement was "the lowest on record" with only 4,153 fish tallied at the historical reference point, well below the 15,000-fish lower end of ADF&G's target escapement range. 2021 Report at 4.

Conservation efforts are further complicated by the fact that the run timing of these different species sufficiently overlap to make it impossible to selectively harvest more healthy species without inadvertently catching those subject to conservation concerns. Blihovde Decl. ¶ 12. Gillnetting is the only practical method for catching enough salmon to meet subsistence needs on the Kuskokwim, but gillnets lethally intercept returning fish and do not allow for selective return of any fish to the river unharmed. *Id.*

B. Federal Management Decisions and Conflicting State Actions

Every year since 2012, both federal and state managers have agreed that a

downward trend in the Chinook salmon population and consistently low pre-season run projections necessitate emergency closures to gillnet fishing at the start of the season for a period of at least several weeks until run strength can be verified and adequate escapement assured. Federal managers have authorized short openings during those extended closures to subsistence fishing by federally qualified users to address the ANILCA Title VIII priority. Federal decision-making always follows pre-season and in-season coordination between state and federal managers, and consultation with the Inter-Tribal Fish Commission, the Kuskokwim River Salmon Management Working Group, and the Chair of the local Subsistence Regional Advisory Council.[4]

Starting in late 2020 and into the first half of 2021, the Refuge manager (and federal in-season manager), Boyd Blihovde, participated in a number of discussions with the Inter-Tribal Fish Commission, ADF&G representatives, and interested stakeholders in preparation for the upcoming season. Blihovde Decl. ¶ 9. Mr. Blihovde issued a federal emergency special action on May 7, 2021, in which he closed the Kuskokwim River main stem to the harvest of all salmon using gillnets, and also closed various tributaries to the harvest of Chinook and the use of all gillnets effective June 1, 2021. *See* Emergency Special Action ("ESA") #3-KS-01-21; Compl. Ex. 1 at 2, ECF No. 1-1. Only federally qualified users were permitted to conduct subsistence fishing for salmon, using

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[4] Ten subsistence regional advisory councils comprised of local residents with traditional knowledge of fish and wildlife in their respective regions provide input into the FSB's decision-making process. The State formed the Kuskokwim River Salmon Management Working Group for consultation and coordination purposes, which also consists of local residents.

dip nets, rod and reel, and other methods allowing for the live release of Chinook. *Id.* at 3. Except for federal subsistence-only openings, the federal closure remained in effect until July 22, 2021. In making his closure decision, Mr. Blihovde relied heavily on both ADF&G's preseason forecast of 94,000-155,000 Chinook and the historical Chinook subsistence harvest range of 67,200-109,800, which, if unrestricted, would mean an escapement projection ranging from 0 to 87,800, well under federal escapement goals even under the best-case scenario. *Id.* at 4. Moreover, much of that escapement range would fall below even the State's goal of 65,000, which the State has deemed necessary to maintain the Chinook salmon population. *See* Blihovde Decl. ¶ 13.

The same May 7 ESA prescribed limited subsistence harvest opportunities for federally qualified subsistence users only, through the use of nearshore set gillnets on June 2, 5, and 9; and the use of set or drift gillnets during 12-hour periods on June 12 and 15. *Id.* at 3. Mr. Blihovde subsequently announced additional openings to federally qualified subsistence users, starting with an ESA allowing harvest with set or drift gillnets for 12 hours on June 19. *See* ESA #3-KS-02-21, Compl. Ex. 1 at 5. He further announced openings to the use of set or drift gillnets downstream of Kalskag Bluffs during 9 or 12-hour periods on July 2, 9, and 16; and harvest with nearshore set gillnets only on July 10-11, and 17-18. *See* ESA #3-KS-03-21, Compl. Ex. 1 at 7-8.

Defendants undermined these federal closure orders in 2021 by issuing their own orders purporting to open the River to all Alaskans. ADF&G first announced a closure to the use of gillnets on the Kuskokwim within the Refuge from June 1 until further notice

consistent with the federal closure. *See* Emergency Order ("EO") #3-S-WR-01-21, Compl. Ex. 2 at 2-4, ECF No. 1-2. But the State then proceeded to adopt several emergency orders purporting to authorize gillnet openings to all Alaskans[5] on Refuge waters during some of the same periods that Mr. Blihovde had announced openings only for federally qualified subsistence users. On May 11, ADF&G adopted an order providing subsistence fishing opportunities for all Alaskans along the entire length of the river within the Refuge with nearshore set gillnets on June 2, 5, and 9. *See* EO #3-S-WR-02-21, Compl. Ex. 2 at 5-6. On June 10, ADF&G ordered subsistence fishing opportunities for all Alaskans with set or drift gillnets along the entire length of the river within the Refuge on June 12 and 15. *See* EO #3-S-WR-04-21, Compl. Ex. 2 at 7-8. On June 18, ADF&G adopted an order allowing opportunities for set or drift gillnet fishing in the easternmost section of the Kuskokwim River within the Refuge (known as section 3) starting on June 19 until further notice even though the federal closure remained in effect. *See* EO #3-S-WR-06-21, Compl. Ex. 2 at 9-10. On July 1, ADF&G adopted an order allowing multiple openings, including using set or drift gillnets in the main stem downstream of Kalskag Bluffs during 9 or 12-hour periods on July 2, 9, and 16 and using nearshore set gillnets on July 10 and 17. *See* EO #3-S-WR-08-21, Compl. Ex. 2 at 14-16.

This pattern prompted communications between the FSB and ADF&G. *See*

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[5] ADF&G interprets "subsistence use" to include "all Alaska residents[.]" *See* https://www.adfg.alaska.gov/index.cfm?adfg=subsistence.definition#:~:text=Both%20Alaska%20state%20law%20(AS,%2C%20barter%2C%20and%20customary%20trade (citing Alaska Stat. § 16.05.940(32)) (last visited May 24, 2022).

generally Compl. Ex. 3, ECF No. 1-3. On May 27, 2021, the Board wrote a letter to "invite discussion" between federal and state officials to more effectively collaborate, and observed that collaboration "has improved significantly[.]" *Id.* at 10-11. In a response dated June 3, 2021, Commissioner Vincent-Lang declined to address the ANILCA rural subsistence priority, but instead conveyed the State's conclusion that there are sufficient salmon to allow harvest by all Alaskans and discussed his perceived obligation pursuant to the Alaska State Constitution to provide for all Alaskans. *Id.* at 13.

In a response dated June 24, 2021, FSB Chair Anthony Christianson reiterated the FSB's rationale and legal obligations under ANILCA Title VIII, while expressing the need for the FSB and the State to work together to attempt to meet both state and federal mandates through coordinated planning efforts. *Id.* at 16-17. The next day, the ADF&G announced an opportunity for subsistence gillnet harvest by all Alaskans to occur on June 28. *See* EO #3-S-WR-07-21, Compl. Ex. 2 at 12-13. There was no opportunity for gillnet harvest on that date for federally qualified subsistence users.

A similar pattern has begun for the 2022 Kuskokwim River salmon fishery. Following similar coordination and outreach as occurred leading up to the 2021 season, Mr. Blihovde issued a federal emergency special action on May 2, 2022, in which he closed the Kuskokwim River main stem to the gillnet harvest of all salmon effective June 1, 2022. *See* ESA #3-KS-01-22, Compl. Ex. 1 at 10. As in 2021, this same announcement included limited openings for federally qualified users to harvest salmon by set gillnet on June 1, 4 and 8, 2022, and to harvest salmon by set and drift gillnet on

June 12 and 16, 2022. *Id.* at 11. In similar fashion, as in 2021, ADF&G announced on May 13, 2022, a closure to the use of gillnets on the Kuskokwim within the Refuge for reasons of conservation from June 1 until further notice consistent with the federal closure. *See* EO #3-S-WR-01-22, Compl. Ex. 2 at 17-18. And then ADF&G issued a second announcement on the same day, purporting to authorize gillnet openings to all Alaskans on Refuge waters on June 1, 4, and 8, 2022, during three of the same periods that Mr. Blihovde had announced openings only for federally qualified subsistence users. *See* EO #3-S-WR-02-22, Compl. Ex. 2 at 19-20; Blihovde Decl. ¶ 16.

Plaintiff has engaged meaningful efforts to resolve the underlying dispute, including in 2022. *See* Decl. of Raina Thiele ¶¶ 2-6, ECF No. 5-2. Unfortunately, the parties have not reached sufficient agreement, making it necessary for Plaintiff to file this action, and the instant motion. *Id.* ¶¶ 9-10.

LEGAL STANDARD

Injunctive relief is an equitable remedy, and "[t]he essence of equity jurisdiction is the power of the court to fashion a remedy depending upon the necessities of the particular case." *Sierra Forest Legacy v. Rey*, 577 F.3d 1015, 1022 (9th Cir. 2009) (quoting *U.S. v. Odessa Union Warehouse Co-op*, 833 F.2d 172, 175 (9th Cir. 1987)). A plaintiff seeking a preliminary injunction must show: "(1) it is likely to succeed on the merits; (2) it is likely to suffer irreparable harm if the preliminary injunction is not granted; (3) the balance of equities tips in its favor; and (4) an injunction is in the public's interest." *Conservation Cong. v. U.S. Forest Serv.*, 720 F.3d 1048, 1054 (9th Cir. 2013)

(citing *Winter v. Nat. Res. Def. Council*, 555 U.S. 7, 20 (2008)).

ARGUMENT

Plaintiff meets its burden here because: (1) it is likely to succeed on the merits; (2) irreparable harm is likely in the absence of preliminary injunctive relief; (3) the balance of equities favors preliminary injunctive relief; and (4) a preliminary injunction serves the public interest. *See Winter*, 555 U.S. at 20.

A. Plaintiff is Likely to Prevail on the Merits

Federal law preempts the State's orders addressing subsistence fishing within the Refuge. There exists an actual and ongoing controversy, and the Court can "declare the rights and other legal relations" of the parties in accordance with the Declaratory Judgment Act. 28 U.S.C. § 2201.

The Supremacy Clause states: "[t]his Constitution, and the laws of the United States . . . shall be the supreme law of the land; and the judges in every state shall be bound thereby, any Thing in the Constitution or Laws of any State to the contrary notwithstanding." U.S. Const. art. VI, cl. 2. The Supremacy Clause "provides 'a rule of decision' for determining whether federal or state law applies in a particular situation." *Kansas v. Garcia*, 140 S. Ct. 791, 801 (2020) (quoting *Armstrong v. Exceptional Child Center, Inc.*, 575 U.S. 320, 324 (2015)). Equitable relief "is traditionally available to enforce federal law." *Armstrong*, 575 U.S. at 327, 329 (2015).[6] The Supreme Court has

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[6] The Supreme Court in *Armstrong* explained that the Supremacy Clause "does not create a cause of action. It instructs courts what to do when state and federal law clash,

"identified three different types of preemption – conflict, express, and field – but all of them work in the same way: Congress enacts a law that imposes restrictions or confers rights on private actors; a state law confers rights or imposes restrictions that conflict with the federal law; and therefore the federal law takes precedence and the state law is preempted." *Murphy v. Nat'l Collegiate Athletic Ass'n*, 138 S. Ct. 1461, 1480 (2018) (internal quotation marks and citation omitted); *see also Chamber of Com. of United States v. Bonta*, 13 F.4th 766, 773-74 (9th Cir. 2021).

This dispute raises issues of conflict preemption. "Such a conflict arises when compliance with both federal and state regulations is a physical impossibility, or when a state law stands as an obstacle to the accomplishment and execution of the full purposes and objectives of Congress." *Wisconsin Pub. Intervenor v. Mortier*, 501 U.S. 597, 605 (1991) (internal quotation marks and citations omitted). In this case, the State's management actions on the Kuskokwim River within the Refuge contradict federal management efforts and create an obstacle to ANILCA's federal purposes and objectives of prioritizing the subsistence use of Chinook and chum salmon within the Refuge over all other uses.

"ANILCA, read as a whole, clearly expresses Congress's intent to create a federal regulatory scheme 'to protect the resources related to subsistence needs' and 'to provide

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but is silent regarding who may enforce federal laws in court, and in what circumstances they may do so." 575 U.S. at 325. This holding does not constrain the United States' ability to "enforce federal laws in court." Rather, the holding appears to limit the ability of private litigants to enforce federal statutes. *See, e.g.*, *Alexander v. Sandoval*, 532 U.S. 275, 286-87 (2001).

the opportunity for rural residents engaged in a subsistence way of life to continue to do so.'" *John v. United States*, 247 F.3d 1032, 1036 (9th Cir. 2001) (en banc) (Tallman, J., concurring) (quoting 16 U.S.C. § 3101(b)-(c)). This Court has recognized that "Title VIII of ANILCA expressly provides that the FSB has the authority to restrict the taking of wildlife on federal public lands . . . [and] that by its plain language Section 815 of ANILCA gives the FSB the authority to adopt restrictions on nonsubsistence uses" as appropriate to ensure continued subsistence use. *Dep't of Fish & Game*, 2020 WL 5625897, at *8. Indeed, courts have enforced the subsistence mandate upon finding that the FSB insufficiently prioritized federally qualified subsistence users over non-federally qualified users. *See Ninilchik Traditional Council v. United States*, 227 F.3d 1186, 1195 (9th Cir. 2000) (upholding validity of a ten-day "advance season" but finding that two days failed to "qualify as a priority" for subsistence hunting).

ANILCA, thus, not only contemplates, but also prescribes the outcome of "a clash of lifestyles and a dispute over who gets to fish. Congress, using clear language, has resolved this dispute in favor of the [federally qualified users] who choose to pursue the traditional subsistence way of life by giving them priority in federal waters." *Kenaitze Indian Tribe v. State of Alaska*, 860 F.2d 312, 318 (9th Cir. 1988). As in *Kenaitze*, Defendants here "ha[ve] attempted to take away what Congress has given[.]" *Id.*

Finally, insofar as Defendants may contend that their management actions are not preempted because ANILCA recognizes a role for Alaska in the management of natural resources, this view does not alter the legal analysis. The Ninth and Tenth Circuits have

rejected similar arguments in the context of the statutory scheme addressing the National Wildlife System.[7] *See Nat'l Audubon Society, Inc. v. Davis*, 307 F.3d 835 (9th Cir. 2002), *amended on denial of reh'g*, 312 F.3d 416 (9th Cir. 2002) (concluding that a California law purporting to ban the use of leghold traps within units of the Refuge System was preempted by contrary authorizations issued by federal managers); *Wyoming v. United States*, 279 F.3d 1214 (10th Cir. 2002) (upholding FWS's refusal of the State of Wyoming's request to vaccinate wild elk against brucellosis on the National Elk Refuge near Jackson, Wyoming). Both courts rejected arguments based on the Refuge Act's savings clause.[8] While acknowledging the traditional role of the states in managing wildlife within their borders, the Tenth Circuit ultimately affirmed the district court's dismissal of the Wyoming's claim:

> If we construed the [Refuge Act] to grant the State of Wyoming the

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[7] That statute is the National Wildlife Refuge System Improvement Act of 1997 ("Refuge Act"), Pub. L. No. 105-57, 111 Stat. 1252-1260 (codified at 16 U.S.C. §§ 668dd-668ee) (as amended) (amending the National Wildlife Refuge System Administration Act of 1966, Pub. L. No. 89-669, 80 Stat. 926-930 (as amended)).

[8] The Refuge Act savings clause provides:

> Nothing in this Act shall be construed as affecting the authority, jurisdiction, or responsibility of the several States to manage, control, or regulate fish and resident wildlife under State law or regulations in any area within the System. Regulations permitting hunting or fishing of fish and resident wildlife within the System shall be, to the extent practicable, consistent with State fish and wildlife laws, regulations, and management plans.

16 U.S.C. § 668dd(m); *see Wyoming*, 279 F.3d at 1229.

> sweeping power it claims, the State would be free to manage and regulate the [Elk Refuge] in a manner the FWS deemed incompatible with the [Refuge]'s purpose. But the Secretary alone is authorized, "under such regulations as he may prescribe," to "permit the use of any area within the System for any purpose . . . whenever he determines that such uses are compatible with the major purposes for which such areas were established[.]"

Id. at 1234 (quoting 16 U.S.C. § 668dd(d)(1)(A)).

This Court relied upon *National Audubon Society* and *Wyoming* in extending a similar conflict preemption analysis to ANILCA. In *Alaska v. Bernhardt*, 500 F. Supp. 3d 889 (D. Alaska 2020), *aff'd sub nom. Safari Club Int'l v. Haaland*, 31 F.4th 1157 (9th Cir. 2022), the State attempted to employ ANILCA's savings clause[9] as a foothold establishing State sovereignty, from which to invert the preemption analysis and overturn a federal statutory management scheme for the Kenai National Wildlife Refuge. 500 F. Supp. 3d at 910-11. The Court rejected the argument and determined that ANILCA "§ 1314 specifically contemplates that federal law will apply to NWRs, and where there is a clear conflict between federal and state law, the federal law controls." *Id.* at 914. The Court concluded that ANILCA represents a "careful regulatory scheme established by federal law" and "that § 1314(a) 'was not meant to eviscerate the primacy of federal

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[9] This savings clause is found in the "administrative provisions" ANILCA Title XIII, codified at 16 U.S.C. § 3202. It states, "[n]othing in this Act is intended to enlarge or diminish the responsibility and authority of the State of Alaska for management of fish and wildlife on the public lands except as may be provided in subchapter II of this chapter [(providing for subsistence management)], or to amend the Alaska constitution," *id.* (a), and further states that taking of fish and wildlife in conservation system units "shall be carried out in accordance with the provisions of this Act and other applicable State and Federal law[,]" *id.* (c).

authority over [national wildlife refuge] management' and instead reflects Congress's intent that 'ordinary principles of conflict preemption apply' to disputes involving ANILCA." *Id.* at 915 (quoting *Nat'l Audubon Soc'y*, 307 F.3d at 854, and *Wyoming*, 279 F.3d at 1234).

