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EFFECTS OF THERMAL INCREMENTS ON EGGS AND YOUNG OF COLUMBIA RIVER FALL CHINOOK[1]

by

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EFFECTS OF THERMAL INCREMENTS ON EGGS AND YOUNG OF COLUMBIA RIVER FALL CHINOOK

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INTRODUCTION

A substantial population of chinook salmon, Oncorhynchus tshawytscha, spawns each fall in the Priest Rapids - Hanford section of the Columbia River, southcentral Washington. Spawning occurs from the middle of October until late in the fall, usually peaking about the first week in November [1]. A single temperature tolerance test on this stock of fish was conducted starting in the fall of 1953 [2]. Results indicated that an average increment of 4 °F over river temperatures produced no significant loss, but an 8 °F increment produced a marked increase in mortality.

The laboratory investigation was conducted to determine more precisely the temperature response of eggs and young derived from local chinook to different heat increments. These increments were superimposed on base river temperatures that followed typical seasonal patterns. The tests involved progeny of fish collected at different times during the duration of the fall spawning period. Thermal effects were defined in terms of mortality and growth of developmental stages.

The results, reported herein, provide biological data required for comprehensive guidelines to determine permissible standards for the addition of heat

to Columbia River water during fall, winter and spring without significant damage to reproductive success of adult chinook.

MATERIALS AND METHODS

Four pairs of sexually mature chinook salmon, provided by the Washington State Department of Fisheries from Priest Rapids stock, were spawned in 1966 on each of four dates: October 30, November 14 and 23, and December 8. Numbers of available eggs ranged from 4,000 to 6,000 eggs per female in each Series. The eggs of each female were fertilized with sperm from a different male. After water hardening, the eggs were transported to the Aquatic Ecology Laboratory at Hanford (100-F Area). The eggs were distributed within three hours of fertilization among seven enameled steel troughs, each 10 ft in length, which received a flow of 3 gal per minute of untreated Columbia River water. The troughs were partitioned into sections that allowed simultaneous incubation and holding of separate egg lots in similar relative positions on shallow trays. Each trough was subjected to a different temperature regime differing by stages of about 2 °F. The median reference temperature was that of the river water entering the hatchery. Three other troughs were held at 2°, 4° and 6 °F, respectively, above median; three others had temperatures of 2°, 4° and 6 °F, respectively, below median. Under these conditions, the experiment covered a test range of 12 °F where temperatures in each trough varied proportionately in response to the river's seasonal pattern. Hatchery water temperatures were generally 4-6 °F warmer than the Columbia River above Hanford because of heat generated by pumping, intake location, line transport and building temperatures. The coldest temperature treatment approximated average river temperatures above the Hanford area. Freon refrigeration units of approximately

7.5 ton capacity were used for cooling, and electrical immersion elements of 2,000 watt capacity were used for heating. Required temperature adjustments were made in the supply system before the water entered the troughs.

The thermometer used for temperature readings and thermograph correlations was read to the nearest 0.1 °F and its accuracy was checked periodically with a certified thermometer. Temperatures were measured in the center of each trough. The average daily temperature variation of the hatchery water was 1 °F. Maximum temperature differences betweem various positions within a trough were about 0.3 °F. The temperatures plotted for analyses are average daily temperatures calculated from the morning and evening readings (closely approximating minima and maxima). In addition, all troughs were monitored by Foxboro thermographs. Recorded tapes were checked against the thermometer records for verification and/or correction of the best estimates of average temperature. The total error from all sources in the calculated average temperature was less than 0.5 °F. Dissolved oxygen levels were near river saturation and pH determinations ranged from 7.52 and 7.97.

The eggs, fry and fingerlings were given routine fish cultural care. Daily records of mortality were maintained. Opaque eggs were preserved and cleared in Stockard's solution for determination of various stages of embryo formation at time of death. Feeding was started when the fish accumulated 1600 temperature units [3]. (One temperature unit equals one degree above 32 °F for 24 hours). Fish were fed Clark's Chinook Mash and Oregon Moist Pellets ad libitum 8 hours per day. Samples of fish from each lot were weighed at similar stages of development. At the completion of rearing, a representative sample of 50 fish was weighed and measured individually for data on size variation within each test lot.

Tests with spawn used in each series were continued for 177 days. Termination times ranged from April to June and coincided with the period of maximum seaward migration of young fall chinooks produced locally in the Columbia [13,14].

RESULTS AND DISCUSSION

Series I (October 30 Spawning)

The daily average temperatures for the experimental series from eggs fertilized on October 30 are plotted in Figure 1. The curves show the characteristic cooling of the river during the fall and early winter, followed by a low temperature plateau during January to March and a spring rise in in April. For reference, the current 5 year average (1964-69) Columbia River temperature above the Hanford Area at Priest Rapids is also shown. Daily cumulative mortalities are given in the upper portion of Figure 1. The approximate hatching dates are indicated by vertical lines on the mortality curves. Thus, the curve to the left of the hatching date represents prehatching egg mortalities while the curve to the right shows posthatching fish mortalities. The shape of the cumulative mortality curve during the egg stage is somewhat hypothetical because the precise time of embryonic death is difficult to determine. The practical criterion of egg mortality is opaqueness of the ovum, a result of globulin precipitation, which often occurs some time after true embryonic death or non-fertilization.

Total mortalities are summarized in Table I and plotted in Figure 2. Lot 2, subject to temperatures averaging 2.9 °F above the 5-year river mean and Lot 1, averaging within less than 1 °F of the mean, had similar mortalities. Lot 3, which averaged 4.9 °F above, revealed a statistically significantly

higher mortality ($P < 0.05$) [4]. However, the total mortality was only 11 percent even in lost 3, which compares favorably with the average mortalities (15%) at the Fish and Wildlife's fall chinook rearing stations at Spring Creek and Little White Salmon on the lower Columbia River [5]. Temperature increments averaging 7 °F above the mean resulted in excessive mortalities.

The mortality pattern and timing were related to the temperatures encountered. Figure 1 shows earlier and greater mortalities occurring under warmer conditions. Since the rate of egg and juvenile development is related to water temperatures, fish held under the warmer conditions developed faster and showed more rapid mortalities than did fish under more normal temperature conditions.

Egg mortalities in Lots 1 through 4 appeared to be similar (Table I, Figure 2). Egg mortality in Lot 5 (+ 9 °F) was significantly higher, and losses were excessive in the two warmest lots. The percent mortality of "eyed" eggs is shown on Figure 2. The "eyed" stage is associated with eye pigmentation in the embryo and is visible through the translucent egg shell. This occurs at approximately one-third of the development time to hatching. In a previous test, chinook eggs subject to unfavorable high temperatures showed a marked increase in mortality during advanced developmental stages, whereas mortality during earlier developmental stages showed less correlation with temperature [2]. In this test, as shown in Figure 2, most egg mortality in the three warmest conditions also occurred after the eyed stage.