Finally, Alaska attempted a similar argument in *Department of Fish & Game v. Federal Subsistence Board*, No. 3:20-CV-00195-SLG, 2021 WL 5756381 (D. Alaska Dec. 3, 2021), which this Court also rejected. In challenging subsistence-based federal closure orders similar to the ones at issue here, Alaska argued that ANILCA "expressly protects the State's authority to manage wildlife, including on federal public lands." *Id.* at *16 (internal quotations omitted). This Court disagreed, and held instead that, "[b]y granting to federal agencies the authority to impose closures under certain circumstances, ANILCA necessarily tolerates some level of federal interference with state authority if an action is otherwise permissible under section 815." *Id.* The same is true here.

In sum, Defendants' actions opening the River to fishing in contravention of federal closure orders both violate the federal orders and stand as an obstacle to the accomplishment and execution of Congress's full purposes in Title VIII of ANILCA. Accordingly, Plaintiff has a likelihood of succeeding on the merits of its preemption claim for purposes of obtaining preliminary injunctive relief.

B. Irreparable Injury is Likely Absent Immediate Injunctive Relief

Irreparable injury is likely in the absence of preliminary injunctive relief. This injury occurs through erosion of cultural identity that Congress sought to preserve

through ANILCA, as well as through threats to declining fisheries resources.

Interference with the FSB's ability to provide for federally qualified subsistence use constitutes irreparable injury to affected rural Alaskans. For local villages comprised almost entirely of federally qualified users, both native and non-native, salmon is a critically important food source. *See* Blihovde Decl. ¶ 8 (and attached KRITFC Report); *Native Vill. of Quinhagak v. United States*, 35 F.3d 388, 393 (9th Cir. 1994). Each opportunity for harvest with a priority over others is important, and cannot be regained once gone. Moreover, every salmon harvested by non-federally qualified users is one less salmon available to upstream rural residents. This compounds existing threats to subsistence use, and local cultural identity, relating to multiple factors affecting Kuskokwim salmon, including the threat of overharvest. *See* Blihovde Decl. at 17-18, 27-28. "Many Alaska natives who are not fully part of the modern economy rely on fishing for subsistence. If their right to fish is destroyed, so too is their traditional way of life." *United States v. Alexander*, 938 F.2d 942, 945 (9th Cir. 1991). It is enough to show that the State's regulations "interfere with [the villages'] way of life and cultural identity" – they need "to prove nothing more in light of the clear congressional directive to protect the cultural aspects of subsistence living." *Native Vill. of Quinhagak*, 35 F.3d at 394 (quoting 16 U.S.C. § 3111(1)).

The State's concerted approach to this controversy also creates uncertainty and confusion rising to the level of irreparable injury. The State's openings create a practical risk that large numbers of Alaskans will arrive at the State-appointed times to set gillnets

on the Kuskokwim, resulting in unpredictable and extensive harvest of the depleted fisheries. And Kuskokwim rural residents face the dilemma of coming closer to their historical subsistence harvest of salmon by capitalizing on the possibility of additional harvest under the State's openings, while facing possible enforcement action or other consequences of being found in violation of federal orders prohibiting such harvest. The State, moreover, seemingly intends to fuel, not resolve, these uncertainties. *See* Compl. Ex. 3 at 21-22 (ADF&G Commissioner admonishing that "*[i]rrespective of federal authorities*, the State of Alaska has a constitutional responsibility to manage for sustainable salmon runs and provide a subsistence opportunity for Alaskans when there is a harvestable surplus of salmon" and cautioning that the State "will continue to manage the river and fishery based on *its* assessment of run strength") (emphasis added).

Furthermore, the imperiled Kuskokwim salmon runs likely face irreparable harm if Defendants' actions are not enjoined. Courts often find that sufficiently likely "environmental" injury, such as to the depleted Kuskokwim Chinook and chum salmon populations, provides a basis for injunctive relief. *See United States v. Oregon*, 718 F.2d 299, 305 (9th Cir. 1983) (allocating treaty and non-treaty fishing rights); *Nw. Env't Def. Ctr. v. U.S Army Corps of Eng'rs & Nat'l Marine Fisheries Serv.*, 558 F. Supp. 3d 1056, 1063-64 (D. Or. 2021); *cf. Nat'l Wildlife Fed'n v. Nat'l Marine Fisheries Serv.*, 886 F.3d 803, 822 (9th Cir. 2018) (analyzing impacts to listed species under the ESA). A State manager's opinions about species abundance do not control analysis of the likelihood of irreparable injury. *See Confederated Tribes & Bands of Yakama Indian Nation v.*

Baldrige, 898 F. Supp. 1477, 1489 (W.D. Wash. 1995) (finding "possibility of an excessive harvest" under challenged plan), *aff'd,* 95 F.3d 1157 (9th Cir. 1996), and *aff'd,* 91 F.3d 1366 (9th Cir. 1996). But even to the extent the State's views on species abundance are relevant to this Court's inquiry, the State's views are best evidenced by its recent request for a federal "fishery disaster determination" for the 2021 Kuskokwim River salmon fishery under the Magnuson-Stevens Fishery Conservation and Management Act. *See* https://media.fisheries.noaa.gov/2022-05/121_Dunleavy%202021%20Kuskokwim%20salmon.pdf (last visited May 24, 2022).

This dispute arises in the context of the ANILCA Title VIII subsistence use priority. Kuskokwim Chinook and chum salmon populations are in decline, and face risk of overharvest. The State's efforts to provide harvest opportunities for all Alaskans undermine the federal subsistence priority, diminish subsistence uses and cultural identity, and threaten the resources. Plaintiff has shown sufficient likelihood of irreparable injury to enjoin Defendants' actions during the impending 2022 Kuskokwim fishing season.

C. The Equities and Public Interest Favor an Injunction

In the unique context of this dispute, ANILCA provides a clear indication that the equities and public interest tip in favor of an injunction. When the federal government is a party, "the balance of equities factor and the public interest factor merge." *Jones v. Bonta*, No. 20-56174, 2022 WL 1485187, at *5 (9th Cir. May 11, 2022).

When it promulgated Title VIII in 1980, Congress established a national policy –

and with it, a determination of equities – that on public lands, conservation and subsistence uses by rural Alaskans be given priority over other consumptive uses. *See* 16 U.S.C. § 3112(2), 3114. It adopted this policy because "the continuation of the opportunity for subsistence uses by rural residents of Alaska, including both Natives and non-Natives, . . . is essential to Native physical, economic, traditional, and cultural existence and to non-Native physical, economic, traditional, and social existence." 16 U.S.C. § 3111(1).

In his communications with the FSB, Commissioner Vincent-Lang points to the Alaska State Constitution as ADF&G's basis for taking actions that undermine federal law. *See* Compl. Ex. 3 at 9 (opining there exists "no reason to restrict opportunity for state qualified users"); 13 (justifying Kuskokwim openings to all Alaskans as addressing "my constitutional obligations"). But nothing in a state's constitution can authorize any state official to contravene a national policy expressed through a federal statute adopted with the long-term goals of requiring conservation of resources and protecting the interests of rural Alaskans in meeting their subsistence needs, preserving their culture, and continuing their way of life. *See Safari Club Int'l v. Haaland*, 31 F.4th 1157, 1169 (9th Cir. 2022). The State's own Working Group, made up of elders, those who practice subsistence, commercial and sport fishing, processors, and others, recommends against state actions that undermine the federal priority. *See* http://www.adfg.alaska.gov/static-f/fishing/PDFs/commercial/krsmwg/2021/05_03-04_21_summary.pdf at 4 (describing motion "to recommend to ADF&G to not have concurrent setnet and driftnet openers to

those announced by the US Fish and Wildlife Service during a Federal Special Action" passed by vote of 6 yes, 1 no, 2 abstentions) (last visited May 24, 2022).

The State cannot plausibly dispute that the federal subsistence priority requires establishment of a "meaningful use preference." *Ninilchik Traditional Council*, 227 F.3d at 1193. Yet here, the State has threatened and continues to threaten those very things that Congress sought to safeguard through the Title VIII rural subsistence priority. For these reasons, the Court should find that the balance of equities and public interest tip strongly in favor of preliminary injunctive relief.

CONCLUSION

For the foregoing reasons, Plaintiffs respectfully requests that the Court grant its motion, and enter a preliminary injunction enjoining implementation of Defendants' EO #3-S-WR-02-22, or from taking similar actions interfering with or contravening federal orders issued pursuant to ANILCA Title VIII.

Respectfully submitted,

DATED: May 24, 2022.

TODD KIM
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CERTIFICATE OF COMPLIANCE

Pursuant to Local Civil Rule 7.4(a)(3), I hereby certify that this memorandum complies with the type-volume limitation of Local Civil Rule 7.4(a)(2), because this memorandum contains 5,633 words, excluding the parts exempted by Local Civil Rule 7.4(a)(4). This memorandum has been prepared in a proportionately spaced typeface, Times New Roman 13-point font, and I obtained the word count using Microsoft Word 2016 (16.0.5290.1000) MSO (16.0.5278.1000) 32-bit.

/s/ Paul A. Turcke
Paul A. Turcke

CERTIFICATE OF SERVICE

I hereby certify that on May 24, 2022, a copy of the foregoing was served by electronic means on all counsel of record by the Court's CM/ECF system.

/s/ Paul A. Turcke
Paul A. Turcke

			EPA Comment on the Response(s)	Response(s) from the Comment Analysis Report (CAR)	CODE
CHAPTER 1. PURPOSE AND NEED					
1.4.1	13	cg	that dredged or fill material should not be discharged into wetlands and other waters unless it can be demonstrated that the discharge will not have unacceptable adverse impacts on those waters	Should avoidance and minimization be discussed?	**CLA 29**
We note that this section is no longer included in the PFEIS and Chapter 1 does not seem to discuss this issue regarding the discharge of dredged or fill material into waters of the United States. The White House Council on Environmental Quality (CEQ) NEPA regulations contain requirements to avoid impacts where possible, minimize impacts that can't be avoided, and mitigate for the remaining impacts. We recommend that avoidance and minimization be discussed in Chapter 1, upfront in the FEIS.				***CLA 29*** *- Recommendations for clarification in Chapter 1 were reviewed and incorporated as applicable.*	
CHAPTER 2. ALTERNATIVES					
2.3.2.2.6	2-49	MJ	No public use would be allowed.	How will this provision be monitored and enforced? Would the public be allowed to cross the road on ATV, snow machine, etc.? There should be some concessions to allow public access/crossing for recreation, subsistence activities, etc.	**LAND 16**
We note that the PFEIS currently indicates no public use of the road, and we have made recommendations in our comments on the PFEIS to clarify this decision regarding public use of the road for agency decision makers and the public to consider when evaluating project alternatives. We also recommend that the response in the CAR identify the specific text, section and/or page number where our comment was addressed in the FEIS.				***LAND 16*** *- Suggested mitigation measures added to Chapter 5, Table 5.5-1, Mitigation Measures being Considered by the Corps. Clarifications added regarding public crossing and winter use of the mine access road, when mine-related traffic would not be present.*	
Tab 2.3-17	2-77	MJ		Identify presence/absence of anadromous fish overwintering. Discuss measures to minimize impacts to fish during water withdrawal.	**FISH 15**
We continue to recommend that measures to minimize impacts to anadromous fish over the winter be discussed in the FEIS. We also recommend that the response in the CAR identify the specific mitigation measure number, section and/or page number where our comment was addressed in the FEIS (Chapter 5; Table 5.2-1).				***FISH 15*** *- Included in the comprehensive list of mitigation measures described in Chapter 5 are those associated with fish and aquatic resources, as well as other related resources (e.g., surface and groundwater hydrology and water quality). A description of mitigation monitoring and adaptive management strategies is described in Section 5.7 of that chapter. In some cases, specific details will not be developed until final design*	

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			EPA Comment on the Response(s)	Response(s) from the Comment Analysis Report (CAR)	CODE
				groundwater modeling information and explains the limitations inherent in this modeling approach. *Compensatory Mitigation Plan developed by Donlin Gold will propose mitigation that follows EPA standards and guidelines, subject to review and approval by the Corps, in a process independent of but parallel to the NEPA process. Reclamation activities would be subject to a monitoring program to ensure regrowth and stability at sites.*	
Pit Lake Contaminants Modelling			**COMMENT MADE IN EPA 309 LETTER – ENCLOSURE 1 (P. 10)** **We recommend that the EIS discuss the modeling results and the conclusions made regarding groundwater contaminants not migrating away from the pit.** The range of hydraulic conductivities (Table 3.6-2) are fairly wide, and indicate that contamination could migrate up to 14-feet per day during the 52-year filling period of the pit lake. Even in the lower aquifer depths, the contaminants could migrate up to 0.2-feet per day. While it is important to assume a uniform conductivity for modelling purposes, using a relatively low geometric mean could potentially underestimate contaminant movement during the pit lake filling period, and potentially during the mine operations period. **We recommend additional modelling and analysis of the hydraulic gradient of the pit lake to determine the potential for the transport and migration of contaminants, such as mercury and arsenic, into groundwater discharging into Crooked Creek and adjacent wetlands. In particular, it is important to evaluate the rate and area of groundwater migration during the period when the pit lake is filling. A greater pumping and advanced water treatment rate may be necessary prior to discharging into Crooked Creek. We recommend using a worst-case and projected hydraulic conductivities multiple times during post-closure to determine the maximum contamination of the bedrock aquifers so that mitigation measures can be proposed and implemented in case of groundwater contamination.**		**GRD 6**
We note that the current response addresses the TSF seepage recovery system. Our comment at the DEIS stage is regarding the open pit and groundwater movement, which is connected to our concerns for groundwater contamination. We continue to recommend that additional modeling and analysis table place and be discussed in the FEIS.				***GRD 6*** *- See response to comment above*	
3.6.1.3.3	3.6-12	bt	Detailed examination of the available data has also not revealed any significant correlation between bedrock hydraulic conductivity and rock type or formation.	This issue should be discussed further in regard to the modeling results and the conclusions made regarding groundwater contaminants not migrating away from the pit. The range of hydraulic conductivities provided in table 3.6-2 are fairly large, and indicated that contamination could migrate up to 14 feet per day during the 52-year filling period of the pit lake. Even in the lower aquifer depths the contaminants could migrate up to .2 ft/day. While it is important to assume a uniform conductivity for modelling purposes, using a relatively low geometric mean could potentially drastically underestimate contaminant movement during the pit filling period, and potentially during	**GRD 6**

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Bureau of Land Management
Agency Comments on the Preliminary Draft EIS
June 6, 2015

Section Number	Page	Original Language	Proposed Language or Comment	Disposition (CAs should leave blank)
FRONT MATTER				
Front Matter – Acronyms and Abbreiations	Xlii		Please add the following to the acronym and abbreviation list: -BSCF -LEDPA -PRPA	
Chapter 1 PURPOSE AND NEED				
1.4.2	1.4-14	Prior to issuing a decision on the requested ROW, the BLM must review the proposed ROW action pursuant to NEPA.	Prior to issuing a decision on the requested ROW, the BLM must review the proposed ROW action pursuant to NEPA and other applicable federal laws and regulations, including the Endangered Species Act and the National Historic Preservation Act.	
1.8.1	1.8-20	**Climate Change:** Climate driven changes over time that could contribute to impacts expected in the project area and are analyzed for impacts to: the physical environment (permafrost, glacial discharge, precipitation, river levels, storms, flooding events); biological environment (vegetation, fish, and wildlife) and social environment (subsistence and barge traffic).	Is this addressing how current climate change will affect the mine, or the effect of the mine (large emissions of CO2) on climate?	

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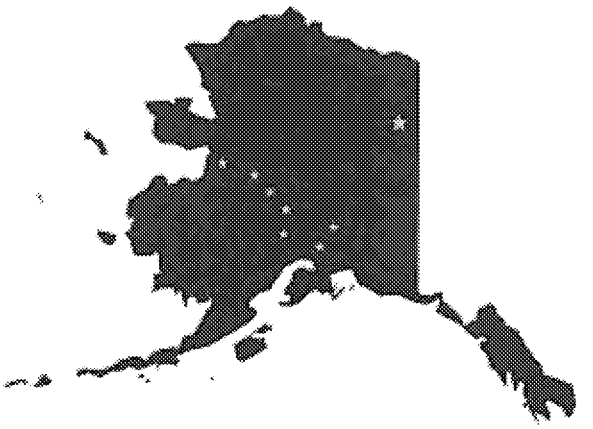
Section Number	Page	Original Language	Proposed Language or Comment	Disposition (CAs should leave blank)
1.9.3	1.9-24	The source of and production methods of natural gas are beyond the scope of this EIS because they are not a component of any federal permit required for this project.	The source of the gas will cause impacts, but are not being addressed. If gas is shipped, it will increase shipping in Cook Inlet, if it is purchased from local supply, it impacts availability of gas to Anchorage and S. Central AK . It is not beyond the scope of this EIS.	
1.10.4.1	1.10-26	MINE SITE FINANCIAL ASSURANCE	The pit lake and dam, and the waste water generated by the mine will have to be monitored and treated into perpetuity with a probability that runoff from the pit lake and mine will flow into the Kuskokwim river, affecting all life downstream. This will not be covered by a trust fund, and will cost the State of Alaska and federal agencies. The long term financial responsibility of waste water after the closure of the mine is not adequate, and how much it will cost and who will pay is not clear.	
1.10.13	1.10-30	The *National Historic Preservation Act* of 1966 (as amended), the *Archaeological Resources Act* of 1979, the *Antiquities Act* of 1906, and the *Alaska Historic Preservation Act* (1971) guide the management of cultural resources and historic properties.	The *National Historic Preservation Act* of 1966 (as amended), the ***Archaeological Resources Protection Act*** of 1979, the *Antiquities Act* of 1906, and the *Alaska Historic Preservation Act* (1971) guide the management of cultural resources and historic properties.	
1.10.13	1.10-30	NA	Can we add something about the regulations allowing for Programmatic Agreements for completing section 106, since that's what we're doing?	
Table 1.10-1	1.10-35	Section 106 Historical and Cultural	This isn't the correct term. All federal agencies need to complete the section 106 process.	