The fish mortalities (mortality after hatching) shown in Figure 2 are similar to the total mortality picture. Lot 3, with temperatures averaging 4.9 °F above that of the river, showed a significantly increased mortality. Temperature increments of 7.0 °F and above resulted in excessive mortalities.

Although no autopsy was possible on dead fish, mortalities of individuals appearing malformed or diseased were recorded. An identifiable portion of the abnormal conditions are noted in Figure 2. Disease clearly obscures the mortality picture by introducing a factor other than temperature that can cause death. Fish are more crowded under experimental conditions then in nature and transfer of disease organisms is thus facilitated. (We accepted losses from diseases as manifested and performed no prophylactic or curative treatment.) Determination of the extent that various temperatures might favor the development of disease was beyond the scope of these tests. However, the effect of excessive temperature increments on the mortality pattern appears similar, differing only in degree, with or without interpretation of disease effects.

While Figure 1 presents gross mortality on a calendar time scale where the various lots were subjected to different temperatures, a more complete interpretation requires comparison of mortalities at similar stages of development in fish maintained at different temperature regimes. Marr [6] discussed the difficulties in obtaining a satisfactory index of development. For efficient comparison, we assumed that the accumulation of a similar number of temperature units (TU) was a reasonable approximation of similarity in stage of development. Although Battle [7] concluded that application of thermal units to determine comparable stages in Atlantic salmon (Salmo salar) embryos was unsatisfactory, its use offered a realistic evaluation tool in the case of chinook salmon. (TU are commonly used as an index of egg development in Pacific salmon hatcheries.) Although hatching data indicated some differences in numbers of TU between fish, the differences were small and appeared comparable within a relatively short period of several days. Figure 3 shows the relationship of mortalities to stage of development, and relates the daily fish deaths in

relation to the accumulated number of TU. Egg mortalities are not shown in relation to TU, but are indicated by a bar to the left for reference.

The period from hatching (∿900 TU) to the start of feeding (1600 TU) is the fry stage. Excessive egg mortalities that appeared in lots subjected to the three highest temperatures extended into the fry stage. The lot held at maximum temperatures experienced total mortality during this period. However, there was little fry mortality in the remaining lots. In all except the two coldest lots, increased mortalities were evident near the termination of the fry stage that continued into the early feeding or fingerling stage (1600-2300 TU). This period is when the young fish are adapting to initial feeding. Once adaptation occurred, usually within one to one and one-half months after first feeding, mortalities nearly ceased and thereafter tended to be only spasmodic and inconsequential.

Identifiable gross external symptoms present during mortality are also noted on Figure 3. The condition marked W refers to designation of "whitefin", which is typically characterized by appearance of light-colored amorphous matter on one or more of the fins, usually the pectorals, and sometimes partial disintegration of the fin rays. Although diagnosis was attempted, the etiological agent remains unidentified. Wood [8] describes a similar condition in young salmon and notes that it appears to be symptomatic of yolk abnormality. There was a tendency for some test lots to be more predisposed to whitefin than others.

The condition marked by X refers to "tail rot". This is a general term that has been applied indiscriminately to describe a variety of disease syndromes. At our hatchery, the caudal fin area characteristically became discolored, while erosion involved the fringes and may eventually extend to

the caudal peduncle. The etiological agent remains unidentified. According to Bullock [9], the cause of tailrot is not firmly established.

Neither whitefin nor tailrot were noted among mortalities in Lot 6.

Only two deformed fish were detected. They represent only fish dying after hatching since deformation in embryos on dead eggs could not be determined.

The total mortalities discussed above consisted of all losses at the termination of the tests and encompass the same calendar time. However, in addition to comparing total mortalities, losses that occurred at similar stages of development must be analyzed. Fish held at colder temperatures had restricted development and required more time to reach a stage comparable to fish held at warmer temperatures. Therefore, mortality data based on a unit time interval favored the colder lots.

Table II compared mortalities at similar stages of development (similar numbers of accumulated TU) and presents some development data. Increased temperatures resulted in more rapid development. The observed midpoints of hatching were approximate since observations were made only on day shift, and rounded estimates for 24 hours could differ by 15 to 25 TU within lots. Estimations for the two lots maintained at warmest temperatures had the greatest imprecision because they experienced maximum egg mortality and the exact time of embryonic death was uncertain. The colder lots apparently required more temperature units to achieve hatching.

At the start of feeding, Lot 4 mortality (total and fry) was relatively greater than experienced during the egg stage, while Lot 3 (+4.9 °F) had mortalities similar to that of the two colder lots.

The final mortality data in Table II compare the mortality of the various lots at the time they had accumulated total TU's similar to Lot 1 (coldest) at the termination of Series I. Results show the same general pattern as that shown by the comparison of all mortalities at the time of termination. Significant mortality ($P < 0.05$) had developed at the time in Lot 3.

Increased temperatures resulted in larger fish. The growth represented by average weights throughout the test period is shown in Figure 4, where dash lines connect the corresponding weight points. The listed weights are based on averages of 200 fish in Lots 1-5, but excessive mortalities in Lot 6 reduced numbers of fish available for weighing to 19 on April 10. At termination, after exposure to similar units of TU's, fish in Lot 5 were about four and one-half times larger than those in Lot 1. A 2 °F increment increased growth by about 1.5 times.

Fish at colder temperatures, however, were larger at similar developmental stages than those reared at warmer temperatures. Figure 4 shows that initial weights listed for each lot (feeding began at 1600 TU) were largest in the coldest (Lots 1 and 2) and smallest in warmest (Lot 6). Seymour [10] found that chinook eggs incubated at low temperatures had embryos larger than those incubated at higher temperatures at hatching. The physiological cause of greater age and/or more efficient growth in fish reared in colder regimes is unknown.

In each lot, 50 fish were weighed and measured (only 19 available in Lot 6) before the termination of Series I. The length and weight data are presented in Figures 5 and 6. A one-way analysis of variance followed by Duncan's multiple range test was employed for comparative analysis [11, 12]. In Lots 1-5, average weights and lengths were significantly greater ($P<0.05$) in each progressively warmer lot, whereas average size of fish in Lot 6 was

smaller than in Lot 5. The graphed growth data shows the increasing variations in size with increasing mean size, i.e., in progressively warmer lots.

Series II (November 14 Spawning)

The daily average temperatures for the experimental troughs in Series II and the average upstream Columbia River temperature, are shown in Figure 7. Daily cumulative mortalities are shown in the upper portion, while total mortalities are summarized in Table III and plotted in Figure 8.

Lot 2, which averaged 2.8 °F above the 5-year river average, and Lot 1 had similar mortalities. Lot 4, which averaged 6.8 °F above, and the warmer lots revealed significantly higher mortalities ($P < 0.05$). However, excessive mortalities did not occur until temperature increments averaged 10.8 °F and above. Figure 7 shows earlier and greater mortalities occurring in the warmer lots. Table III and Figure 8 show mortalities resulting at the different life stages.

Egg mortalities in Lot 6 (+10.8 °F) and Lot 7 were significantly increased. The percentage of eyed egg mortality is shown on Figure 8. Total and eyed egg mortalities in the warmest lots were strikingly lower than experienced by earlier spawn (10/30), presumably because of cooler river temperatures. The trend persisted in the warmer lots to have a greater proportion of eyed egg mortality.

Fish mortalities shown in Figure 8 were similar to total mortalities, and reflected adverse effects of increased temperatures more dramatically than did the eggs. Lot 3, where temperatures averaged 4.8 °F above the river, showed significantly greater losses. Temperature increments of 10.8 °F and above resulted in excessive mortalities of fish. Dead abnormal

and diseased individuals are also shown. Although disease confused the mortality pattern, the numbers involved were so small that the effect of a given temperature increment was apparently not influenced.

Figure 9 relates daily fish mortalities in relation to the accumulated number of TU's. Excessive egg mortalities that appeared in Lot 7 were continued into the fry stage. However, the fry period tended to have less mortality than the other lots held at lower temperatures. Immediately after the fry stage and extending into the fingerling stage (1600-2100 TU), there was a marked increase in mortalities in the two warmest lots (6 and 7) and a slight increase in Lot 5. These mortality peaks resumbled losses in Series I but they were less severe and not as universal, probably reflecting cooler temperatures prevailing at this time. Lots 3 and 4 showed slight mortality peaks after 2300 TU. Crippled, diseased and pinhead fish noted among the mortalities are indicated. "Pinhead" condition is characterized by the gradual weakening of the fish, which cannot efficiently utilize food, and a resulting atrophy of the body. We have noted that some groups of spawn were more predisposed toward this condition than others. Death usually was not observed until the early feeding period and then occured more frequently with continuing development until a point when all affected fish died. Whitefin and tailrot were seldom observed. While pinhead was noted to a limited extent in all lots, it was most prevalent in the warmest (Lot 7).

Total mortalities at the termination of Series II are given in Table III and Figure 8, while Table IV compares mortalities at similar stages of development and presents some development data. A more rapid development was evident at increased temperatures. Again there was a trend for the colder

lots to require more temperature units to hatch.

The significantly increased mortalities in the two warmest lots (6 and 7), which were evident at the completion of the egg stage, were maintained until the start of feeding. The last mortality data in Table IV compare mortalities of the various lots when they had accumulated similar numbers of TU. At this time there were significantly increased mortalities in Lot 5 but not in Lot 4, which subsequently showed a significant increase when all mortalities were compared at termination.

Increased temperatures resulted in larger fish. Figure 10 shows the growth represented by average weights throughout the test period. The data were again averages of 200 fish, except in Lot 7 where excessive mortalities provided only 48 fish. At termination of Series II, fish in Lot 7 were almost eight times larger than those in Lot 1. A 2 °F increment increased growth by about 1.5 times.

At termination of each test, a random sample of 50 fish from each lot (only 48 from Lot 7) were individually weighed and measured. The average weights and lengths, ranges and standard deviations are shown in Figures 11 and 12. In Lots 1-6, weights and lengths increased in each progressively warmer lot. However, fish in Lot 7 were slightly smaller than those in Lot 6. The growth data revealed increasing variations in individual size with increasing mean size, i.e., in progressively warmer lots.

Series III (November 23 Spawning)

Figure 13 shows the daily average temperatures for the experimental troughs in Series III and the 5-year average Columbia River temperature.

The resulting daily cumulative mortalities are shown in the upper portion. Total mortalities are summarized in Table V and plotted in Figure 14.

The apparent tolerance of this series to high temperature increments was greater than the preceding two because of the rapid decrease of Columbia River temperatures during the winter. Increments as high as 10.8 °F resulted in low total mortalities of 10.3 percent, well within the range of normal hatchery production. Excessive mortalities were evident only at the greatest increment tested (12.8 °F). An addition of 2 °F over the 10.8 °F increment of Lot 6 resulted in a drastic mortality increase. Total mortalities revealed an erratic pattern that was inconsistent with increasing temperature increments up to 10.8 °F. Statistical tests reflected the erratic results since mortalties of Lot 5 (+8.8 °F) were not significantly greater than Lot 1, whereas losses in the other lots (Lots 2,3 and 4) showed significantly greater mortalities. Although temperature levels in these lots resulted in generally low mortalities even with thermal increments as great as 10.8 °F, the erratic pattern showed no consistent trend over this temperature range.

Figure 13 shows that the earliest mortalities occurred in the two warmest lots and the greatest mortality in the warmest lot. Table V and Figure 14 also show mortalities at the different stages of early development.

Egg mortalities in Lot 6 (+10.8 °F) and Lot 7 were greater than those maintained at lower temperatures. Because of cooler water, the total and eyed egg mortalities in the two warmest lots were markedly lower than those experienced in the preceding series. Although the differences were small, the warmer lots had a higher eyed egg mortality than those at lower temperatures.

Fish mortalities were similar to total mortalities, and losses in the warmest lot reflected adverse effects of increased temperatures more dramatically than the preceding egg stage. Statistical tests showed no significant differences between mortalities in Lots 5 and 6 (+8.8 °F and +10.8 °F) and Lot 1. But the other lots (including the colder Lots 2, 3 and 4) showed significantly greater mortalities than Lot 1. The number of cripples were small and were randomly distributed among the test groups. Diseases were noted only in the two warmest lots, the greater incidence of both whitefin and tailrot occurring in the warmest lot.

The relationship of mortalities to accumulated number of TU is shown in Figure 15. Emerging fry in all lots had little mortality. After the fry stage and extending into the early feeding or fingerling stage (1600-2300 TU), a marked increase in mortality occurred in the warmest lot. These losses paralleled the mortality trends of the adversely effected lots from the two earlier series. Mortalities in Lots 2 and 3 also showed an increased rate at this time, but this trend was not noticeable in the other lots.

Table VI shows total mortalities at similar stages of development and some development data. Increased temperatures caused more rapid development. The colder lots again required more TU to hatch.

Although egg mortalities in the two warmest lots were significantly increased, fish mortalities at the start of feeding were inconsistent with increasing temperature increments through 12.8 °F. These mortalities were all low, however.

Mortalities in the various lots when accumulated temperature units were approximately equal are totalled in Table VI. At this stage of development,

erratic mortality patterns were still evident. Mortalities were not consistently related to increasing temperature increments through 10.8 °F.

Increased temperatures again resulted in larger fish, Figure 16. Fish in Lot 7 were more than eight times larger than those in Lot 1 at the termination of the test. A 2 °F increment resulted in increased growth by about 1.4 times. Individual weights and lengths of fish surviving in the various lots are shown in Figures 17 and 18. The average weights and lengths increased with temperature. Variations in individual size were directly related to increasing mean size.