Alaska Implementation Guidance for
DoD Alaska Native Related Policies and Instructions

13 April 2020



Alaska Implementation Guidance for
DoD Alaska Native Related Policies and Instructions

Authorities.

1. Executive Order 13175, Consultation and Coordination with Indian Tribal Governments.
2. DoD Instructions 4710.02, DoD Interactions with Federally-Recognized Tribes (24 Sep 18).
3. USNORTHCOM CONPLAN 3400, *Homeland Defense.*
4. USNORTHCOM CONPLAN 3500, *Defense Support of Civil Authorities.*
5. Memorandum, Lead for Arctic Affairs, CDRUSNORTHCOM (11 Mar 19).

I. Introduction.

1. Purpose. The Alaska Implementation Guidance (AIG) conveys the application of the revised Department of Defense Instruction for American Indian/Alaska Native (AI/AN) Policy (DoDI 4710.02; 24 September 2018) to the unique aspects of Alaska. The AIG applies to DoD components conducting activities that may affect Alaska Native communities. The AIG highlights the nuances of Alaska in order to better assist DoD components with requirements when DoD activities intersect with Alaska Native interests and is designed to inform DoD components on how to approach trust relationships with Alaska Native peoples. This document supercedes all previous versions of the "DoD American Indian/Alaska Native Policy: Alaska Implementation Guidance."

2. Rationale. Due to the variability of governance structures, land ownership, jurisdiction in Alaska, and the changes published in the revised DoDI 4710.02, the following guidance serves as a means to assist those working on behalf of DoD components in building and sustaining trust relationships with various types of Alaska Native communities. This guidance informs DoD components' obligations to engage tribes in government-to-government relations through engagement and meaningful consultation based on the US Constitution, Federal treaties, statutes, executive orders, and policies. The following are the guiding principles for interacting with Alaska Native tribes: the recognition of tribal sovereignty and cultural traditions, applications of federal trust responsibilities, consultation on a government-to-government basis, and protection of natural and cultural resource of tribal importance.

The legal model created from the Alaska Native Claims Settlement Act (ANCSA) render situations and issues unique to Alaska. The inclusion of Alaska Native corporations (ANCs) in the DoDI consultation requirement necessitates a clarification on how instructions are implemented in Alaska.

3. Delimitation. The AIG is designed to assist DoD agencies in identifying and initiating consultation with federally-recognized tribes and ANCs. The AIG is not intended to be a substitute for: individual protocols already established with tribes; DoD component policies, directives, instructions, or regulations; or installation standard operating procedures (SOPs). However, it is important that service components leverage their respective liaisons who are familiar with Alaska Native governance and protocols. Where there is a perceived conflict

with federal law or DoD regulations, this guidance should be interpreted in a manner as not to conflict with law or regulation.

4. Federal Law and DoD Policy. Where there is a perceived conflict with federal law or DoD regulations, this guidance should be interpreted in a manner as not to conflict with law or regulation. It is important to note that in the same way, neither does DoD policy supersede federal law or regulation. In this regard, the Federal Acquisition Regulation (FAR) and the Defense Federal Acquisition Regulation Supplement (DFARS) continue to govern the rules and regulations as they pertain to federal contracting with DoD contractors and potential DoD contractors. Since the ANCs fall within this category, the general contracting rules continue to apply notwithstanding the language in DoDI 4710.02, to include paragraph 3.2.(10) of the DoDI, which requires consultation with ANCs for "proposed actions, plans, or ongoing activities that may have the potential to significantly affect: (10) Business contracting matters." DoD entities must still comply with the guiding principles of the Federal Acquisition System found in FAR Part 1, Subpart 1.1, as well as the need to prevent any unfair competitive advantage and avoid organizational conflicts of interest, as specified in FAR Part 9, Subpart 9.505. Consult your servicing Staff Judge Advocate on this issue as required.

5. Consideration. The AIG follows the DoD Policy focus on consultation when DoD actions may have the potential to significantly impact protected tribal resources, tribal rights, and/or interests in Indian land. Unlike many American Indian tribes in the contiguous 48 states that occupy Indian land, the AIG recognizes ***trust responsibilities*** due to the uniqueness of Alaska, are not limited to protected tribal rights and resources associated with Indian land, but extend to rights and resources off Indian land. This includes understanding the impacts DoD may have on those resources of importance, such as those resources that support a subsistence way of life for Alaska Natives. DoD agencies or services are strongly encouraged to become informed of natural and cultural resources that are important to Alaska Native tribes, even when not specifically protected by law, through relationship processes including government-to-government consultation.

6. Audience. This Guidance is designed to assist several entities:

- DoD agencies and components;
- Federally-recognized tribes;
- Alaska Native Corporations (ANCs);
- Other agencies seeking to better understand how DoD interacts with Alaska Native tribes and ANCs.

II. Roles and Responsibilities

Local DoD agencies and component commanders adhere to their respective instructions, regulations, policies, procedures and/or protocols with tribes for their respective defined roles and responsibilities with regard to AI/AN interactions.

Tribal Liaisons (TLs) are commanders' representatives and advisors regarding Native Affairs. There are eight TLs assigned to DoD components with responsibilities in Alaska.

- Native Affairs Liaison, Alaskan Command, Joint Base Elmendorf Richardson (JBER);
- Tribal Liaison, Pacific Air Forces Regional Support Center, JBER;
- Tribal Liaison, US Army Corps of Engineers (USACE), JBER;
- Tribal Liaison, US Army Garrison Alaska (USAG), Fort Wainwright;
- Tribal Liaison, US Coast Guard, District 17, Juneau;
- Tribal Liaison, 673rd Civil Engineer Squadron, JBER;
- Tribal Liaison, Alaska National Guard, Department of Military & Veterans Affairs;
- Tribal Liaison, US Navy, Region Northwest, Washington State.

Primary responsibility for implementing the DoD AI/AN policy and instruction rests with installation commanders. Commanders rely on their TLs to advise them on Alaska Native cultural awareness, tribal governance structures and the ANC framework, among other related aspects. Further, TLs can establish consultation processes, advise commanders on engaging key personnel, and serve as an ambassador to Alaska Native peoples and organizations on behalf of their respective installations and agencies.

The Commander, Alaskan Command (CDRALCOM), is designated as the lead for Arctic Affairs by U.S. Northern Command (USNORTHCOM). One of several roles and responsibilities specified to CDRALCOM is to maintain critical relationships and to act as a DoD interlocker with the state-wide Alaska Native community. The ALCOM Native Affairs Liaison develops and maintains relationships with Alaska Native communities for the senior military commander in Alaska, advises DoD components on policy implementation, liaises with the Senior Advisor and Liaison for Native American Affairs for the Office of the Secretary of Defense (OSD), and coalesces the DoD TLs working in Alaska in order to seek consistent approaches and avoid duplicative efforts.

III. Definitions and Concepts.

To understand the complex socio-political landscape of the Alaska Native community at large, it is important to learn the differences between federally-recognized tribes, Alaska Native regional and village corporations, and Alaska Native regional non-profit service provider organizations. Key concepts are defined below to facilitate consistency and consensus on usage.

1. Alaska Native Claims Settlement Act (ANCSA) was signed into law by President Richard Nixon on December 18, 1971. This legislation settled the legal question of land claims within Alaska, something that up until then, had been left unaddressed both when the land was purchased by the United States from Russia, and again when Alaska gained statehood. ANCSA formed 13 regional corporations and over 200 village corporations, which received both land (private, fee simple) and monetary compensation from the settlement. ANCSA extinguished all claims based on aboriginal right, title, use, occupancy of land or water, or based on statute or treaty of the United States relating to Native use or occupancy (43 USC 1603(c)); aboriginal title to all prior conveyances of public land and

water areas in Alaska (43 USC 1603(a)); and aboriginal title in Alaska based on use and occupancy, including aboriginal hunting or fishing rights (43 USC 1603(b)).

2. Alaska Native Corporations (ANCSA Corporations, aka ANCs) are any Alaska Native regional or village corporation as defined in or established pursuant to ANCSA. More specifically, "Any Regional Corporation, Village Corporation, Urban Corporation, or Group Corporation organized under the laws of the State of Alaska in accordance with Section 1601, et seq. of Chapter 33 of Title 43, U.S.C., also known and referred to in this issuance as the 'Alaska Native Claims Settlement Act of 1971,' as amended (DoDI, 2018, p. 12)." These are for-profit, private business corporations chartered under Alaska State law and the lands conveyed to ANCs are private fee title (not trust lands).

3. Alaska Native Regional Non-Profit Organizations (Service Providers) were created to provide services and health care for Alaska Native peoples. Through federal compacts, grant funding, support from the regional corporations, collaboration with village non-profit organizations, and other means, the regional non-profit service providers deliver a range of services. The specific objectives of the organizations vary but generally focus on resource research and management, healthcare, cultural services, and educational opportunities. Programs can include physical and behavioral health care, scholarships for Alaska Native students, sponsorship of cultural events, Alaska Native language preservation efforts, and protection of sites with historic or religious importance.

4. Consultation. "Rarely a singular event but part of a process to inform a pending decision or course of action, it is information and opinion respectfully exchanged in both directions and likely involves different forms of communication, and must begin with a face-to-face dialogue. If agreed to by the tribe, ongoing daily business communications may be considered part of the consultation process and may include written, telephonic, and electronic communication" (DoDI, 2018, p. 12).

a. Government-to-Government Consultation is a *meaningful* process to discuss in a transparent way a pre-decisional course of action between DoD components and federally recognized tribes where information and opinions are respectfully exchanged in both directions. Although government-to-government consultations must be conducted pursuant to instructions and policies, specific outcomes are not mandated. Instead, tribes are included in the decision-making process and final decisions have incorporated tribal input.

b. ANC Consultation. The Office of the Under Secretary of Defense for Acquisition and Sustainment requires DoD components to "consult in a timely and good faith manner with Alaska Native corporations on any proposed action or policy that may have substantial direct effect on corporate lands, waters, or other natural resources, or on the ability of an Alaska Native corporation to participate in a DoD or DoD component program for which it may otherwise be eligible" (DoDI 4710.02, p. 6). The intention of the instruction is to provide ANCs opportunities to discuss DoD activities that may impact ANC natural resources (e.g., land and associated renewable resources that are relied upon to support subsistence practices). Please note the discussion in paragraph *I.4.*

Federal Law and DoD Policy regarding consultation with ANCs on business contracting matters.

The DoD recognizes that while consultation with ANCs is required, ANCs are not tribes nor sovereign governments. Although ANCs must be informed in a timely and good faith manner as related to their land, they are not federally-recognized tribal governments and are not granted government-to-government status.

5. Cultural, Religious, and Historic Interests. These include tribes' rights to protect interest in access to sacred sites, use and possession of sacred objects, and the exercise of traditional religions. These are protected under Executive Order 13007 (Indian Sacred Sites, 24 May 96).

Tribes have a protected interest in identification and rightful disposition of funerary objects, sacred objects, and items of cultural patrimony that are in federal possession or control. These are protected by the Native American Graves Protection and Repatriation Act (NAGPRA; 25 USC 3001-3013) and the Archeological Resources Protection Act (ARPA; 16 USC 470aa-II). NAGPRA provides for the return of funerary objects, sacred objects, and items of cultural patrimony from federally funded museums and from collections from federal and Indian lands. Additionally, it provides for repatriation of these items and of Native American human remains discovered on federal and Indian lands.

Under the National Historic Preservation Act (NHPA; 54 USC 300101 et seq.), "tribal land" is defined as lands within the boundaries of a reservation or dependent Indian community. All federally recognized tribes in Alaska have the right to be a consulting party for historic properties, or federal undertakings which may affect historic properties, when the tribe attaches religious and cultural significance to those properties.

Alaska Native individuals who dwell on the coast of the North Pacific Ocean or the Arctic Ocean have an interest in marine mammals for food, handcraft or clothing. This interest is protected by the Marine Mammal Protection Act (16 USC 1371(b)). Tribes that have an interest in taking bald or golden eagle for religious purposes fall under the Bald Eagle Protection Act (16 USC 668a).

6. Federally-recognized tribes. "A federally recognized Indian or Alaska Native tribe, band, pueblo, village, community or other tribal entity that the Secretary of Interior acknowledges to exist as an Indian tribal entity pursuant to the annual update to the Department of Interior list of Indian Entities Recognized and Eligible to Receive Services from the United States Bureau of Indian Affairs published in the Federal Register" (DoDI, 2018, p. 13). Further, the Secretary of the Interior acknowledges those listed exist as a tribe pursuant to the Federally Recognized Indian Tribe List Act of 1994, (25 USC 479a. (EO 13175)). Those tribes may be represented by traditional councils, or organized under the

Indian Reorganization Act (IRA) as IRA Councils. Tribal sovereignty is a retained status by federally-recognized tribes.

7. Protected Tribal Resources. "Those natural resources and properties of traditional or customary religious or cultural importance, either on or off Indian lands, retained by or reserved by or for Indian tribes through treaties, statutes, judicial decisions, or E.O.s, including tribal trust resources" (DoDI, 2018, p. 18). Tribal resources of importance are tribally defined and informed through the relationship processes between tribes and local DoD agency or service component commanders (i.e., government-to-government relations). This is in addition to those natural resources or properties of traditional or customary religious or cultural importance, either on or off Indian land, retained by or reserved for Indian tribes through treaties, statutes, judicial decisions, or executive orders, including tribal trust resources.

8. Subsistence. Congress granted a subsistence preference for individual Alaska Natives on Native land and for both Native and non-native rural residents on public land, per the Alaska National Interest Lands Conservation Act (ANILCA; Public Law 96-487, 1980, 16 USC 3101-3126 and 3111(a)(1)). The preference means that when it is necessary to restrict taking of fish and wildlife, subsistence uses shall be given priority over other consumptive uses (16 USC 3112).

While Congress acknowledged the importance of subsistence to all rural Alaska residents, it noted that the continuation of the opportunity for subsistence uses is essential to the Native physical, economic, traditional, and cultural existence (16 USC 3111(a)(1)). DoD agencies must determine whether their activities may have the potential to significantly affect renewable resources relied upon for subsistence, because Alaska Native communities may perform subsistence activities on both Native Land (as defined by ANILCA) and public land in Alaska. Local DoD agencies and service component commanders (e.g., *installation commanders*) or their respective agency representatives will enhance trust and understanding by consulting with the applicable Alaska Native tribes when a proposed DoD action may have the potential to adversely affect the subsistence activities of members of the same village or tribe.

9. Indian Land in Alaska. Indian land, as defined by DoDI 4710.02, is: "Any lands to which the title is either held in trust by the United States for the benefit of any Indian tribe or Indian, or held by an Indian tribe or Indian subject to restrictions by the United States against alienation in accordance with Part 229 of Title 32, CFR. Also applies to any lands conveyed in accordance with the 'Alaska Native Claims Settlement Act of 1971,' as amended" (p. 12).

a. Reservation. The Metlakatla Indian Community Federal Reservation on Annette Island. This is the only reservation in Alaska that is held in trust by the United States (25 USC 495).

b. Individual Native Allotments under the Alaska Native Allotment Act. Under the Alaska Native Allotment Act of 1906, Alaska Natives not residing on a reservation were allotted federal land of the US to be held in trust by the US, but for the sole benefit and

use of the Native allottee. The Act authorized the BIA to manage the program. The BIA could convey the land free of trust to the allottee after 25 years or upon a determination that the allottee could manage the land. Various methods of alienation were also authorized but with BIA approval (43 USC 1634).

Under these authorities, BIA issued Native Allotment Certificates. Under the Indian Self-Determination Act (25 USC 450j), BIA contracted out with regional nonprofit providers to monitor these allotted trust lands.

ANCSA (43 USC 1603c (1971)) extinguished all interests in land based on federal statute at that time. Therefore, Natives covered by ANCSA, or their descendants, are not eligible for further allotment (43 USC 1617). However, there are Native allotments that continue to be valid because of express language in ANCSA (43 USC 1617) recognizing then existing (1971) allotments but precluding further allotments to ANCSA eligible Natives. Subsequently, in the ANILCA (Public Law 96-487, 1980; 16 USC 3101-3126), Congress amended ANCSA to approve Native allotment applications pending on or before the enactment of ANCSA (43 USC 1634).

In sum, Indian land in Alaska for DoD policy purposes includes existing Native allotments under the above authorities only so long as held in trust by the US subject to restriction on alienation. Once BIA has approved alienation or issues the land in fee simple, the allotment ceases to be Indian land.

c. Townsite Lots under Native Townsite Act. In 1926 Congress authorized the Federal Townsite Trustee to issue restricted deeds in trust to Alaska Natives living in Federal townsites. In 1948 Congress authorized the townsite trustee to issue unrestricted deeds upon approval by BIA. In 1976 Congress repealed the Townsite Act.

Any restricted Townsite deeds held by Alaska Natives, which have not been alienated with approval of BIA are still held in trust and may be Indian land. DoD policy would, therefore, apply to interests in that land. The majority of lots in Alaskan towns, outside the rail belt, have restricted deeds.

d. ANCSA Land, 43 USC 1601. This includes surface and subsurface estates held by the 12 for-profit Regional ANCSA Corporations under 43 USC 1606, and the surface estates of for-profit Village ANCSA Corporations under 43 USC 1607. ANSCA land are fee simple (private land not held in trust.)

e. ANCSA Village Corporation Land Transferred to Tribes. Congress authorized BIA to hold IRA land in trust, 25 USC 463-465. However, ANCSA extinguished all IRA interests.

In recent years, several ANCSA village corporations have been deeding their land to tribes located in the same village, often with the same membership. Because these deeds originated from corporate fee land, they are not held in trust by the US and do not qualify as Indian land within the DoD policy definition. A trust relationship is not

recreated by transfer to the tribes because the land does not qualify as a "dependent Indian community" within the meaning of 18 USC 1151[1], and is, therefore, not Indian Country. (see *Alaska v. Native Village of Venetie Tribal Government*. Supreme Court No. 96-1577 (1998).)

IV. Trust Responsibility in Alaska.

In the Federally Recognized Indian Tribe List Act of 1994 (P.L., 103-45), Congress declared that the United States has a trust responsibility to recognized Indian Tribes, maintains a government-to-government relationship with those tribes and recognizes the sovereignty of those tribes. Federally recognized tribes in Alaska participate in that trust relationship with the US. DoD values the enduring trust relationship with tribes.

The federal trust obligation of the United States to the tribes in Alaska applies to tribal rights and protected tribal resources as described in this guidance. It also applies to Indian land held in trust by the US, such as the Metlakatla Reservation and existing Native allotments.

There is no trust obligation with respect to land held under ANCSA or land held by tribes, which was transferred from ANSCA corporations. However, there is a trust obligation for identified protected tribal rights and resources that may exist on those lands. There is no trust obligation by virtue of aboriginal title, which was extinguished by ANCSA.

V. Government-to-Government Relations

DoD components will consult on a government-to-government basis, as described in DoDI 4710.02, Section 3.2 *What to Consult About,* with tribes concerning DoD activities, which may have the potential to affect tribal rights and resources. This includes, but is not limited to: ground-disturbing activities, construction, training, low level over-flights, management of properties of traditional religious and cultural importance, protection of sacred sites from vandalism and other damage, access to sacred sites, access to treaty-reserved resources, disposition of cultural items, and land use decisions, on or off Indian Land, and interests in Indian Land. This consultation is not satisfied by compliance with general existing statutory public participation requirements, but requires separate consultation with the tribe on identified tribal interests. Guidance for Consultation, set forth below, describe how DoD components will identify those interests with tribes.

The DoD components shall afford tribes that have a cultural or historical affiliation with the lands encompassed by the installation an opportunity to consult on the development of the management plans that may potentially be affected.

The DoD recognizes that there are other governments or government agencies representing Alaska Natives, which are affected by DoD activities. Consultation with tribes is intended to supplement and not replace consultation with these other governments and government agencies as necessary. The DoD in Alaska must take into consideration the interests of all government

[1] 18 USC 151 defines Indian Country to include reservations, dependent Indian communities and Indian allotments with unextinguished title.

affected by DoD activities. If a DoD activity does not have a potential to affect an identified tribal right, resource, or interest in Indian land, as described in this guidance, consultation with the tribe on a government-to-government basis is not required for that activity. The DoD also recognizes that while consultation with ANCSA Corporations as landowners may be necessary, ANCSA Corporations are not tribal governments.

It is the responsibility of the DoD component to identify potential effects to known tribal rights and resources and initiate consultation with affected tribes early in the planning process. It is anticipated that tribes will assist the DoD in this effort by identifying rights, protected resources, or interests in Indian land that may be affected by the DoD activity. The tribal response to the DoD component should provide the information necessary to determine whether government-to-government consultation is necessary. However, if it is determined that consultation is not required, this guidance does not relieve the DoD of its responsibility to communicate with tribal members as affected members of the public under other public participation requirements.

Native Regional Nonprofit Organizations (service providers) under contract with BIA for protecting the trust resources of Native allotment holders will also be consulted when in the performance of their contractual trust responsibilities, but such Native organizations will not be considered governments.

VI. Guidance for Consultation

Government-to-government consultation is a two-way dialogue between federally-recognized tribes and DoD agencies and components to respectfully share information and opinion in both directions. The following guidance is to be used in conjunction with Section 3 of DoDI 4710.02 entitled Guidance for Consultation with Federally Recognized Tribes, and in addition to service component specific instructions, and standard operating procedures.

1. Requirement. Notification and consultation is triggered when a proposed DoD action may have the potential to significantly affect protected tribal rights, resources or Indian land, as described in this guidance. Because of extensive renewable resources, cultural, and religious interests in Alaska, which are not limited to Indian land, notification of any DoD activity will be provided to tribes in the area potentially affected by the activity.

2. Notification and offer of consultation. Notification and offers of consultation letters may be prepared by agency staff members, but will be signed by the installation commander or equivalent agency director. The letter may designate a TL, project manager, or other management level individual to coordinate logistics for potential consultation. The letter will notify the prospective affected tribe of the proposed DoD activity and request that the tribe identify what tribal rights, protected resources, or interest in Indian land may be affected. Such letters will be followed-up by phone call and e-mail communications to confirm receipt and understanding. If the tribe identifies any such interests, consultation will be required. If the tribe does not respond within a reasonable period after notification (typically, 30-60 days depending on the project), the DoD component may proceed with the activity. However, the DoD component should continue to make reasonable efforts to receive a tribal response by telephone or email before making a decision to proceed.

Proceeding without consultation under this protocol does not relieve the DoD of other consultation requirements established by law. Each service component in Alaska may format its own notification procedures within these guidelines.

3. Consultation. If consultation is required as set forth, the DoD installation or component and the tribe will collaboratively establish a consultation process setting forth representatives, an agenda of issues to be discussed, location for the meeting, logistics, schedules, procedures, etiquette and any other such matters relevant to the proposed DoD activity. When tribal chiefs/presidents enter an installation for the purpose of government-to-government consultation, they will be afforded the protocol of an official government visitor. The DoD component should advise other affected federal agencies of its requirement for tribal consultation.

4. Documentation. Careful and considerate documentation of consultation meetings is an important part of the process. DoD agencies shall work with tribes to determine what level of documentation is appropriate. Best practices can include various levels of documentation such as: a complete transcript; a document listing outcomes that each party signs off on; or a letter from the commander to the tribal leader which informs the tribe of a decision.

VII. Develop Enduring Relationships

Each DoD agency or component conducts its relationship building and consultation with Alaska Native communities in accordance with their respective authorities (policies, instructions, SOPs, and protocols developed with tribes and in honor of the principles outlined in DoD Policy and Instructions). Additionally, commanders, TLs and DoD personnel can demonstrate trust by building enduring relationships in various ways under the three following frameworks:

1. Awareness. Learn about historical interactions that continue to negatively impact and shape the relationship between DoD and Alaska Native people today. Through open communication, DoD leadership and staff can learn these histories from a Native perspective and work together with tribes and communities to find paths to move forward with the ultimate goal of healing.

2. Advocacy. Participate in bi-lateral education opportunities. This includes DoD invitations to Alaska Native leaders and experts to provide education to DoD leadership and personnel, while also finding opportunities for DoD to provide education for Alaska Native communities on items of interest.

3. Action. DoD leadership, TLs, and personnel can greatly improve working relationships by informing Alaska Native leaders and representatives about educational programs, surplus resources, and economic opportunities that may be of value. Some of these opportunities include but are not limited to the following:

a. **Innovative Readiness Training** (IRT) projects are achieved following successful application between DoD and communities. They are projects that can support mission-readiness for US forces by providing training opportunities with real world applications through community-based projects such as construction, health care, and

National Guard can be reached at 907-428-6815; or contact the Alaskan Command Native Affairs Liaison at 907-552-3268.

b. The Native American Lands Environmental Mitigation Program (NALEMP) provides funding for tribal community-based DoD clean-up projects on eligible sites. In recognition of the need to address tribal concerns in DoD environmental programs, Congress has, since 1993, provided funds annually to mitigate environmental impacts to Indian lands and Alaska Native Claims Settlement Act (ANCSA)-conveyed properties. Under NALEMP, DoD enters into Cooperative Agreements (CAs) with tribal governments to address problems attributable to past DoD activities. These agreements incorporate traditional ecological knowledge into the design for cleanup, involve the tribe in project decision making, and develop tribal capacity regarding environmental services and technical remediation skills. In Alaska it is administered by the US Army Corps of Engineers. More information can be obtained at www.denix.osd.mil/na/nalemp/ or by contacting the Alaska NALEMP Program Manager at (907) 753-5771.

c. US Government surplus goods acquisition can benefit tribes with affordable material support. Excess federal property comes from many federal agencies and is available to qualified organizations through the State of Alaska Federal Surplus Property Program. Qualified organizations that have obtained property through the federal surplus property program have experienced substantial cost savings when obtaining property. More information can be obtained at https://gsaxcess.gov/ or by contacting the Alaska Federal Surplus Property Officer at (907) 754-3405.

d. Military personnel volunteerism opportunities can be leveraged to benefit personnel cross-cultural understanding while increasing relations between the agency and tribal partners. Care should be paid by subject matter experts that personnel receive adequate orientation prior to volunteerism in order to maximize their experience and provide the best assistance to volunteerism recipients.

The DoD supports tribal self-governance and values government-to-government relations between the federal government and tribes. Alaskan Command is committed to continue building enduring trust-relationship with the Alaska Native community. This Guidance is endorsed by the CDRALCOM for use by DoD agencies and Components to implement applicable DoD policies and instructions.

THOMAS A. BUSSIERE
Lieutenant General, USAF
Commander, Alaskan Command

13 April 2020
Date

APPENDIX A

References

Laws

National Historic Preservation Act of 1966, as amended (54 USC 300101 et seq.)

American Indian Religious Freedom Act of 1978 (42 USC 1996)

Archaeological Resources Protection Act of 1979, as amended (16 USC 470aa et seq.)

Native American Graves Protection and Repatriation Act of 1990, as amended (25 USC 3001 et seq.)

National Environmental Policy Act of 1969 (Public L 90-191)

Agency-specific Policy

DoD Instruction 4710.02, *"DoD Interactions with Federally-recognized Tribes,"* 24 September 2018

DoD American Indian and Alaska Native Policy, 21 October 1998, and implementing instruction

SECNAVINST 11010.14A, *"Department of the Navy Policy for Consultation with Federally-recognized Indian Tribes,"*11 October 2005

Air Force Instruction 90-2002, *Air Force Interactions With Federally-Recognized Tribes,* 19 November 2014

Marine Corps Order P5090.2A, "*Cultural Resources Management, Ch. 8*"

Army Regulation 200-1, *"Environmental Protection and Enhancement,"* 13 December 2007

Army American Indian and Alaska Native Policy, 24 October 2012

Army AI/AN Policy Implementation Guidance, 10 July 2014

US Army Corps of Engineers Tribal Consultation Policy (2013)

Executive Orders (EO)

EO 13007, "Indian Sacred Sites," 24 May 1996

EO 11593, "Protection and Enhancement of the Cultural Environment"

EO 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations"

EO 13006, "Locating Federal Facilities on Historic Properties in our Nation's Central Cities"

EO 13175, "Consultation and Coordination with Indian Tribal Governments"

EO 13287, "Preserve America"

EO 13327, "Federal Real Property Asset Management"

EO 13423, "Strengthening Federal Environmental, Energy, and Transportation Management"

Other Guidance

Executive Memorandum: "Government-to-Government Relations with Native American Tribal Governments," 29 April 1994

Appendix B

DoD Tribal Liaisons in Alaska

Alaskan NORAD Region and Alaskan Command
Native Affairs Liaison
Current Tribal Liaison Officer: Amanda Andraschko
Commercial: 907.552.3286
Email: Amanda.andraschko@us.af.mil

Department of the Army
U.S. Army Garrison Alaska
Current Tribal Liaison Officer: Elizabeth Cook
Commercial: 907.361.3002
Email: elizabeth.a.cook80.civ@mail.mil

Pacific Air Force
Regional Support Center
Current Tribal Liaison Officer: Tommie Baker
Commercial: 907.552.4187
Email: Tommie.Baker@us.af.mil

U.S. Coast Guard District 17
Current Tribal Liaison Officer: Robert Edwardson
Commercial: 907.463.2034
Email: robert.h.edwardson@uscg.mil

U.S. Army Corps of Engineers
Current Tribal Liaison Officer: Kendall Campbell
Commercial: 907.753.5582
Email: kendall.d.campbell@usace.army.mil

673rd Civil Engineer Squadron
Current Tribal Liaison Officer: Margan Grover
Commercial: 907.384.3467
Email: margan.grover@us.af.mil

Alaska Army National Guard
Dept. of Military & Veterans Affairs
Current Tribal Liaison Officer: SMSgt Lucy Nagel
Commercial: 907.428.6906
Email: lucy.m.nagel.mil@mail.mil

US Navy
Commander Navy, Region Northwest
Current Tribal Liaison Officer: Danielle Page
Commercial: 360.315.5400
Email: danielle.page@navy.mil

Appendix C

ANILCA Definitions:

'Public land' is defined as Federal lands, title to which is in the United States, after December 2, 1980, except selections by the State of Alaska under the Statehood Act or other Federal law, and selections of a Native Corporation under ANCSA. 16 USC 3102(2).

'Native land' for ANILCA purposes includes land owned by Native Corporations and any native group. 16 USC 3102(11).

'Subsistence' is the traditional use of wild renewable resources for direct or family consumption as food, shelter, fuel, clothes, tools or transportation, and the making of handcrafts out of non-edible byproducts of fish and wildlife. 16 USC 3113.

For additional copies, please contact the Alaskan Command Native Liaison Officer at (907) 552-3268.

ALCOM/NAL
9480 Pease Avenue, Suite 121
JBER AK 99506

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MENU

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International Cooperation

CONTACT US <https://epa.gov/international-cooperation/forms/contact-us-about-international-cooperation>

Minamata Convention on Mercury

The Minamata Convention on Mercury is a multilateral environmental agreement that addresses specific human activities which are contributing to widespread mercury pollution. Implementation of this agreement will help reduce global mercury pollution over the coming decades.

- History of the Minamata Convention
- Why is a global response needed?
- What will the Minamata Convention require?
- Additional Resources

History of the Minamata Convention

On November 6, 2013 the United States signed the Minamata Convention on Mercury EXIT <http://www.mercuryconvention.org/>. In addition to signing, the United States deposited its Instrument of Acceptance to become a party to the Convention. EPA worked closely with the State Department and other federal agencies in the negotiation of this agreement.

The Minamata Convention is named after the **Japanese city of Minamata**, which experienced a severe, decades-long incidence of mercury poisoning after industrial wastewater from a chemical factory was discharged into Minamata Bay. The wastewater contained methylmercury, which bioaccumulated in fish and shellfish in the bay. Local people who consumed seafood from Minamata Bay became very sick, and many died or were left severely disabled.

The text of the Minamata Convention (PDF) EXIT <https://www.mercuryconvention.org/sites/default/files/2021-06/minamata-convention-booklet-sep2019-en.pdf> (71 pp, 434 K, About PDF <https://epa.gov/home/pdf-files>) **was adopted by delegates from over 140 countries on January 19, 2013, after three years of negotiation.** The Convention opened for signature at the Diplomatic Conference in Kumamoto, Japan, on October 10, 2013. The Convention entered into force in 2017, and the first Conference of the Parties (COP1) EXIT <https://www.mercuryconvention.org/en/meetings/cop1> took place September 24 - 29, 2017 in Geneva, Switzerland. One hundred and twenty-three countries have joined the Convention as of September 2020. Explore additional information about

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the Minamata Convention implementation and future meetings EXIT <http://www.mercuryconvention.org/>.

Why is a global response needed?

Mercury pollution is a global problem that requires global action. It moves with air and water, transcends political borders, and can be transported thousands of miles in the atmosphere.

In the United States, we are significantly reducing our use and emissions of mercury, but domestic efforts alone are not sufficient to address the effects of global mercury pollution on the U.S. population. According to some estimates, global sources contribute about 70 percent of mercury deposited in the contiguous United States, although the percentage varies geographically. These global sources include natural sources, re-emitted mercury, and man-made emissions from other countries. (Source: National Research Council. 2010. *Global Sources of Local Pollution: An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States*. EXIT <https://www.nap.edu/catalog/12743/global-sources-of-local-pollution-an-assessment-of-long-range> Washington, DC: The National Academies Press.)

The Minamata Convention on Mercury is an opportunity for the global community to address this mounting problem before it gets worse. Over the next decades, implementation of this international agreement will help reduce mercury pollution from the specific human activities responsible for the most significant mercury releases to the environment.

- Learn more about the global context for mercury emissions <https://epa.gov/international-cooperation/mercury-emissions-global-context>.
- Learn more about how the United States is reducing our use and emissions of mercury <https://epa.gov/mercury/what-epa-doing-reduce-mercury-pollution-and-exposures-mercury>.

What does the Minamata Convention require?

Delegates assemble at plenary session of first intergovernmental negotiating committee meeting in Stockholm, Sweden in June 2010. Photo Credit: Carl Mazza.