Series IV (December 8 Spawning)

Figure 19 shows the daily average temperatures for the experimental troughs in Series IV and the 5-year average Columbia River temperatures as well as the daily cumulative mortalities. Total mortalities are summarized in Table VII and Figure 20.

This final series was spawned at the lowest Columbia River temperature and was capable of tolerating greater thermal increments than did earlier groups. An increment as great as 12.5 °F showed total mortalities of only 12.4 percent, well within the normal range of hatchery production. Total mortalities in Lot 5 were greater than in either Lot 6 or 7. While all mortalities tended to be low and inconsistent with increasing temperature increments, a definite mortality increase was shown at increments of 8.5 °F and higher. Lots 5, 6 and 7 revealed a significantly higher mortality than Lot 1. The initiation of increased mortalities of young fish in the three warmer lots appeared to be a function of temperature, occurring first in the warmest lot (Figure 19).

Mortalities at the different developmental stages are shown in Table VII and Figure 20. Egg mortalities in Lot 7 (+12.5 °F) were greater than those of Lot 1. Egg mortalities, however, were generally so low that little evaluation of losses in the eyed stage could be made.

Fish mortalities resembled total mortalities (Figure 20). Complete fish mortalities revealed a somewhat erratic pattern when related to thermal increments. Although mortalities in Lots 3, 5 and 6 were significantly higher than Lot 1, those in the warmest Lot 7 and Lot 4 were not. Disease was inconsequential and the occurrence of cripples was not related to increasing temperature.

The relationship of mortality to developmental stage as determined by the accumulated number of TU is shown in Figure 21. There was no increase in mortalities during the early feeding or fingerling stage (1600 + TU), a characteristic of other groups subjected to elevated temperatures, presumably because of the cooler river water. There was some increased mortality prior to the start of feeding in Lots 3 through 6, particularly in 5 and 6. Only one case of tailrot was noted, from the warmest lot.

Total mortalities at the termination of Series IV are given in Table VII and Figure 20, whereas Table VIII compares mortalities of similar developmental stages and presents some development data. The more rapid development caused by increased temperatures was evident. Again the colder lots required more temperature units to hatch.

Bottom entries of Table VIII compare mortalities among experimental lots after exposure to equla numbers of TU. Total mortalities in the three warmer Lots 5, 6 and 7 were significantly higher than in Lot 1. The fish mortality, showing more of an erratic pattern, was significantly

greater than Lot 1 in Lots 3, 5 and 6, but not in Lot 4 or in the warmest Lot 7.

Increased temperatures resulted in larger fish, Figure 22. At termination of Series IV, fish in Lot 7 were almost seven times larger than those in Lot 1. A 2 °F increment resulted in increased growth by about 1.4 times among all lots. The average weights and lengths were greater in each progressively warmer lot, Figures 23 and 24. Variations in individual size were directly related to increasing mean size.

CONCLUSIONS

A 177 day study was conducted on the temperature tolerance of various developmental stages of chinook salmon originating from adults spawning between October and December in the Priest Rapids area of the Columbia River. Four series of spawn were tested. Lots within series were subjected to seven temperature increments differing by intervals of about 2 °F, which encompassed a test range of 12 °F. Rearing temperatures paralleled the Columbia's normal seasonal pattern where the coldest test temperatures approximated the mean river temperature.

Because of falling river temperatures after the start of the initial experiment, successively later series tolerated greater thermal increments. Temperatures 7.0 °F in excess of base river temperatures resulted in excessive mortalities in Series I (spawned Oct. 30) and 12.0 °F resulted in total mortality. However, a 12.5 °F increment above river temperatures in Series IV (spawned Dec. 8) produced a mortality of only 12.4%, well within the range of normal hatchery production. Temperature increments averaging 2.9 to 2.8 °F for Series I and II (spawned Oct. 30 and Nov. 14) and 6.5 °F for Series IV

(spawned Dec. 8) did not significantly increase either total or fish mortalities over the coldest lots experiencing normal base river temperatures. Experimental temperatures that produced no significant increase in the mortality of these three series are shown in Figure 25. Data from Series III (spawned No. 23) were not used because of erratic and hard-to-relate mortality-temperature correlations.

Mortality patterns and time of mortality were related to temperature increases. High egg mortality occurred at the warmest temperatures, but there was considerable embryonic development even in those lots and most deaths (coagulation) occurred just prior to hatching. Lots with excessive egg mortalities also experienced greater losses during the fry stage. Under cooler, but still adverse temperature treatments, egg and fry mortalities were not obviously greater, but increased losses occurred primarily during the critical transition period at commencement of active feeding. Once the fry adapted to feeding, mortalities decreased and remained low.

Increased temperature clearly accelerated growth. A 2 °F increment increased growth by an average of about 1.4 times throughout all series. In the same series of spawn, fish in the warmest lot were as much as 8 times heavier than those in the coldest lot when exposed to similar TU's at the conclusion of rearing.

This study indicates that the developmental stages of fall chinook can safely withstand greater thermal additions during winter when temperatures are low. It also suggests that elevated temperatures will favor egg and fry survival of late spawners over those of the earlier when spawning temperatures were higher.

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21. Relationship of mortality to stage of development, Series IV (Dec. 8 spawning).

22. Increase in weight of chinook reared under different temperature conditions, Series IV (Dec. 8 spawning).

23. Average weight, range and standard deviation of chinook reared under different temperature conditions, Series IV (Dec. 8 spawning).

24. Average length, range and standard deviation of chinook reared under different temperature conditions, Series IV (Dec. 8 spawning).

25. Experimental temperatures resulting in no significantly increased mortalities.

TABLE 1. MORTALITY OF YOUNG CHINOOK SALMON EXPOSED TO DIFFERENT TEMPERATURE CONDITIONS DURING REARING, SERIES I (OCT. 30 SPAWNING, TERMINATED APRIL 24)

CRITERION	LOT: 1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL) +0.9°F	+2.9°F	+4.9°F	+7.0°F	+9.0°F	+11.2°F	+11.7°F
INITIAL TEMPERATURE	54.6°F	56.6°F	58.6°F	60.6°F	62.6°F	64.6°F	66.6°F
TOTAL MORTALITY AT COMPLETION OF TEST							
INITIAL NUMBER EGGS	700	714	790	789	754	817	815
NUMBER TOTAL MORTALITY	32	26	87	222	449	796	815
PERCENT TOTAL MORTALITY	4.57	3.64	11.01	28.14	59.55	97.43	100.00
EGG MORTALITY							
INITIAL NUMBER EGGS	700	714	790	789	754	817	815
NUMBER EGG MORTALITY	27	18	28	43	111	447	777
PERCENT EGG MORTALITY	3.86	2.52	3.54	5.45	14.72	54.71	95.34
FISH MORTALITY *							
INITIAL NUMBER FISH HATCHED	673	696	762	746	643	370	38
NUMBER FISH MORTALITY	5	8	59	179	338	349	38
PERCENT FISH MORTALITY	0.74	1.15	7.74	23.99	52.57	94.32	100.00