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The Minamata Convention requires that party nations:

- Reduce and where feasible eliminate the use and release of mercury from artisanal and small-scale gold mining <https://epa.gov/international-cooperation/reducing-mercury-pollution-artisanal-and-small-scale-gold-mining> (ASGM).
- Control mercury air emissions from coal-fired power plants, coal-fired industrial boilers, certain non-ferrous metals production operations, waste incineration and cement production.
- Phase-out or take measures to reduce mercury use in certain products such as batteries, switches, lights, cosmetics, pesticides and measuring devices, and create initiatives to reduce the use of mercury in dental amalgam.
- Phase out or reduce the use of mercury in manufacturing processes such as chlor-alkali production, vinyl chloride monomer production, and acetaldehyde production.
- In addition, the Convention addresses the supply and trade of mercury; safer storage and disposal, and strategies to address contaminated sites.
- The Convention includes provisions for technical assistance, information exchange, public awareness, and research and monitoring. It also requires Parties to report on measures taken to implement certain provisions. The Convention will be periodically evaluated to assess its effectiveness at meeting its objective of protecting human health and the environment from mercury pollution.

Additional Resources

- Read the text of the Minamata Convention (PDF) EXIT <https://www.mercuryconvention.org/sites/default/files/2021-06/minamata-convention-booklet-sep2019-en.pdf> (71 pp, 434 K, About PDF <https://epa.gov/home/pdf-files>)
- Explore EPA's leadership and specific activities in the Global Mercury Partnership <https://epa.gov/international-cooperation/epa-leadership-global-mercury-partnership>.
- Learn more about the UNEP Global Mercury Partnership EXIT <https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-partnership>, including information on becoming a partner.
- View the Summary of United States Mercury Emissions for Annex D Source Categories under the Minamata Convention <https://epa.gov/international-cooperation/summary-united-states-mercury-emissions-annex-d-source-categories-year>, as filed for our 2021 Minamata Convention reporting obligations.
- Our work on the international stage to control mercury use and emissions is an important complement to our strong domestic actions on mercury <https://epa.gov/mercury/what-epa-doing-reduce-mercury-pollution-and-exposures-mercury>.
- United States Department of State: U.S. Actions to Reduce Mercury Pollution from Transboundary Sources EXIT <https://www.state.gov/key-topics-office-of-environmental-quality-and-transboundary-issues/u-s-actions-to-reduce-mercury-pollution-from-transboundary-sources/>
- UNEP Global Mercury Assessment 2018 EXIT <https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment>

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- Decisions and documents from the Third Conference of the Parties (COP3) in November 2019 EXIT <http://www.mercuryconvention.org/meetings/cop3/tabid/7854/language/en-us/default.aspx>

Contacts

For additional information on EPA's work with mercury, contact:

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The following are detailed comments submitted by the U.S. Environmental Protection Agency in response to Special Public Notice SPN-1995-120 Crooked Creek, Donlin Gold LLC.

The administrative record for the project should clearly document compliance with the Section 404(b)(1) Guidelines.

The Clean Water Act Section 404 regulatory program provides that the U.S. Army Corps of Engineers evaluate applications for the discharge of dredged or fill material into waters of the United States in accordance with the Section 404(b)(1) Guidelines (Guidelines). The Guidelines are codified at 40 CFR 230 and are the substantive environmental criteria used to evaluate proposed discharges of dredged or fill material. Proposed discharges may not be permitted unless they are determined to comply with the Guidelines.

Clearly demonstrating compliance with the Guidelines is the responsibility of the applicant. A proposed discharge is considered noncompliant if the application contains insufficient information to determine compliance[1]. As the permitting agency, the Corps is responsible for determining and documenting whether a proposed discharge complies with the Guidelines[2].

The Guidelines only allow authorization of the Least Environmentally Damaging Practicable Alternative (LEDPA).

The Guidelines at 40 CFR § 230.10 identify several specific restrictions on discharges. The first[3] is that, "no discharge of dredged or fill material shall be permitted if there is a practicable alternative to the proposed discharge which would have less adverse impact on the aquatic ecosystem, so long as the alternative does not have other significant adverse environmental consequences." Once practicable alternatives are determined for a proposed discharge, only the LEDPA may be authorized.

An alternative is practicable if it is available and capable of being done after taking into consideration cost, existing technology, and logistics in light of the overall project purposes[4]. Once the LEDPA has been identified, that is the version of the project which is evaluated against the other restrictions on discharge[5].

As detailed in the FEIS, the current proposal is for the mine vehicles and equipment such as the 300-ton haul trucks to be fueled by diesel. 64 barge trips up the Kuskokwim River would be required to transport diesel to the Jungjuk port site during each open-water season of mine operations, and 37.5 million gallons of diesel would be stored at the mine.

The fuel barge traffic could result in erosion of the Kuskokwim River banks and scour of the bed, with impacts to fish and fish habitat. Three alternatives that would reduce or eliminate the fuel barge traffic during operations were evaluated in the FEIS. Fuel barge traffic to support mine construction would not be affected.

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[1] 40 CFR 230.12(a)(3)(iv)
[2] 40 CFR 230.5 & 33 CFR 332.1(c)(2)/40 CFR 230.91(c)(2).
[3] 40 CFR § 230.10(a)
[4] 40 CFR § 230.10(a)(2)
[5] 40 CFR § 230.10(b), (c), and (d)

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As expressed in our earlier letters, Alternative 3A (LNG-powered haul trucks) and Alternative 3B (co-located natural gas and diesel pipelines) would each substantially reduce the total amount of barge traffic necessary to support the mine, resulting in fewer impacts to the Kuskokwim River. Either of these alternatives could represent the LEDPA.

As explained in the FEIS, the use of LNG and compressed natural gas in industrial applications is proven and equipment manufacturers are actively developing duel-fuel options for the mining industry. For example, Caterpillar mine haul trucks in the 793, 795, and 797 series are currently offered with a natural gas fuel option. These trucks use a high pressure direct injection system that allows them to use a 95% LNG/5% diesel fuel mix. The 795 has a 320-ton capacity, while the 797 has a 400-ton capacity. Combined-fuel systems for haul trucks produced by other manufacturers have different ratios.

Project impacts should be evaluated for their potential to cause or contribute to significant degradation.

The Guidelines[6] specify that: "no discharge of dredged or fill material shall be permitted which will cause or contribute to significant degradation of the waters of the United States. Findings of significant degradation related to the proposed discharge shall be based upon appropriate factual determinations, evaluations, and tests required in subparts B and G, after consideration of subparts C through F, with special emphasis on the persistence and permanence of the effects outlined in those subparts."

The referenced subparts of the Guidelines require that direct, secondary, and cumulative impacts be assessed to determine the potential for significant degradation. They establish specific approaches to evaluate four categories of effects. These include effects on: 1) human health or welfare, including but not limited to effects on municipal water supplies, plankton, fish, shellfish, wildlife, and special aquatic sites; 2) the life stages of aquatic life, other wildlife dependent on aquatic environment including the transfer, concentration, and spread of pollutants or their byproducts outside of the disposal site through biological, physical, and chemical processes; 3) aquatic ecosystem diversity, productivity and stability. Such effects may include, but are not limited to, loss of fish and wildlife habitat or loss of the capacity of a wetland to assimilate nutrients, purify water, or reduce wave energy; or to 4) recreational, aesthetic, and economic values.

The rigor and detail of analysis when evaluating compliance with the Guidelines should reflect the extent, severity, and permanence of predicted project impacts[7]. Donlin Gold has indicated that they will conduct a watershed assessment that will include an evaluation of the potential for significant degradation. The watershed assessment will be submitted as part of a revised compensatory mitigation plan. We applaud Donlin Gold's willingness to take this step, as the impacts associated with the proposed project certainly warrant detailed analysis.

The FEIS indicates that the project will result in significant impacts to Crooked Creek, primarily through the alteration of the flow regime. As we expressed in our earlier letters, these impacts could potentially cause or contribute to significant degradation in violation of 40 CFR §

[6] 40 CFR § 230.10(c)

[7] See, for example, 40 CFR 230.6, introductory sentence in 40 CFR 230.10, and RGL 93-02.

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230.10(c). If these impacts were unavoidable, it would be questionable whether compliance with the Guidelines could be demonstrated.

However, Donlin Gold's application materials and the FEIS indicate that the flow impacts to Crooked Creek may be avoided and minimized such that compliance with both 40 CFR § 230.10(c) and (d) may be demonstrated.

The Guidelines require application of the mitigation sequence to minimize impacts.
The Guidelines[8] further specify that "no discharge of dredged or fill material shall be permitted unless appropriate and practicable steps have been taken which will minimize potential adverse impacts of the discharge on the aquatic ecosystem. Subpart H identifies such possible steps."

To evaluate compliance with Section 230.10(d), the Guidelines tell us to "Identify appropriate and practicable changes to the project plan to minimize the environmental impact of the discharge, based upon the specialized methods of minimization of impacts in Subpart H[9]."

The multiple sections within Subpart H (40 CFR § 230.70-.77) identify many possible steps to avoid, minimize, and compensate for direct and secondary adverse impacts. Taken together, these steps form the mitigation sequence: a mandatory, sequential process undertaken to "minimize potential adverse impacts of the discharge on the aquatic ecosystem." As explained in the preamble, the Guideline's use of the term "minimize" includes all categories of mitigation: "Section 230.10(d) uses the term "minimize" to indicate that all reasonable reduction in impacts be obtained. As indicated by the "appropriate and practicable" provision, steps which would be unreasonably costly or would be infeasible or which would accomplish only inconsequential reductions in impact need not be taken[10]."

Demonstrating compliance with Section 230.10(d) requires the applicant to identify the appropriate and practicable steps they will take to avoid, minimize and compensate for remaining unavoidable impacts. Donlin Gold has identified a range of adaptive management measures that could be implemented to ensure that minimum flows in Crooked Creek are maintained. While no specific measure has been proposed, they have identified several potential measures: lining or relocating a portion of the Crooked Creek channel, augmenting Crooked Creek flows from the proposed Snow Gulch reservoir, pumping water from the Kuskokwim River, or grouting areas of bedrock demonstrating high flow rates.

We appreciate Donlin Gold identifying measures that could be taken to minimize impacts to Crooked Creek. The requirement of the Guidelines, however, is not to "ensure minimum flows in Crooked Creek." Aquatic resource impacts must be avoided and then minimized to the maximum extent practicable. This means that measures must be taken now, rather than as contingencies. The operative question is not whether flow impacts to Crooked Creek will be greater than currently predicted, but whether it is practicable to avoid or minimize the predicted impacts.

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[8] 40 CFR § 230.10(d)
[9] 40 CFR § 230.5(j)
[10] 45 Fed. Reg. 85344 (1980)

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Mitigation, monitoring, and adaptive management measures are presented in Chapter 5 of the FEIS. Tables 5.5-5.7 include information about whether individual measures are reasonable/practicable; whether they are likely to be effective; and whether they are likely to be implemented.

Lining or relocating a portion of the Crooked Creek channel may be practicable. This measure would prevent flow loss from the channel into the alluvium and then to the dewatering wells, but would not result in a net reduction in impacts to Crooked Creek. The alluvial aquifer would still be dewatered, and isolating the stream channel from the alluvium, from its floodplain and associated riparian wetlands, would result in different but equally serious impacts. As the stage maintenance pumping of the pit lake post-mining will maintain hydraulic gradients that draw water from the alluvium in perpetuity, any alteration of the Crooked Creek channel would need to be permanent.

Releasing water from the proposed Snow Gulch reservoir would be practicable, at least early in the mine life and during the summer high flow periods. While such releases would reduce the Crooked Creek flow losses specifically associated with the Snow Gulch reservoir, they would not avoid the bulk of the predicted Crooked Creek flow losses through the alluvium to the dewatering wells. It is also questionable how much water could be released from the reservoir during the periods of greatest cumulative flow loss, which are during the winter later in the mine life. The freshwater reservoirs are specifically intended to provide process water during these periods when other water sources are limited.

Table 5.5 of the FEIS suggests that sourcing water for mine operations from the Kuskokwim River would not be practicable because of the potential for the introduction of invasives and non-endemic pathogens. This appears to conflict with other information in the FEIS. Chapter 3.10 states that 27 nonnative invasive terrestrial plant species have been recorded in the project area: 12 at the mine site, 21 along the transportation corridor, and 15 along the pipeline route. This chapter explains that virtually all the proposed mine components have the potential to increase the spread of nonnative invasive terrestrial plants, but does not suggest that this risk affects practicability.

Unlike the case for invasive terrestrial plants, the FEIS suggests that there are no aquatic organisms of concern that might exist at the confluence of Crooked Creek with the Kuskokwim River but not near the mine site. Chapter 3.10 states that "There are no known reproducing populations of nonnative invasive marine or freshwater aquatic plants, fish, or animals…within the Project Area." The FEIS also states that nonnative invasive pathogens currently are "either not known to occur in Alaska or are not considered serious threats to public health."

As discussed above, the pros and cons associated with an alternative do not determine whether it is practicable within the context of the Guidelines. The relevant question is whether an alternative is "available and capable of being done."

Table 5.5 indicates that the purpose of pumping water from the Kuskokwim River would be to supplement the Crooked Creek flow to offset the dewatering losses. The primary reason to pump water from the Kuskokwim River would be to ensure an adequate supply of water for mine

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operations. All contact and process water from the mine will be treated prior to discharge, which should reduce the risk of nonnative introductions.

According to Chapter 2 of the FEIS, the ore processing plant for the Donlin mine would require approximately 18,000 gallons per minute (gpm) on average over the life of the mine. Sourcing water from off-site is not uncommon for metal mines, like Donlin, that have substantial water needs. For example, the Casino project in the Yukon Territory near Whitehorse is a proposed copper, gold, molybdenum, and silver mine currently undergoing environmental review. The Casino mine proposes to source water from the Yukon River eleven miles away via an insulated, aboveground 36-inch diameter pipeline with a 15,000 gpm capacity.

Outside of the mining industry, the use of insulated pipe on vertical support members to transport treated seawater for tens of miles for injection at production pads is a common practice on Alaska's North Slope.

Sourcing water from the Kuskokwim River would eliminate the need for the proposed freshwater reservoirs, and the tributary flows could be diverted to Crooked Creek to avoid flow losses. Treated water discharges could be to the alluvial aquifer via percolation pits rather than to the channel to reduce the potential for bed scour and bank erosion. If flow augmentation was identified as desirable, and testing indicated that there was no risk, water from the Kuskokwim River could be discharged to these same authorized locations to actively maintain the Crooked Creek hydrograph.

Installation of a cutoff wall as discussed below would reduce flow losses from dewatering, and dewatering volumes could be re-directed to Crooked Creek as they would not be needed for ore processing. These combined measures would avoid most of the flow impacts to Crooked Creek.

A grout curtain could be installed to protect Crooked Creek and its alluvial aquifer from the effects of the proposed drawdown wells and mine pit development. Data in the FEIS suggests that a two-phase cutoff wall using a trench cutter would be effective in preventing flow loss from the alluvial aquifer. To be effective, the cutoff wall would need to extend over the area where the drawdown wells would capture flow from the alluvial aquifer. Rather than grouting some bedrock fractures, this would require a wall of approximately 2.3 miles in length with an average cut depth of about 35 feet.

A cutoff wall of the size necessary may take several years to install. By way of comparison, the cutoff wall installed at the Red Dog Mine back dam was begun in 2007 and completed in 2009. Using the same installation rate as at the Red Dog Mine, the hypothetical grout curtain at Donlin mine would take just over two years to install.

All the adaptive management measures proposed by Donlin Gold to address the Crooked Creek flow losses would require extended time periods to implement. This makes them better suited to being incorporated into the mine design and construction than implemented as contingencies during mine operations. The multi-year installation of a cutoff wall would best be accomplished during the 3 to 4-year mine construction phase. Ideally, it would be completed prior to the

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initiation of dewatering, as the hydraulic stress from dewatering would potentially destabilize the trenches.

As mentioned just above, the stage-maintenance pumping of the pit lake post-closure would continue to draw flow from Crooked Creek in perpetuity. A cutoff wall has a limited operational life, and would need to be maintained over time to continue protecting the alluvial aquifer.

Chapter 5 of the FEIS identifies other potential measures to reduce impacts to Crooked Creek. These include installation of a well field on the west side of Crooked Creek to supplement flow loss from dewatering with pumped groundwater, and relocating treated water discharge points upstream of the area of greatest flow loss.

The unavoidable project impacts to aquatic resource function should be fully offset. Compensation is the third step of the mitigation sequence, and appropriate and practicable compensatory mitigation is required for unavoidable adverse impacts which remain after all appropriate and practicable minimization has been accomplished. All direct and secondary impacts should be offset, including the temporal functional loss from non-permanent impacts. In the Section 404 regulatory program, compensatory mitigation is defined as the restoration, establishment, enhancement, and/or in certain circumstances preservation of aquatic resources for the purposes of offsetting unavoidable adverse impacts which remain after all appropriate and practicable avoidance and minimization has been achieved[11].

The Guidelines identify that "[c]ompensatory mitigation requirements must be commensurate with the amount and type of impact that is associated with a particular DA permit[12]." They also specify that "the amount of required compensatory mitigation must be, to the extent practicable, sufficient to replace lost aquatic resource functions. If a functional or condition assessment or other suitable metric is not used, a minimum one-to-one acreage or linear foot compensation ratio must be used[13]."

A mitigation ratio greater than one-to-one must be used when preservation is the method of compensation, and to address issues such as: differences between the functions lost at the impact site and the functions produced by the compensatory mitigation project, temporal losses of aquatic resource functions, and/or the distance between the affected aquatic resource and the compensation site[14].

Maintaining the ecological sustainability of watersheds by fully offsetting impacts is critical to achieving the Clean Water Act's objective to restore and maintain the chemical, physical, and biological integrity of the Nation's waters, and is necessary to support and connect fish and wildlife habitat, and to support human uses such as commercial fisheries and subsistence.

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[11] 40 CFR § 230.92
[12] 40 CFR § 230.93(a)(1)
[13] 40 CFR § 230.93(f)(1)
[14] 40 CFR § 230.93(f)(2) and (f)(3)

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The regulations[15] require applicants to prepare a mitigation plan for proposed compensation activities, and the mitigation plan must be approved prior to permit issuance. Donlin Gold submitted a conceptual compensatory mitigation plan (CMP) which was incorporated into the DEIS as Appendix M. A revised CMP was submitted in December of 2017. It is our understanding that Donlin Gold will continue to work with the District to revise its CMP as necessary.

The current CMP includes proposals for two permittee-responsible projects. One project is stream restoration in the Crooked Creek watershed near the proposed mine site. The second project is preservation of streams and wetlands in the Chuitna River watershed.

The proposed stream restoration project is located just upstream of the Donlin Gold mine site. The project would address historic placer mining impacts to Ruby and Queen gulch, which are tributaries of Crooked Creek, and to Quartz and Snow gulch, which are tributaries of Donlin Creek. Inclusive of riparian buffers, the project is approximately 172 acres. The proposed restoration has the support of the surface and subsurface owners, which are The Kuskokwim Corporation and Calista Corporation, respectively, as well as the current leaseholder.

The proposed preservation project would place deed restrictions on approximately 5,888 acres of land owned by the Tyonek Native Corporation and the Alaska Mental Health Trust Authority. The parcels include approximately 2,558 acres of wetlands, 2,994 acres of upland riparian and floodplain habitat, and 43 miles of streams. The stream miles include 19.8 miles of the Chuitna River, over five miles of Lone Creek, and several miles of Lone Creek tributaries.

The proposed preservation parcels are located on the west side of Cook Inlet, within the Cook Inlet Basin ecoregion. The preservation project is proximal to the natural gas pipeline route (Beluga option), but the majority of aquatic resource impacts from the Donlin Gold mine would occur on the other side of the Alaska Range within the Kuskokwim Mountains ecoregion.

Evaluation of the proposed compensation should be based on functional losses and gains. As referenced above, the Guidelines encourage the use of function or condition assessments to determine the amount of compensation that would be sufficient to offset the authorized impacts. Function and condition assessments provide tools to quantify the extent of functional loss (debits) and functional gain (credits). Debits represent the loss of function at the impact site, while credits represent the accrual or attainment of aquatic functions at a compensatory mitigation site.

The use of debits and credits is important because ratios based only on acres or linear-feet almost always result in a net loss of aquatic resource function. The net loss occurs because direct impacts within a fill footprint may result in a complete loss of function for the affected acres, while the functional gains from restoring, enhancing, or preserving aquatic resources tend to be smaller and incremental. The more limited functional losses caused by secondary impacts are more comparable to the gains from compensation. Specific to credit production, the Guidelines state that "[t]he number of credits must reflect the difference between pre- and post-

[15] 40 CFR § 230.94(c)(1)(i)

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compensatory mitigation project site conditions, as determined by a functional or condition assessment or other suitable metric[16]."

The Alaska District adopted a Credit Debit Methodology (CDM) in September of 2016. The CDM uses function or condition data to quantify the functional losses or gains between the current and proposed future condition. These functional deltas are used to calculate debits and credits, as recommended by the regulations.

The CDM also incorporates the requirements for the use of preservation found at 40 CFR § 230.93(h), including that the preserved resources provide important physical, chemical, or biological functions for and contribute significantly to the ecological sustainability of the watershed. The CDM explicitly quantifies the importance of the preservation site for the watershed, the threats to the site, and the functional lift associated with the preservation. The incorporation of these elements strongly influences the number of calculated credits from preservation projects, and results in an effective mitigation ratio for the use of preservation much greater than 1:1.

We believe that the District's Methodology, or at least a consistent approach, should be used to support decisions about compensation for this project.

Donlin Gold's CMP does not use functional data to quantify project impacts or the functional gains from their proposed compensation projects. Extensive functional data were collected for the areas of the proposed project components, and included in the DEIS. These data, or revised data, or even best professional judgment, could be used to calculate project debits.

Our understanding is that sufficient baseline data exists for the proposed stream restoration sites to quantify functional lift. Regarding the proposed preservation project, we support the collection and use of function or condition baseline data for calculating the number of credits that the proposed preservation would generate. Where appropriate quantitative assessment tools are available, the regulations require their use to determine the contribution of resources that would be preserved to the ecological sustainability of the watershed[17]. Functional assessment data have consistently been used to calculate credits for preservation projects in Alaska. Diverging from this practice would be counter to the intent of the regulations.

Donlin Gold's CMP does not use the District's CDM or other method to calculate debits and credits. Instead, the CMP compares the acres and linear feet of their direct, permanent impacts with the acreage and linear feet of their compensation projects. The current CMP does not propose to offset all of the aquatic resource functional loss associated with the project. Nor would the proposed compensation generate sufficient functional lift to fully offset even the subset of project impacts, when evaluated consistent with District practice.

In addition, the current CMP does not propose the use of available third-party credits, although we understand that Donlin is considering the purchase of credits to offset impacts within the Matanuska-Susitna Borough along the pipeline route. The use of third-party credits is presumed

[16] 40 CFR § 230.98(o)(3)
[17] 40 CFR § 230.93(h)(1)(ii)

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to be practicable, and the regulations establish a rebuttable presumption that third-party credits are environmentally preferable to permittee-responsible mitigation due to the lower risk associated with their use. Mitigation bank and in-lieu fee compensation projects are considered as more likely to: address watershed needs, be implemented successfully, and be ecologically sustainable.

The CMP addresses the practicability of several specific potential compensation projects. It does not, but should, address why the proposed compensation is environmentally preferable. The discussion of what is environmentally preferable should address the proposed use of out-of-kind compensation, and compensation that is outside of the watershed.

Credits are generally restricted in use to the area where they can effectively compensate for adverse environmental impacts[18]. The CMP should address how the proposed preservation would effectively offset the authorized impacts, given that the preservation project is not within the same ecoregion as most of the project impacts. As referenced above, the regulations identify that proximity to the impact site is a legitimate consideration when evaluating proposed compensation and in calculating credits. We believe that when and how out-of-watershed compensation is allowed should be a matter of consistent District practice.

Stream assessment tools should be used to assess changes in stream function.
As we have expressed in comments on other projects, functional losses and gains to streams should be assessed analogously as functional losses and gains to wetlands. Provided that the approach to assessing function or condition is analogous between methods, we are unaware of negative implications of using resource-specific assessments for wetlands, streams, and marine resources. Resource-specific assessments generally provide outputs with greater accuracy and precision than more generic assessments which are applied to a variety of resource types.

The EPA contributed to the development of the Stream Functions Pyramid Framework, and has been promoting use of this approach nationally. We have been working with state and federal agencies in Alaska to facilitate use of the Framework by collecting reference data and providing training. The Bureau of Land Management has implemented multiple stream restoration demonstration projects using the approach, with plans for additional projects. The National Park Service also plans to use the Framework to design stream restoration projects.

Like many wetland assessment approaches, the Stream Functions Pyramid Framework measures the condition of multiple variables relative to reference data to infer functional performance. An associated Stream Quantification Tool is used to measure the change in condition and quantify the relative degree or delta of functional gains or losses. This delta may be used as input for the District's Credit Debit Methodology to calculate the credits or debits associated with specific activities. The assessment area for the Framework and SQT includes the stream channel, floodplain, and channel migration zones. Because of this, stream credits and debits may be acre-based, making them directly compatible with acre-based wetland credits and debits. If desired, the stream credits and debits can be converted to use a linear foot metric rather than acres.

[18] 40 CFR § 230.98(d)(6(ii)(A)

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We recommend that the functional gains attributed to the proposed stream restoration to be quantified using the Framework and SQT, or a similar stream assessment method. We further recommend that the functional delta generated by the stream assessment be used with the District's CDM to calculate the credits that would be produced by the compensation project.

Out-of-kind compensation may be environmentally preferable.
The Guidelines require the district engineer to identify what form of compensation would be environmentally preferable, and to use a watershed approach for compensatory mitigation decision-making, to the extent appropriate and practicable[19]. The district engineer should consider relevant environmental factors and appropriate locally developed standards and criteria when determining the appropriate watershed scale in guiding compensation activities.

In-kind compensation projects are more likely to be effective in directly offsetting authorized impacts, but the watershed approach may indicate that out-of-kind compensatory mitigation will better serve the high-priority aquatic resource needs of the watershed. This may be particularly true where specific resource types are uncommon, are of high value relative to other types, or if the historic impacts within the watershed were to a different type of aquatic resource than what is affected by current activities. The rationale for any out-of-kind compensation should be documented in the administrative record for the permit action[20].

In this case, the proposed stream restoration would be proximate to the authorized impacts. It would also address cumulative impacts to stream function in the watershed which have accrued over time, and which have generally not been offset. In addition, restoration of aquatic resources results in active functional lift, while preservation results in passive lift and a net loss in aquatic resource area and function.

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[19] 40 CFR § 230.93(c)(1)
[20] 40 CFR 230.93(e)(2)

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EPA Comments
Preliminary Draft EIS (Phase I)
Donlin Gold Project

Section	Page	Original Language	Proposed Language, Comment, Recommendation	Disposition
General Comments				
Alternatives. We recommend evaluating Option No. MS-72. *Designing the TSF with multiple cells in an upstream to downstream sequence* as an Alternative to carry forward in the EIS. In light of the recent Mount Polley Mine incident and the recommendations of the independent review panel, the EIS should evaluate another alternative to the project sponsor's subaqueous tailings storage method. Under Alternative 5A (Dry Stack Tailing) another option may be to incorporate the design of a lower main dam and two upper dams for subaqueous tailings storage, rather than dry stack, as a form of secondary containment.				
Mine Pit Dewatering. The EIS should provide a detailed description of the expected footprint impacted by dewatering and the characteristics of the landscape, particularly in regards to the carbon content. There should be discussion of the potential to switch these areas from carbon sinks to carbon sources after they are dried.				
Crooked Creek. We have concerns regarding the loss of groundwater recharge to Crooked Creek and the adjacent areas as a result of the mine pit dewatering. Certain areas may run dry over a 2 – 3 mile stretch around the mine and downstream. We recommend evaluating options to ensure that flows in Crooked Creek are maintained to support downstream water quality and habitat throughout the mine life. On-going monitoring of the water levels and flows in Crooked Creek and the adjacent areas should be required, as well as implementing an adaptive management plan to address this issue.				
Methylation. The edge of the groundwater drawdown is a zone where there will be greater water level fluctuation (wetting/drying cycles). This could impact methylation and should be addressed in the section on methylation. At mine closure, there will be a large area re-wetted, the impacts on methylation should be discussed.				
Water Quality Monitoring. Biological Assessments should be incorporated into the surface water quality monitoring for closure and post closure.				
Liners. We encourage the use of impermeable liners for all contact water ponds and the waste rock facility to minimize potential groundwater contamination and the volume of mine contact water treatment.				
Verify that all units of measurement are in Standard International Units (e.g., acres, feet, miles, tons, cubic yards, etc.). Convert metric units to SI units, if applicable.				
Verify that project information, estimates, and data are consistent between the different chapters and sections.				
For volume estimates, in addition to providing a rate (gpm – gallons per minute), include the volume estimate (e.g., total gallons or gallons per year, etc.)				
Chapter 1. Purpose and Need				
1.1	1.1-1	Lead Agency: U.S. Army Corps of Engineers BLM State of Alaska PHMSA EPA FWS Aniak Crooked Creek Naipaimute Chuathbaluk Akiak Knik	Lead Agency: U.S. Army Corps of Engineers Cooperating Agencies Federal: BLM PHMSA EPA FWS State of Alaska Tribal Governments: Aniak Crooked Creek Naipaimute Chuathbaluk Akiak Knik	

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SECTION	PAGE	ORIGINAL LANGUAGE	PROPOSED LANGUAGE, COMMENT, RECOMMENDATION	DISPOSITION
			downstream, etc. - MJ	
3.6 Synopsis	3.6-2	Effects of Alt 2 on flow to Crooked Creek during mining are expressed as summer flow and winter flow reductions as well as annual average. Post closure estimate is just for "average flow reduction."	Inclusion of the seasonal flow reductions for the post closure period would allow a more complete evaluation of effects. (LE)	
Figure 3.6-2		This figure, in particular, is very hard to read in a black and white print. Even in color, some of the text is barely legible.	Whenever possible, make an effort to make figures legible in black and white as well as color. It isn't always possible, but it often takes just a little effort to communicate the majority of the information in both formats by varying line weight or pattern as well as color, for example. (LE)	
3.6.1.4.1	3.6.1.8	"The amount and uncertainty of inaccuracies of these simulations are difficult to gauge. Therefore, sensitivity analysis simulations of mine pit dewatering are used to assess model uncertainty and robustness. These assessments are subsequently used to evaluate possible mitigation conditions such as additional data collection and periodic model revision as dewatering of the pit progresses. *These concepts are further developed in Section 3.6.1.4.*"	Section 3.6.1.4 only briefly mentions that sensitivity analyses were done and does not discuss periodic model revision or mitigation. (LE) Sensitivity analyses are described in section 3.6.2.2.1 under Model Robustness and Accuracy. It isn't clear from this section where in the document modeling results are used to evaluate mitigation. (LE)	
3.6.2.2.1	3.6-32	Pit Lake Closure section "The pit lake level will be managed to remain below the level of water in Crooked Creek, thereby inducing ground water flow from the creek to the lake at all times."	Where is the consideration of environmental consequences of the failure of this part of the system? The failure of pumping from the SRS is the final topic of that section, so it is not unreasonable to include pit lake water level management failure here as a low probability but high magnitude event. (LE)	
3.9 Noise				
		General Comment For example, in Table 3.9-8 This sound level is comparable to the sound level of a	For all the tables in this section, please reevaluate the examples of the real noise levels. Please convert all units of measurements from metrics (meter) to standard English units (feet) to be consistent throughout the EIS. This sound level is comparable to the sound level of a very quiet room fan at low speed at 3.28 feet distance. – MJ	

ID No.	Section	Page No.	EPA Reviewer	Original Language	Proposed Language, Comment and/or Recommendation
EXECUTIVE SUMMARY					
1	1.1	ES-1	cg	Project Summary Box: Tailings: Fully lined tailings storage facility	We recommend including the amount of tailings that would be anticipated to be stored at the facility.
2	1.3	ES-3	cg	Text describing the project phases	The discussion does not mention post-closure so it is unclear whether the facility will always be in the closure phase, in which case monitoring would never cease.
3	Table ES-2	ES-3	cg/MJ	Under the heading "Issue Topic or Resource" The first row has "1" in the top right hand cell below the title cell.	We recommend changing "1" to "Air Quality" and/or include "GHG emissions" in this row. We recommend that this number be explained in the context of this table as it is currently unclear to the reader what the number means.
4	2.2.1.3	ES-10	MJ	Tailing Storage Facility	We recommend highlighting that the TSF dam would be constructed on bedrock.
5	2.2.1.4	ES-10	TR	2,240-acre WRF would be immediately east of the pit in the American Creek valley (Figure ES-2). The WRF would be unlined; drainage control would be provided using engineered rock drains and secondary rock (finger) drains. ....the PAG waste rock would be isolated in the WRF to reduce contact with water and minimize the acidification potential.	We recommend that the FEIS describe the amount of mercury remaining in this waste rock that will be in a form that can be mobilized and how this acid generating waste rock will be isolated, as we understand that liners will not be used in the design and operation of the WRF. We recommend further clarification on these points for Agency decision makers and the public.
6	2.2.1.5	ES-11	MJ	Fuel Storage and Distribution	We recommend expanding the heading to "Fuel and Cargo Storage and Distribution" We recommend that the summary information discuss the details of the proposed Angyaruaq Port on the Kuskowkim River, access road, airstrip, camp, and expansion of the Bethel Port; as well as the distribution of fuel and cargo from the Pacific Northwest, etc.
7	2.2.1.6	ES-12	cg	TSF – In the first year of reclamation, during Operations, TSF water would be pumped back into the pit	While it is not uncommon for reclamation to begin during operations, it is usually limited to re-contouring and revegetating specific areas. It usually does not include flooding the pit where operations would take place. We recommend that this sentence be clarified by perhaps removing the phrase "during Operations."
8	2.2.1.6	ES-12	TR	Mobile equipment and vehicles that cannot be reused or are not desired would be buried in	We have concerns regarding the practice of burying equipment and vehicles in the WRF. This can generate voids over time, cause