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

TABLE 2. COMPARISON OF MORTALITY AT SIMILAR STAGES OF DEVELOPMENT, SERIES I (OCT. 30 SPAWNING, TERMINATED APRIL 24)

CRITERION LOT:	1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL)	+0.9°F	+2.9°F	+4.9°F	+7.0°F	+9.0°F	+11.2°F	+11.7°F
INITIAL TEMPERATURE	54.6°F	56.6°F	58.6°F	60.6°F	62.6°F	64.6°F	66.6°F
APPROXIMATE MID-POINT HATCHING	12/19/66	12/12/66	12/7/66	12/3/66	12/1/66	11/28/66?	11/26/66?
ESTIMATED TEMPERATURE UNITS	928	914	902	886	906	892	891
PERCENT EGG MORTALITY	3.86	2.52	3.54	5.45	14.72	54.71	95.34
START OF FEEDING	2/23/67	2/2/67	1/20/67	1/10/67	1/2/67	12/27/66	NEVER REACHED
APPROXIMATE TEMPERATURE UNITS TO START OF FEEDING	1617	1615	1619	1618	1616	1618	
PERCENT MORTALITY TO START OF FEEDING TOTAL (EGGS + FISH)	4.14	3.08	3.92	7.22	20.42	74.42	
FISH ONLY *	0.30	0.57	0.39	1.88	6.69	43.51	
DATE	4/24/67	3/28/67	3/3/67	2/14/67	2/2/67	1/23/67	
APPROXIMATE TEMPERATURE UNITS	2181	2184	2186	2183	2185	2174	
PERCENT MORTALITY TOTAL (EGGS + FISH)	4.57	3.36	10.13	26.87	58.62	96.45	
FISH ONLY *	0.74	0.86	6.82	22.65	51.48	92.16	

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

TABLE 3. MORTALITY OF YOUNG CHINOOK SALMON EXPOSED TO DIFFERENT TEMPERATURE CONDITIONS DURING REARING, SERIES II (NOV. 14 SPAWNING, TERMINATED MAY 9)

CRITERION	LOT: 1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL)	+0.8°F	+2.8°F	+4.8°F	+6.8°F	+8.8°F	+10.8°F	+12.9°F
INITIAL TEMPERATURE	53.0°F	55.0°F	57.1°F	59.1°F	61.2°F	63.2°F	65.2°F
TOTAL MORTALITY AT COMPLETION OF TEST							
INITIAL NUMBER EGGS	576	499	481	506	544	576	654
NUMBER TOTAL MORTALITY	59	55	79	98	94	248	607
PERCENT TOTAL MORTALITY	10.24	11.02	16.42	19.37	17.28	43.06	92.81
EGG MORTALITY							
INITIAL NUMBER EGGS	576	499	481	506	544	576	654
NUMBER EGG MORTALITY	42	38	41	49	57	89	179
PERCENT EGG MORTALITY	7.29	7.62	8.52	9.68	10.48	15.45	27.37
FISH MORTALITY *							
INITIAL NUMBER FISH HATCHED	534	461	440	457	487	487	475
NUMBER FISH MORTALITY	17	17	38	49	37	159	428
PERCENT FISH MORTALITY	3.18	3.69	8.64	10.72	7.60	32.65	90.11

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

TABLE 4. COMPARISON OF MORTALITY AT SIMILAR STAGES OF DEVELOPMENT, SERIES II (NOV. 14 SPAWNING, TERMINATED MAY 9)

CRITERION LOT:	1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL)						
	+0.8°F	+2.8°F	+4.8°F	+6.8°F	+8.8°F	+10.8°F	+12.9°F
INITIAL TEMPERATURE	53.0°F	55.0°F	57.1°F	59.1°F	61.2°F	63.2°F	65.2°F
APPROXIMATE MID-POINT HATCHING	1/20/67	1/8/67?	12/30/67	12/25/66?	12/21/66	12/17/66?	12/15/66
ESTIMATED TEMPERATURE UNITS	964	949?	930	927?	926	905?	920
PERCENT EGG MORTALITY	7.29	7.62	8.52	9.68	10.48	15.45	27.37
START OF FEEDING	4/3/67	3/6/67	2/16/67	2/5/67	1/27/67	1/19/67	1/13/67
APPROXIMATE TEMPERATURE UNITS TO START OF FEEDING	1615	1610	1610	1629	1629	1616	1616
PERCENT MORTALITY TO START OF FEEDING TOTAL (EGGS + FISH)	8.51	8.62	9.15	11.07	12.68	16.84	37.61
FISH ONLY *	1.31	1.08	0.68	1.53	2.46	1.64	14.11
DATE	5/9/67	4/15/67	3/25/67	3/6/67	2/20/67	2/10/67	2/2/67
APPROXIMATE TEMPERATURE UNITS	2061	2057	2058	2061	2053	2061	2064
PERCENT MORTALITY TOTAL (EGGS + FISH)	10.24	9.62	9.77	12.85	15.81	41.15	88.53
FISH ONLY *	3.18	2.17	1.36	3.50	5.95	30.39	84.21

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

TABLE 5. MORTALITY OF YOUNG CHINOOK SALMON EXPOSED TO DIFFERENT TEMPERATURE CONDITIONS DURING REARING, SERIES III (NOV. 23 SPAWNING, TERMINATED MAY 18)

CRITERION	LOT: 1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL) +0.7°F	+2.7°F	+4.7°F	+6.8°F	+8.8°F	+10.8°F	+12.8°F
INITIAL TEMPERATURE	50.0°F	51.8°F	54.0°F	56.0°F	58.0°F	59.8°F	61.8°F
TOTAL MORTALITY AT COMPLETION OF TEST							
INITIAL NUMBER EGGS	650	702	730	651	683	681	751
NUMBER TOTAL MORTALITY	36	65	90	61	47	70	279
PERCENT TOTAL MORTALITY	5.54	9.26	12.33	9.37	6.88	10.28	37.15
EGG MORTALITY							
INITIAL NUMBER EGGS	650	702	730	651	683	681	751
NUMBER EGG MORTALITY	25	20	16	33	31	47	74
PERCENT EGG MORTALITY	3.85	2.85	2.19	5.07	4.54	6.90	9.85
FISH MORTALITY *							
INITIAL NUMBER FISH HATCHED	625	682	714	618	652	634	677
NUMBER FISH MORTALITY	11	45	74	28	16	23	205
PERCENT FISH MORTALITY	1.76	6.60	10.36	4.53	2.45	3.63	30.28

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

TABLE 6. COMPARISON OF MORTALITY AT SIMILAR STAGES OF DEVELOPMENT, SERIES III (NOV. 23 SPAWNING, TERMINATED MAY 18)