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16	2.6	ES-23	TR	Unlined Option: The TSF would not be lined with an LLDPE liner. The area would be cleared and grubbed and an underdrain system placed in the major tributaries under the TSF and operating pond to intercept groundwater base flows and infiltration through the DST and convey it to a Seepage Recovery System (SRS).	We recommend additional discussion in the FEIS of the unlined TSF option. We recognize that this underdrain system may have some problems during operations and that over time, there is the potential for the drains to clog with no way to repair them. It is also possible that the ground may shift due to differential settling of the permafrost or from seismic activities impacting the drains from working properly.
17	2.6	ES-23	TR	The operating pond and main dam liners would be removed, the dam walls would be breached and graded back into the footprint, and the footprint reclaimed.	We recommend that the Final EIS clearly describes how the project intends to assure that surface flows do not expose the liner placed over the TSF.
18	3.1:3.2	ES-27: ES-28	TR	The extent or scope of impacts would range from the immediate vicinity of project facilities, to potentially affecting hydraulically connected waters beyond the Project Area. Flow reductions in Crooked Creek adjacent to the Mine Site could range from 20 to 100 percent in winter, depending on bedrock and precipitation conditions; This would reduce or stop groundwater flow to Crooked Creek and drainages east of the creek as groundwater would flow toward the dewatering wells.	Changing Crooked Creek from an effluent stream to an influent stream is a major impact to the environment. In addition, up to 100 % of the stream water may be gone for at least part of the year. This change in stream flow will impact aquatic species and invertebrates that depend on the interconnectedness of this system. We recommend additional discussion, evaluation of the impact of flow reductions in Crooked Creek, and the potential mitigation measures to be taken to reduce those impacts in the FEIS.
19	3.1: 3.2	ES-27: ES-28	TR	...treatment would begin around year 50 to 55 after Closure. The pit lake would be almost full at year 50, when water would be directed through the WTP plant prior to discharge to Crooked Creek. The extent or scope of impacts would range from the immediate vicinity of project facilities, to potentially affecting hydraulically connected waters beyond the Project Area.	Not treating the pit water until year 50-55 after closure and waiting until the pit is almost full would assure that some of this contamination would reach groundwater. The groundwater gradients may be inward initially. But as the pit fills, there may be some flow out of the bottom and sides of the pit. We recommend additional evaluation of the potential impacts of not treating the pit water for 50 years after closure and any mitigation measures to be taken to address those impacts in the FEIS.
20	3.2	ES-29	TR	Groundwater system recovery would cause the cone of depression and water table to slowly recover to the elevation of the post-Closure operating lake level about 30 feet below the pit rim. This level would be permanently managed by pumping to maintain hydraulic containment of contact water in the pit lake.	Please describe in the FEIS how the project will mitigate or minimize acid mine drainage into Crooked Creek and potentially into the Kuskokwim River when pumping stops. We note that the Berkeley Pit, a former open pit copper mine in Butte, Montana, and one of the largest Superfund sites in the U.S., continues to cause ecological damage such as mortality of avian species. Mercury and arsenic are two elements of concern at Donlin, as well. Cyanide will

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	1	42		activities and surface disturbances would expose bedrock at the mine site to erosion from potential channelization of runoff.	migration to the rivers. The faults and fractures would be exposed. We recommend including additional evaluation of bedrock erosion and mercury migration in the FEIS.
73	3.1.3.2.1	3.1-43	TR	546 Mt of ore that would be blasted… And 3,000 Mt of waste rock would be blasted…	We recommend that the FEIS analyze the potential contamination/impacts associated with the blasting material (nitrites).
74	3.1.3.2.1	3.1-43	TR	During closure and reclamation activities, about 2.5 Mt of potentially acid-generating (PAG) waste rock temporarily stored in the low-grade stockpile at the toe of the WRF would be moved to backfill portions of the pit	As the pit is constructed, faults and fractures within it will be left open to groundwater flow. Thus contaminates of concern within the native rock and the PAG waste will have direct access to dissolve out and move within the groundwater system. We recommend including additional evaluation of this potential for groundwater contamination in the FEIS.
75	3.1.3.2.2	3.1-49	TR	TSF closure would also include a cover of waste rock overlain by overburden material and growth media. The finished surface would be contoured to promote controlled runoff and reduce the potential for infiltration through the cap. While the physical and chemical characteristics of the existing surficial deposits could impede potential vegetative growth and/or be susceptible to erosion, these effects would be minimized through reclamation practices such as tilling prior to media placement, surface roughening, and soil amendments	We note that The planned revegetation has the potential to break down the surface cover and promote infiltration. We recommend that the FEIS provide additional discussion of the potential for surface cover damage from revegetation as it might affect infiltration.
76	3.1.3.2.3	3.1-54	TR	Figure 3.1-5 depicts PFYC values for the mine site region.	Figure 3.1-5 does not actually currently depict PFYC values for the mine site region. Figure 3.1-6 depicts the PFYC values. We recommend making this correction in the FEIS.
3.2 Soils					
77	3.2.2.1.2	3.2-9	TR	Regionally, the Mine Site is located in an area characterized by discontinuous, moderately thick to thin permafrost in fine-grained soils, and isolated masses in coarse-grained soils….permafrost is more prevalent on north and east facing slopes. Permafrost also tends to be more prevalent in lower topographic features such as valley bottoms, drainages and	As previously stated, we have concerns regarding differential settling due to permafrost melting that could create issues with the liner itself, with the rock drains under the liner, and with the drains placed on top of the liner. This is especially true since the thickest permafrost is located in the valley bottoms. We also note that the tailings will be heated to facilitate conveyance and placement. Therefore, we again recommend including additional evaluation of the issue of melting permafrost in the FEIS.

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	1	156		seepage flow, consisting of base groundwater flows and infiltration through the dry stack collected and conveyed through rock drains	pump replacement may affect the three-day storage capacity.
3.6 Ground Water Hydrology					
132	Expected Effects Summary	3.6-2	TR	A strong hydraulic gradient driven by topographic highs well beyond the temporary bedrock storage area, would direct overall groundwater flow towards the pit lake, maintain hydraulic containment of all contact groundwater, and block pathways for escape of contaminated water.	We note that the groundwater flow direction may be controlled by fracture flow and not necessarily topographic highs. We encourage you to discuss fracture flow in the FEIS as well.
133	Expected Effects Summary	3.6-3	TR	Trench plugs are installed to minimize the potential for the pipeline trench to create a preferred pathway and alter the natural flow of groundwater.	If you are aware of instances where these trench plugs have been used under these arctic conditions, and how effective are they with permafrost, deep frost levels, and shifting ground, we recommend that this discussion and evaluation also be included in the FEIS.
134	3.6.1.1	Table 3.6-1	LT	Table 3.6-1. Federal and State Regulations Affecting Groundwater Quality.	We note that while there are no federal regulatory programs specific to groundwater protection, there is a public water supply system at the mine site (Donlin Gold Camp, AK2271983) listed in EPA's Safe Drinking Water Information System (SDWIS) Federal Reporting Database as being Inactive since March of 2015. In the event that the system is not intended to be reactivated for use as a drinking water supply, we are including a link to ADEC's Best Management Practices for well decommissioning: http://dec.alaska.gov/eh/pdf/dw/dwp-alaska-bmps-for-decommissioning-water-wells-and-boreholes.pdf and the ADEC Drinking Water Protection Program page: http://dec.alaska.gov/eh/dw/dwp/dwp-main.html We recommend that the FEIS include this information regarding the inactive public water system, and any plans for use of this or other public water systems at or around the mine site in the future for decision makers and the public. We also recommend that, should the Inactive Donlin Gold Camp public water system become active again in the future, then source water protection measures pursuant to the Safe Drinking Water Act (SDWA) should be

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					implemented within the state designated Source Water Protection Areas for this water system. We also recommend that the FEIS incorporate discussion of the design features and/or mitigation measures to be implemented at the mine site to ensure the protection of human health should any additional public water supply wells be drilled into the bedrock aquifer in the vicinity of the mine site.
135	3.6.1.1	3.6-4	TR	Alaska also has in-stream flow water rights regulations designed to protect certain in-stream flow quantities or lake levels for aquatic habitat	We have concerns that Crooked Creek's hyporheic zone would be greatly disrupted. As noted earlier, the creek would be shifting towards losing water, not gaining it. We again recommend including additional evaluation of this issue in the FEIS.
136	3.6.1.2.1	3.6-6	TR	Hydraulic head and hydraulic conductivity data are less abundant at the full depth of the pit....Of the 198 permanent stations where water-level data have been collected, 21 were deeper than 330 ft and 5 were deeper than 800 feet.... Nevertheless, additional boreholes (i.e., exploration and geotechnical) would be drilled and hydrogeologic testing (e.g., dewatering well testing) would be conducted as the project develops. There would be opportunity at that time to collect additional deep hydrogeologic data and to modify/refine interpretations and analyses as required	We note that no pumping tests were done to the full depth of the mine pit. Hydraulic conductivity is the only parameter estimated. The fractured bedrock system in the area of the mine site would make a large-scale pumping test the most accurate method for determining K values. It appears that more data will be collected only after the mine has begun operations to lower the water table and we recommend collecting baseline data prior to that time, in order to assess how the system is changing due to mining operations, in order to better inform the adaptive management strategies that may be needed. We recommend including additional evaluation of this issue in the FEIS.
137	3.6.1.3.2	3.6-11	TR	The difference in water levels between shallow and deep wells at all but four of the sites was less than 10 ft.	We note that this difference may indicate a highly permeable, fractured system or vertical conductivity. See previous comments regarding additional discussion in the FEIS.
138	3.6.1.3.3	3.6-15	TR	practically all water flow is considered to occur through secondary fractures in the rock mass....The testing has shown that the bedrock aquifer is generally less permeable with greater depth.	The variability or range of hydraulic conductivity (three orders of magnitude) may indicate that some testing was in non-fractured portions of the aquifer. We have concerns that this may change the geometric mean used in the modeling. We recommend another look at this and including additional description of the aquifer testing in the FEIS.
139	3.6.1.3.3	3.6-16	TR	Within the pit area, more detailed hydrogeological information is available and hydraulic conductivity variations associated with different rock types was mapped and	We have concerns that these potentially higher hydraulic conductivities were not incorporated into the models. We recommend another look at this and including more discussion on the aquifer testing in the FEIS.

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				corrosion products from the steel pipe sections.	
299	AB.5.3	AB.5-15	TR	At mine closure, contact water would be managed and low permeability covers installed so that release of leachate from the waste rock and tailing facilities is controlled, although some infiltration and seepage through the unlined WRF and then to the pit lake is expected to continue in post-closure.	Infiltrating water may also increase over time due to borrowing activity of animals and plant root growth. We recommend additional evaluation be conducted to address this issue in the FEIS.
300	AB.5.4	AB.5-20	TR	Without food sources and with the expected short durations of visits to the pit lakes, waterfowl are unlikely to stay long in the TSF.	Waterfowl land at the Berkeley Pit in Montana and do not need to stay on the surface of the water long to be exposed to the chemicals within the water. We recommend additional evaluation be conducted to address this issue in the FEIS.
301	2.2	2-3	LK		Occupational exposures are based on 8-hour work days and exposures to healthy adults. Resident workers and potentially children could have exposures that differ and are greater than workers. We recommend that the FEIS consider potential exposures and hazards to workers residing within the mine site.
302	2.3	3-4	LK		The FRA addresses exposures in terms of the time frame of mine operations. However, options preventing contaminant entry into the environment, such as long term treatment of pit water or dam tailings containment, could fail. We recommend that the FRA or FEIS discuss the environmental impacts of failure of the described containment and treatment systems.
303	3.2	3.5	LK		We recommend that a discussion of the values used for COPC screening including the assumptions employed and whether or not the screening values are truly appropriate for human health be included in the FEIS. For example, many of the sediment screening levels developed by the WA Dept. of Ecology are used to evaluate ecological health and are not of relevance to evaluating human health concerns. We recommend that the assumptions used in deriving EPA RSLs should be evaluated in the FEIS relative to assumptions that describe subsistence resource use. Screening levels based on subsistence resource use exposures may further differ from more commonly considered exposures. The term to compare with a screening level is not specifically an RME but is often a risk based concentration corresponding to a

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					hazard quotient of 1.0 or a cancer risk of 1 in 1,000,000. EPA Region 10 utilizes an HQ of 0.1 and a cancer risk of 1 in 10,000,000 to develop risk based screening level benchmarks.
304	3.3	3-6	LK		We suggest that the additive effects of site and regional exposure are important because of endemic mercury exposure and should be further discussed in the FEIS. To identify whether non-cancer hazards exceed acceptable levels, we recommend that the chemicals contributing to that HA should be segregated by toxic endpoint to develop toxic endpoint specific HIs if an HI exceeds one.
305	4	4-7	LK		The treatment of background here does not match the EPA approach for addressing background in the risk assessment process. EPA develops estimates of total and background risks and then derives an estimate of site related risk. Consideration of background is particularly important for mercury. Individuals are already exposed to mercury given its endemic presence in the Kuskokwim region. It is important to determine the sum of background and site related exposures, as the background dose of mercury already potentially predisposes individuals to mercury's adverse effects. The FRA cites the HHRA, which does discuss baseline and project risks for various contaminants. We recommend that the FEIS/FRA correctly present EPA's treatment of background in the CERCLA process and identify the importance of overall risk in determinations of public health. The FRA should summarize total, baseline, and site related risks/hazards, and discuss the significance of the additional increment of risk/hazard posed by the Donlin project relative to baseline risks/hazards.
306	4.1.1	4-8	LK		We recommend that consideration of COPCs be expanded in the FEIS to address the following: • Site related exposures to workers that may reside on site when not working. This would include ingestion exposure to soils and dust and ground water exposures if site groundwater is used for drinking, showering, and cooking. • Provide a more detailed and specific list of WTP effluent chemicals. The Donlin gold ore deposits are high in arsenic. Please describe whether WTP effluent chemicals

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					include arsenic and antimony. Please also assure that mercury is defined as a heavy metal. • Arsenic in deep groundwater mine pit flow. If this is described elsewhere, please reference in this section. • Describe how transportation corridor air pollutants consider arsenic, antimony, and mercury.
307	4.1.2	4-9			Given that contaminants associated with the mine pit, tailings, and waste rock overburden will exist in perpetuity, even very low probability releases could plausibly occur. We recommend that the impacts of these low probability events be quantified in the FEIS as per previous comments.
308	4.2.1	4-10	LK		Given that contaminants associated with the mine pit, tailings, and waste rock overburden will exist in perpetuity, we recommend that exposures deemed incomplete because of the efficacy of management practices, controls, and containment still be evaluated. Quantification of the severity of these exposures and risks should be considered along with a health protective evaluation of the long term efficacy of best management practices, treatment, and containment. For example, please describe how melting permafrost may affect the stability of leachate systems.
309	4.2.1	4-11	LK		As per previous comments, we recommend that the FEIS consider groundwater exposure to mine workers that may reside on site and use site groundwater as a drinking water source.
310	4.2.1	4-11	LK		We recommend that arsenic, mercury, and antimony releases to the environment as a result of road construction and use be evaluated and discussed in the FEIS, particularly in association with use of material excavated from the mine for road construction.
311	4.2.3	4-12	LK		OSHA regulations are designed to protect healthy adult workers from exposures to hazardous chemicals during work hours. OSHA regulations do not address exposures that may occur to individuals residing on site outside of work hours (e.g. incidental soil ingestion, exposure to contaminants in groundwater). We recommend that the FEIS address non-occupational chemical exposures for workers that may reside on site.
312	4.2.4	4-13	LK		We recommend that the FRA provide references to specific sections that provide the justification for determining that exposure pathways are "complete but insignificant." It would be helpful to

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Donlin Gold Mine DEIS
DEIS – Cooperating Agency Review through April, 2016
USFWS Comment Response Matrix

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
USFWS DEIS New Comment	Entire DEIS		General Comment on the entire DEIS			New Comment DEIS	Recommend the Summary of Impacts in the Executive Summary, Synopsis and Summary of Impacts for each resource in Chapter 3 - Environmental Analysis revised. In addition the USFWS recommends Chapter 3.6 - Groundwater Hydrology, Chapter 3.24 - Spill Risk, Chapter 4 - Cumulative Effects, Chapter 5 - Mitigation, and Chapters affected by revised mercury analysis in the DEIS be revised and made available for public review for at least 90 days to address major issues as listed in our cover letter.	
CHAPTER 1: PURPOSE AND NEED								
USFWS 1	1.1		The Corps is joined in this effort by many cooperating agencies, including five federal and state agencies and five tribal governments (see Figure I-1) that are	Comment: Suggest modifying the language with an explanation that cooperating agencies will be providing recommendations to the Corps. According to	Edited.	The text is acceptable.		

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Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
				conservation units in Alaska. Title III of ANILCA combined three existing wildlife refuges: Nunivak Island Reservation, Hazen Bay Migratory Bird Waterfowl Refuge, and Clarence Rhode National Wildlife Range and created the Yukon Delta National Wildlife Refuge				
USFWS 22	1.9.12		Some marine mammals, including the northern sea otter, are managed by FWS.	Some marine mammals, including the Pacific walrus and northern sea otter, are managed by FWS.	Edited.	The text is acceptable.		
USFWS 23	1.9.17		Under the *Migratory Bird Treaty Act*, takings are prohibited unless expressly authorized or exempted. Losses from habitat impacts are also considered takings under US law.	Please remove the language about what is considered take, see suggested language for the revision. Under the *Migratory Bird Treaty Act*, takings are prohibited unless expressly authorized or exempted. The EIS will address potential impacts of the project and associated infrastructure on all birds protected under the Migratory Bird	Edited.	The text is acceptable.		

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
				Treaty Act including birds of conservation concern and areas of bird concentrations.				
USFWS 24	1.9.18		The *Bald and Golden Eagle Protection* Act (16 USC 668 *et seq.*) provides for the protection of the bald eagle and the golden eagle by prohibiting, except under certain specified conditions, the take, possession, and commerce of such birds. The Donlin Gold project area contains bald eagle and golden eagle habitat, but would not result in the take of bald or golden eagles.	It is too early in the analysis process to make definitive statements about take, please replace this language, see suggestion. The *Bald and Golden Eagle Protection* Act (16 USC 668 *et seq.*) provides for the protection of the bald eagle and the golden eagle by prohibiting, except under certain specified conditions, the take, possession, and commerce of such birds. Eagle take permits may be necessary for activities that result in removal of nests, loss of habitat, and disturbance of birds during construction, operation, and maintenance of the project. The EIS will identify the presence of eagles or their nests in the project area (along	Edited.	The text is acceptable.		