CRITERION LOT:	1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL) +0.7°F	+2.7°F	+4.7°F	+6.8°F	+8.8°F	+10.8°F	+12.8°F
INITIAL TEMPERATURE	50.0°F	51.8°F	54.0°F	56.0°F	58.0°F	59.8°F	61.8°F
APPROXIMATE MID-POINT HATCHING	2/9/67	1/27/67	1/17/67	1/9/67	1/3/67	12/30/66	12/26/66
ESTIMATED TEMPERATURE UNITS	993	992	980	957	943	940	921
PERCENT EGG MORTALITY	3.85	2.85	2.19	5.07	4.54	6.90	9.85
START OF FEEDING	4/18/67	3/27/67	3/6/67	2/20/67	2/9/67	2/1/67	1/26/67
APPROXIMATE TEMPERATURE UNITS TO START OF FEEDING	1615	1624	1625	1626	1619	1615	1622
PERCENT MORTALITY TO START OF FEEDING TOTAL (EGGS + FISH)	4.62	4.84	6.44	7.53	5.86	8.08	12.12
FISH ONLY*	0.80	2.05	4.34	2.59	1.38	1.26	2.51
DATE	5/18/67	4/28/67	4/8/67	3/21/67	3/6/67	2/23/67	2/14/67
APPROXIMATE TEMPERATURE UNITS	2036	2040	2039	2036	2040	2039	2041
PERCENT MORTALITY TOTAL (EGGS + FISH)	5.54	8.55	11.37	8.45	6.44	9.54	33.56
FISH ONLY*	1.76	5.87	9.38	3.56	1.99	2.84	26.29

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

TABLE 7. MORTALITY OF YOUNG CHINOOK SALMON EXPOSED TO DIFFERENT TEMPERATURE CONDITIONS DURING REARING, SERIES IV (DEC. 8 SPAWNING, TERMINATED JUNE 2)

CRITERION	LOT: 1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL) +0.4°F	+2.4°F	+4.4°F	+6.5°F	+8.5°F	+10.5°F	+12.5°F
INITIAL TEMPERATURE	48.1°F	50.1°F	52.1°F	54.2°F	56.1°F	58.1°F	60.0°F
TOTAL MORTALITY AT COMPLETION OF TEST							
INITIAL NUMBER EGGS	480	505	464	504	482	469	434
NUMBER TOTAL MORTALITY	23	28	35	37	82	66	54
PERCENT TOTAL MORTALITY	4.79	5.54	7.54	7.34	17.01	14.07	12.44
EGG MORTALITY							
INITIAL NUMBER EGGS	480	505	464	504	482	469	434
NUMBER EGG MORTALITY	12	22	8	14	22	20	36
PERCENT EGG MORTALITY	2.50	4.36	1.72	2.78	4.56	4.26	8.29
FISH MORTALITY *							
INITIAL NUMBER FISH HATCHED	468	483	456	490	460	449	398
NUMBER FISH MORTALITY	11	6	27	23	60	46	18
PERCENT FISH MORTALITY	2.35	1.24	5.92	4.69	13.04	10.24	4.52

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

TABLE 8. COMPARISON OF MORTALITY AT SIMILAR STAGES OF DEVELOPMENT, SERIES IV (DEC. 8 SPAWNING, TERMINATED JUNE 2)

CRITERION	LOT: 1	2	3	4	5	6	7
AVERAGE TEMPERATURE INCREMENT OVER 5 YEAR MEAN COLUMBIA RIVER TEMPERATURE IMMEDIATELY UPSTREAM FROM HANFORD WORKS (1964-1969)	(CONTROL) +0.4°F	+2.4°F	+4.4°F	+6.5°F	+8.5°F	+10.5°F	+12.5°F
INITIAL TEMPERATURE	48.1°F	50.1°F	52.1°F	54.2°F	56.1°F	58.1°F	60.0°F
APPROXIMATE MID-POINT HATCHING	3/17/67	2/23/67	2/10/67	1/31/67	1/25/67	1/19/67	1/15/67
ESTIMATED TEMPERATURE UNITS	1037	1012	1000	971	969	943	938
PERCENT EGG MORTALITY	2.50	4.36	1.72	2.78	4.56	4.26	8.29
START OF FEEDING	5/8/67	4/17/67	4/1/67	3/15/67	3/3/67	2/22/67	2/15/67
APPROXIMATE TEMPERATURE UNITS TO START OF FEEDING	1611	1606	1616	1610	1614	1614	1623
PERCENT MORTALITY TO START OF FEEDING TOTAL (EGGS + FISH)	3.33	5.15	5.17	6.35	16.60	12.79	11.29
FISH ONLY *	0.85	0.83	3.51	3.67	12.61	8.91	3.27
DATE	6/2/67	5/15/67	4/28/67	4/12/67	3/29/67	3/17/67	3/7/67
APPROXIMATE TEMPERATURE UNITS	2036	2041	2032	2041	2029	2033	2036
PERCENT MORTALITY TOTAL (EGGS + FISH)	4.79	5.35	7.54	6.94	16.60	13.65	11.98
FISH ONLY *	2.35	1.04	5.92	4.29	12.61	9.80	4.02

* FISH MORTALITY IS BASED ON NUMBER OF FISH THAT HATCHED RATHER THAN INITIAL NUMBER OF EGGS

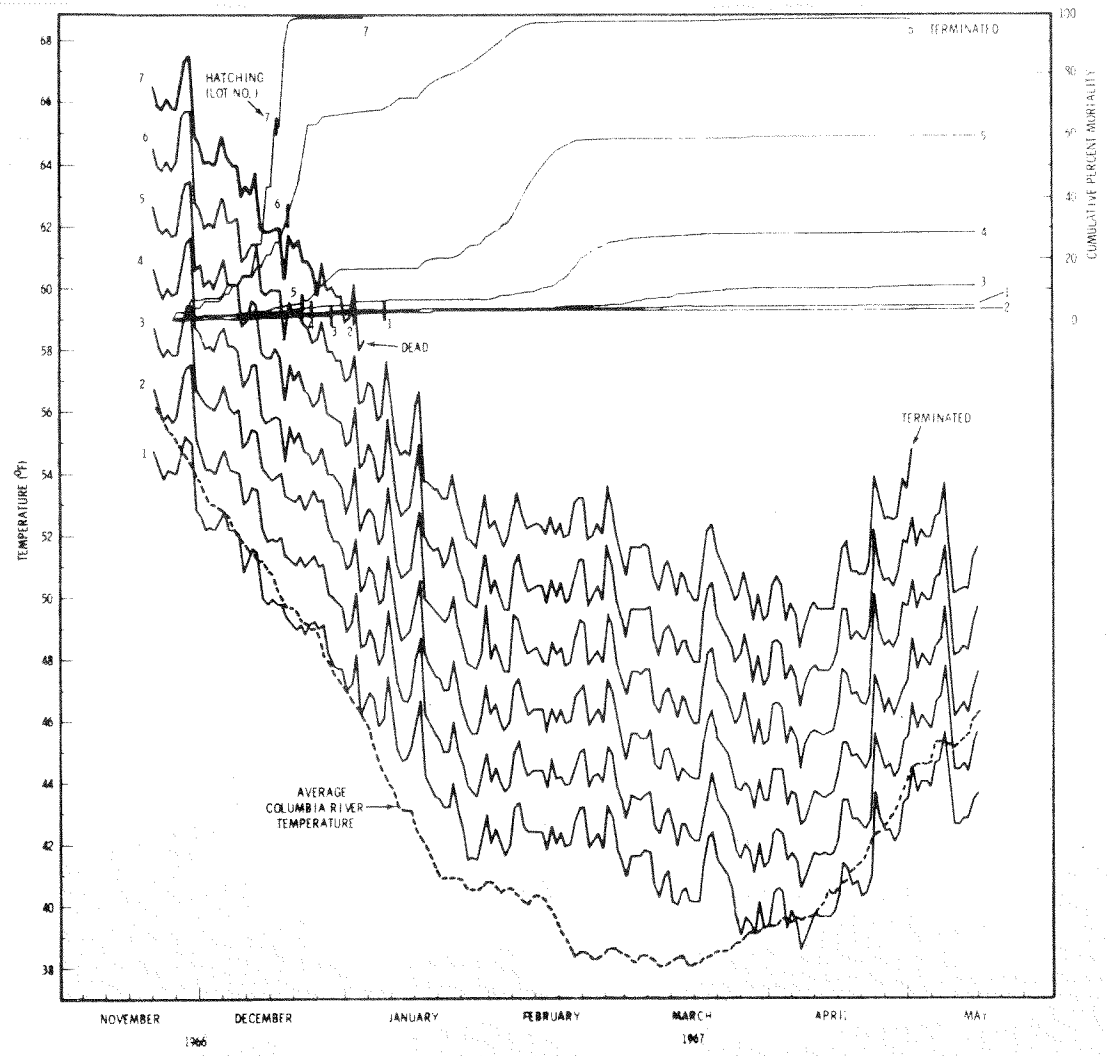

FIGURE 1. DAILY AVERAGE TEMPERATURES AND CUMULATIVE MORTALITIES, SERIES I (OCTOBER 30 SPAWNING)

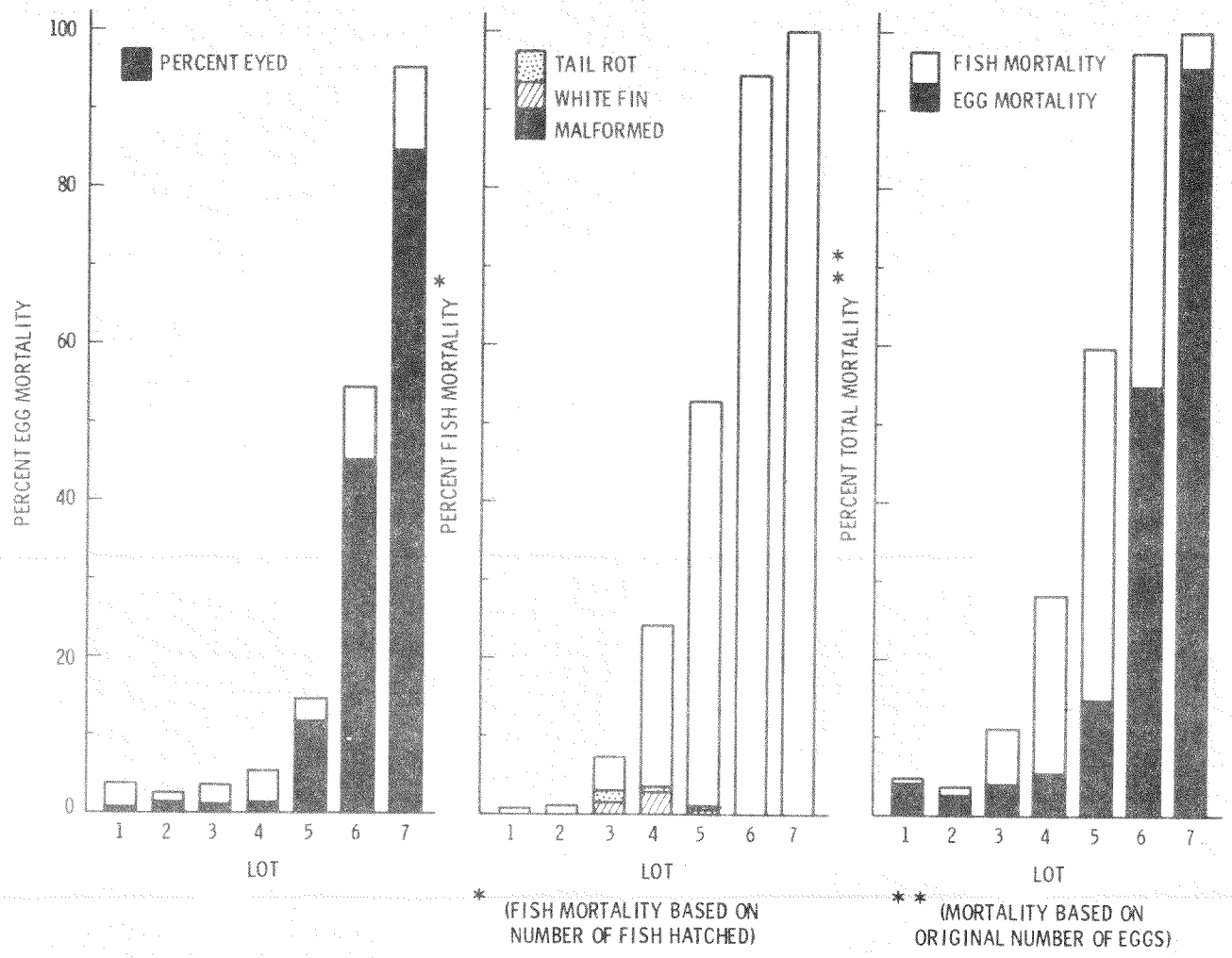

FIGURE 2. MORTALITY OF DIFFERENT STAGES AND TOTAL TERMINAL MORTALITY FOR YOUNG CHINOOK SALMON, SERIES I (OCTOBER 30 SPAWNING)