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
				with associated infrastructure routes), and analyze potential impacts of the proposed project on both bald and golden eagles as protected under the Bald and Golden Eagle Protection Act. Alaska specific information can be found at: http://alaska.fws.gov/eaglepermit/index.htm.				
USFWS DEIS New Comment	DEIS 1.10.19	1-32	FISH AND WILDLIFE COORDINATION ACT			New Comment DEIS The full text of the FWCA would be more applicable. Suggest revising the text.	Suggest revising text as follows: The Fish and Wildlife Coordination Act, as amended, (FWCA), (16 U.S.C. §§ 661 et seq.), requires the agency that is authorized to permit or licenses changes in a water body to first consult with the FWS and appropriate State fish and game agency. The FWCA provides that wildlife conservation shall receive equal consideration, and be coordinated with other features, of the	

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
							development project. The FWCA authorizes the FWS to conduct surveys and investigations to determine the possible damage of proposed developments on wildlife resources, to make recommendations for preventing their loss or damage. The term wildlife resources is explicitly defined to include "birds, fishes, mammals, and all other classes of wild animals and types of aquatic and land vegetation upon which wildlife is dependent" (16 U.S.C. 666 (b)). Further the FWCA states that reports determining the possible damage to wildlife resources and an estimation of wildlife loss shall be made an integral part of any report prepared or submitted the agency with permitting authority (16 U.S.C.	

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
							662 (b),(f)).	
USFWS DEIS New Comment	DEIS Table 1.10-2	1-37	Bald and Golden Eagle Protection Act FWS permits relocation of bald and golden eagle nests that interfere with resource development or recovery operations.			New Comment DEIS Suggest the text be more project specific.	Suggest revising text as follows: Eagle take permits may be necessary for activities that result in removal of nests, loss of habitat, and disturbance of birds during construction, operation, and maintenance of the project.	
USFWS DEIS New Comment	Table 1-10-2	1-38	Endangered Species Act of 1973 (ESA) FWS provides consultation on effects to threatened or endangered species, and to designated critical habitat, and issues incidental take authorizations. Species include terrestrial mammals, plants, birds, Pacific walrus, northern sea otters, and polar bears. (NOAA also administers the ESA.)			New Comment DEIS Suggest the text address only the species located within the action area, remove polar bear.		
USFWS 25	Table 1-3		Under US Fish and Wildlife Service (FWS)	For the sake of consistency it may be helpful to list authorizations from	Edited.	The text is acceptable.		

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
				section 1.9 above. Noted missing: the Marine Mammal Protection Act.				
CHAPTER 2: ALTERNATIVES								
USFWS 1	2.2		The EIS contractor completed preliminary screening, which was reviewed and refined by the Corps and cooperating agencies.	The EIS contractor completed preliminary screening, which was reviewed and refined by the Corps. There were options reviewed and approved by the cooperating agencies to be carried forward for further analysis in the EIS but were subsequently eliminated in Step 4 without sufficient justification and without cooperating agency agreement (Specifically Transportation Options Accepted as of 08-23-13: TI34; TI35; TI38; and TI39).	Noted.	No, the comment was not addressed adequately. The specific transportation option was addressed in detail but the general comment applies to other options that were eliminated.	Recommend an Alternative that considers constructing both a diesel and a natural gas pipeline in one corridor be fully analyzed in the DEIS.	
USFWS 2	2.2.1.1.2		Where the order of magnitude cost review was not sufficient to decide whether an option was economically feasible, it was advanced for	Although the Service agrees that alternatives that are clearly infeasible or impractical be eliminated, provided there is sufficient justification, we are	In the March 12, 2014 alternatives workshop, there was additional discussion and clarification of	Yes, the analysis in the Technical Memo dated March 05, 2014 from URS is acceptable.		

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
			additional review, and additional information gathered before reaching a screening conclusion.	concerned that alternative transportation routes may have been dismissed prematurely without conducting adequate analysis in the EIS.	the Service's concerns related to transportation routes. Additional analysis of transportation routes using the Yukon River for barging was conducted. The Corps evaluated the additional information and dismissed transportation routes relying on the Yukon River.			
USFWS 3	2.2.1.2		Alternatives to barging;	The Service recommends alternatives to barging be analyzed. Otherwise, there would be no alternatives other than barging on the Kuskokwim River analyzed in this EIS and this bullet would need to be revised. Specifically we recommend that an alternative for a road between the Yukon and	See comment response above.	Yes, the analysis in the Technical Memo dated March 05, 2014 from URS is acceptable.		

Comment	Section Number	Page	Original Language	Proposed Language or Comment	Response	Comment Addressed Adequately for Draft EIS?	Revised Response	Additional Review Comments
				the Kuskokwim River be analyzed in the EIS.				
USFWS 4	2.2.1.2		• Alternatives to barging;	The Service recommends alternatives to barging be analyzed. Otherwise, there would be no alternatives other than reduce impacts from barging on the Kuskokwim River analyzed in this EIS and this bullet would need to be revised. Specifically we recommend that an alternative for a road between the Yukon and the Kuskokwim River be analyzed in the EIS.	As it is not technically or economically feasible to transport cargo to the mine site without barges, Alternatives 3A and 3B explore reduced barging options. Additionally, constructing a road between the rivers would still require barging; but on both rivers.	The general comment about analyzing Alternatives to reduce impacts from barging on the Kuskokwim River is not fully addressed.	Recommend an Alternative that considers constructing a diesel pipeline parallel to the proposed natural gas pipeline be analyzed in full detail in the DEIS.	
USFWS 5	232		These common features are largely due to the use of standard construction and environmental protection measures.	These features are similar due to the use of conventional methods of construction and standard environmental protection measures. Suggest adding a footnote with the definition of mitigation[3]. As stated in this section the meaning of "standard construction	Comment noted.	Text is acceptable.		

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				and environmental protection measures" is not clear. The term could be interpreted as standard operating procedures, best management practices, or design features. The meaning is further convoluted by the definition of terms "design features" and "mitigation measures" provided on Page 83. [3] "Mitigation" includes: (a) Avoiding the impact altogether by not taking a certain action or parts of an action. (b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the				

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				action. (e) Compensating for the impact by replacing or providing substitute resources or environments (40 CFC §1508.20). See Page 83 for further recommendations.				
USFWS 6	2.3.2		FEATURES AND ENVIRONMENTAL PROTECTION MEASURES COMMON TO ALL ACTION ALTERNATIVES	DESIGN FEATURES AND MITIGATION MEASURES[3] COMMON TO ALL ACTION ALTERNATIVES The Service suggests the term "mitigation measures" be used in place of "environmental protection measures". Suggest adding a footnote with the definition: "Mitigation" includes: (a) Avoiding the impact altogether by not taking a certain action or parts of an action. (b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (c) Rectifying the impact by repairing,	Comment noted.	Text is acceptable.		

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				rehabilitating, or restoring the affected environment. (d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action. (e) Compensating for the impact by replacing or providing substitute resources or environments (40 CFC §1508.20) [3] "Mitigation" includes: (a) Avoiding the impact altogether by not taking a certain action or parts of an action. (b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (d) Reducing or eliminating the impact over time by preservation and				

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				maintenance operations during the life of the action. (e) Compensating for the impact by replacing or providing substitute resources or environments (40 CFC §1508.20)				
USFWS 7	2.3.2		Features common to all action alternatives are discussed in the following sections and Section 2.3.2.4: Common Features – Environmental Protection Measures describes the protection measures (often permit terms and conditions or regulatory requirements) that would potentially be implemented for any of the action alternatives.	Features common to all action alternatives are discussed in the following sections. Section 2.3.2.4 describes the design features and mitigation measures (often permit terms and conditions or regulatory requirements) that would potentially be implemented for all of the action alternatives.	Text changed as suggested.	Text is acceptable.		
USFWS DEIS New Comment	2.3.2.1.4	17	Auxiliary fleet vehicles would be used for road maintenance, bench development in the			New Comment DEIS	Recommend text be revised. Please remove or otherwise make this paragraph relevant to	

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			open pit, construction of the WRF, and miscellaneous mine site projects. Graders would maintain the haul roads, including the mine access road. Water trucks would spray roads and working areas to mitigate dust impacts to air quality.				the subject. The subject of the section is Flotation; it's unclear what fleet vehicles have to do with flotation?	
USFWS DEIS New Comment	2.3.2.1.4	19	FIGURE 2.3-5			New Comment DEIS	Suggest revising this information. Ore processing involves sequential steps after the ore has been transported from the open pit to the nearby facilities. Are there Arsenic controls in the process outlined in Figure 2.3-5? What are the projected Arsenic emissions from this autoclave step?	
USFWS DEIS New Comment	2.3.2.1.4	19	FIGURE 2.3-5			New Comment DEIS	Suggest revising this information. Identify the type of acid used in the acid washing step.	
USFWS DEIS New Comment	2.3.2.1.4	20	Gas vented from the autoclaves would be cooled and sent to the mercury abatement			New Comment DEIS	Suggest revising this information. Describe other hazardous air pollutants (HAP) that	

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			system.				are present in autoclave gas and how these are being removed prior to discharge into the environment.	
USFWS DEIS New Comment	2.3.2.1.4	20	After stripping (desorption of gold from carbon), the barren carbon particles would be re-generated using high temperatures in a rotary kiln to remove organic contaminants and to capture mercury.			New Comment DEIS	Suggest revising this information. Describe the capture process for mercury (Hg) and discuss whether or not it will it capture other HAPs.	
USFWS DEIS New Comment	2.3.2.1.4	20	off gas from the retort is cooled to condense mercury and then passes through sulfur-impregnated carbon columns to capture any residual mercury.			New Comment DEIS	Suggest revising this information. Is there a way to remove the carbon from this step and facilitate Hg reduction and formation of HgS?	
USFWS DEIS New Comment	2.3.2.1.4	20				New Comment DEIS	Suggest revising this information. How will the Dore bars be taken offsite?	
USFWS DEIS New Comment	2.3.2.1.4	20	SO2 gas would be added at a rate sufficient to reduce the weak acid dissociable cyanide (CNWAD, referring to those			New Comment DEIS	Suggest revising this information. Describe the chemical reaction including the end products that will be discharged to the	

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			cyanide species measured by specific analytical techniques) levels in the tailings to <10 parts per million (ppm) prior to discharge				tailings facility. Is the cyanide (CN) transformed or destroyed in this reaction?	
USFWS DEIS New Comment	2.3.2.1.5	21	Donlin Gold estimates the mine would remove approximately 34,600 pounds of mercury per year from the gaseous waste streams.			New Comment DEIS	Suggest revising this information. Donlin Gold estimates the mine would remove approximately 17.3 tons of mercury per year. Please describe the total amount of Hg estimated to be in the ore body and its eventual fate – a figure may help? Although Hg will be removed, our understanding is only ~50% of the total Hg of what would be released would be recovered, see USFWS comment in Water Quality. The totals need to be transparent to the reader in the document.	
USFWS DEIS New Comment	2.3.2.1.5	21	Table 2.3-2: Mercury Control Efficiency			New Comment DEIS If this process describes the removal of Hg from	Suggest additional information be provided. This information would be	

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						the gas, it does not describe the proportion of Hg that continues on down the line in the ore/tailings this makes the percentages somewhat misleading.	more transparent if put in context of total Hg in the ore. There are footnotes on these numbers; however it's unclear what they reference? A more transparent presentation of this information would follow the Hg from the ore, and show % removed versus percent going downstream, as a % of the original estimated amount in the ore by mass.	
USFWS DEIS New Comment	2.3.2.1.5	22				New Comment DEIS	Suggest revising this information. What are the process temperatures, could a catalyst be added to oxidize the elemental Hg at some of these steps.	
USFWS DEIS New Comment	2.3.2.1.5	22	The primary mercury removal bank is filled with a sulfur-impregnated carbon that captures mercury through chemical adsorption (chemisorption). The			New Comment DEIS	Suggest revising this information. Is there also a straight condensation step that pulls the elemental Hg?	

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							magnitude) and its recovery; • estimates of changes in stream baseflows due to pit dewatering (areal extent, magnitude, and timing) and their recovery; • estimates of the rate of formation of the pit lake; and • other project/closure-related numerical analyses.	
USFWS DEIS New Comment	3.6.2.2.1; Environmental Consequences, Alternative 2 (Donlin Gold's Proposed Action), Mine Site – Closure, Reclamation, and Monitori	3.6-33 - p 3.6-35				Suggest the Groundwater Hydrology section 3.6 be revised.	Possible substantial misconception regarding the hydraulics of the pit lake during its formation and once "maximum managed stage" is established. The pit and partially-formed pit lake act like a very large partially-penetrating well, the depth of the "sink" defined by the level of water in the pit. Consequently, the zone of converging	

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	ng, Pit Lake						flow (capture) which is created by the pit, and then partially-formed pit lake, is finite in its vertical extent (due to the finite extent of upward flow components induced), and the zone of capture follows the rising level of water in the pit lake. This is recognized, although not clearly articulated in the DEIS and elsewhere in the supporting documents. What does not appear to be recognized, but has significant ramifications for the fate of any contaminated water generated or disposed of in the pit, is that these conditions (capture of limited vertical extent) will also prevail once the level of water in the pit lake reaches and is maintained at the somewhat reduced	

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							"maximum managed stage" (which is otherwise protective of Crooked Creek). Contrary to what is currently hypothesized, the pit (in its entirety) will not be rendered a sink for groundwater flow as a result of maintaining the level of water in the lake at a maximum managed stage of 331 ft amsl (or any other level below the steady pit lake elevation) – containing any contaminated water in the pit lake. Rather, at depths that exceed the finite vertical extent of capture, any contaminated water in the pit lake will be free to flow out of the (former) pit into the surrounding groundwater flow system(s). Depending on the depth below ground surface at which contaminated water	

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							flows out of the pit lake, it *may be* discharged to local streams, drainages or lowlands. If groundwater flow in the vicinity of the mine site is truly "local" at all relevant depths, as hypothesized by the current conceptual and numerical models, then contaminated water in the pit lake (below the zone of upward flow/capture) is *certain* to be discharged over time to local streams and low lying areas. Alternatively, depending on depth in the pit lake, contaminated water may be introduced to and transported offsite by regional groundwater flow, which would likely be southwesterly (in the direction of the Kuskokwim River and extensive marshlands	

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							beyond); or may be introduced to and transported by local, as well as regional, groundwater flow away from the former pit, and possibly the site, in different directions.	
USFWS	3.6.2.2.1	2	Pit dewatering would be initiated during the construction phase. Initially, approximately 17 wells would be drilled around the perimeter of the initial excavations and pumped at an average total rate of approximately 1,700 gpm when the dewatering system is turned on two years prior to operations.	Please provide a map of the wells and well depths, this information would be useful in analyzing potential mitigation measures. For example, could a well field of more shallow dewatering wells be drilled between Crooked Creek and the pit in order take back the groundwater by pumping it back to the creek before it reaches the pit?	Figure 3.6-6 has been added showing the locations of dewatering wells.	Comment was partially addressed.	We propose the following mitigation measure: Water should be discharged year round to Crooked Creek to reduce effects on system from stream flow reductions. The USACE should work with the State, USFWS, and Donlin Gold to establish minimum flows in Crooked Creek	
USFWS	3.6.2.2.1; Environmental Consequences, Alternative 2 (Donlin Gold's	3.6-33 - p 3.6-35				Suggest the Groundwater Hydrology section 3.6 be revised.	Implications for the planned disposal of acid-generating waste rock, seepage from the unlined WRF, and tailings-contaminated liquids in the pit at or after closure: Given that water at depth in	

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Chapter 3				
3.6 Groundwater	All	At Closure, contact water would temporarily migrate out of the pit lake into local surrounding bedrock, but would flow back towards the pit after about eight years…	As provided in our 2016 comments on the November 2015 Draft EIS, groundwater level (hydraulic head) measurements collected to date at the Donlin site are not adequate to characterize (understand) groundwater flow in the vicinity of the proposed project under present-day (pre-project) conditions. We also provided technical expertise at the December 2016 technical working group meetings and have provided follow-up information from that meeting directly to the USACE. At mine closure, contact water would temporarily migrate out of the pit lake into local surrounding bedrock. The plume of contaminated water into the surrounding bedrock and presence of "regional" groundwater flow at relevant depths have not been sufficiently addressed to determine potential for groundwater (and surface water) contamination depending on connectivity. Impacts to water quality could affect migratory birds, fish, and other aquatic dependent species, as well as subsistence users downstream of the mine. Please see our forthcoming cover letter, additional comments and suggestions for mitigation below, under Chapters 3.6 and 5.	
	3.6-52 to 3.6-56	Summary of impacts for Alternative 2	Based on information and analyses provided in this PFEIS and supporting documents, deficiencies exist in the current hydrogeologic data and analyses for the mine site which are substantial, please refer to the technical comments associated with evaluating impacts to groundwater from the pit. Given the uncertainties, we are not seeing that direct and cumulative effects to groundwater-related resources, including impacts to streamflows and water quality, under Alternative 2 (Donlin Gold's Proposed Action) have been adequately characterized and, in particular, that net overall groundwater-related impacts following closure have been demonstrated to be minimal or limited.	
3.10 Vegetation and NNIS	3.10-58	Negative ecological consequences of invasions are well documented. Invasion impacts can include degradation of	During Construction and Operations, 9,819.3 acres of vegetation would be removed at the Mine Site, 1,093.4 acres removed in the Transportation Corridor, and 6,981.9 acres removed in the Pipeline component, for a total of 17,894.6 acres removed. Page 3.10.58 states the primary goal for vegetation management, and all project activities, is preventing introduction and spread of non-native invasive species. Yet page 3.10-58 states, "Donlin Gold has developed a draft Invasive Species Prevention and	