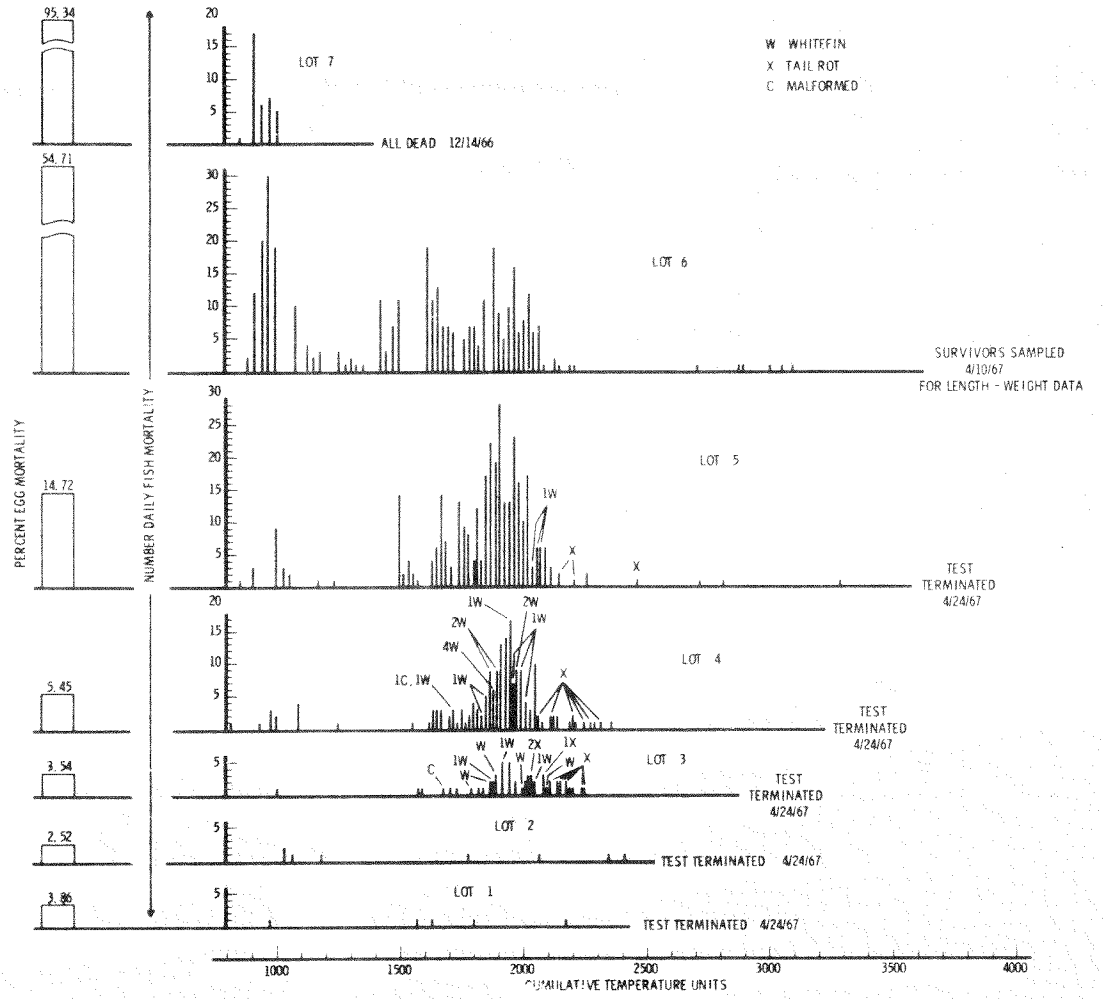

FIGURE 3. RELATIONSHIP OF MORTALITY TO STAGE OF DEVELOPMENT, SERIES I (OCTOBER 30 SPAWNING)

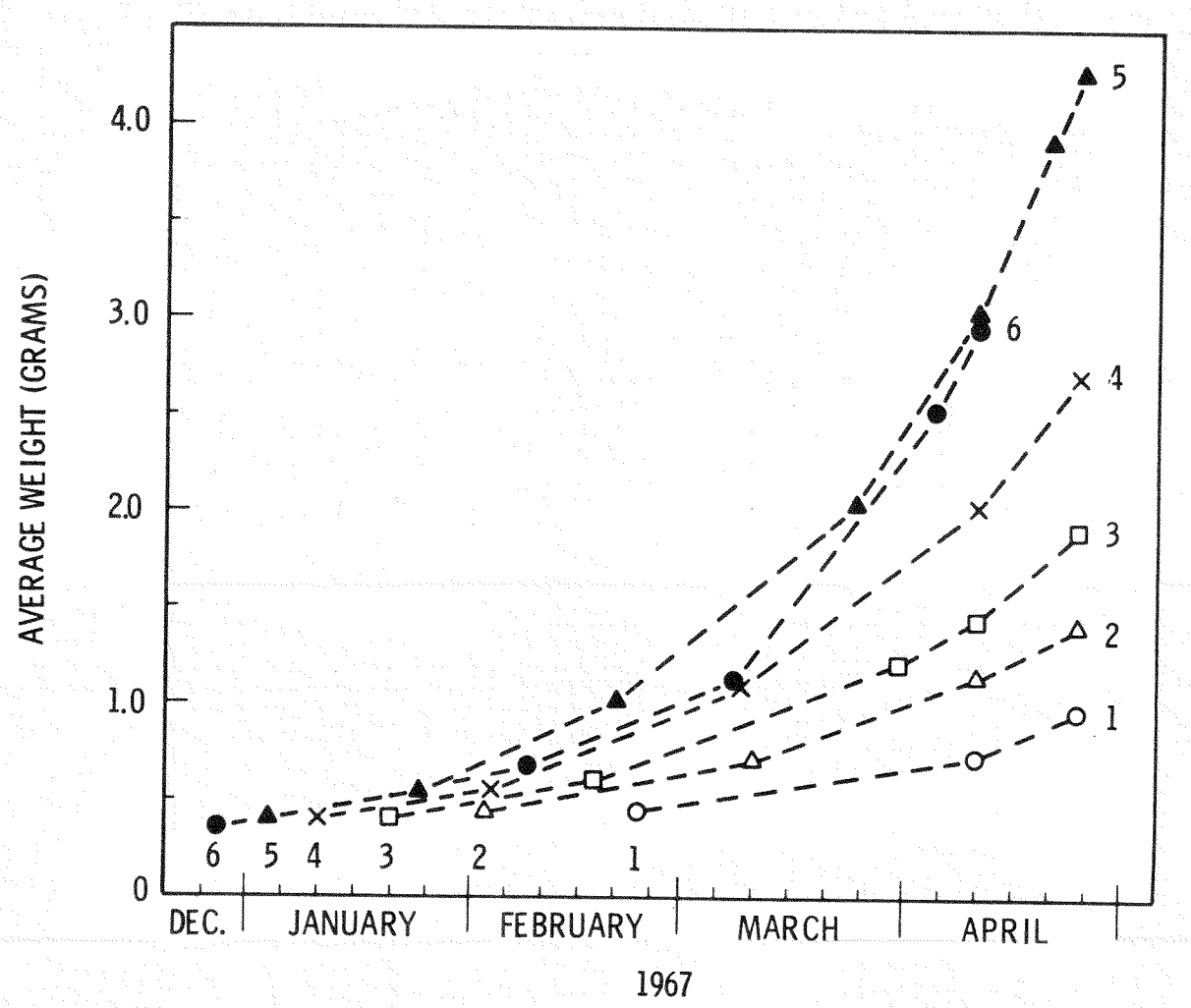

FIGURE 4. INCREASE IN WEIGHT OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES I (OCTOBER 30 SPAWNING)

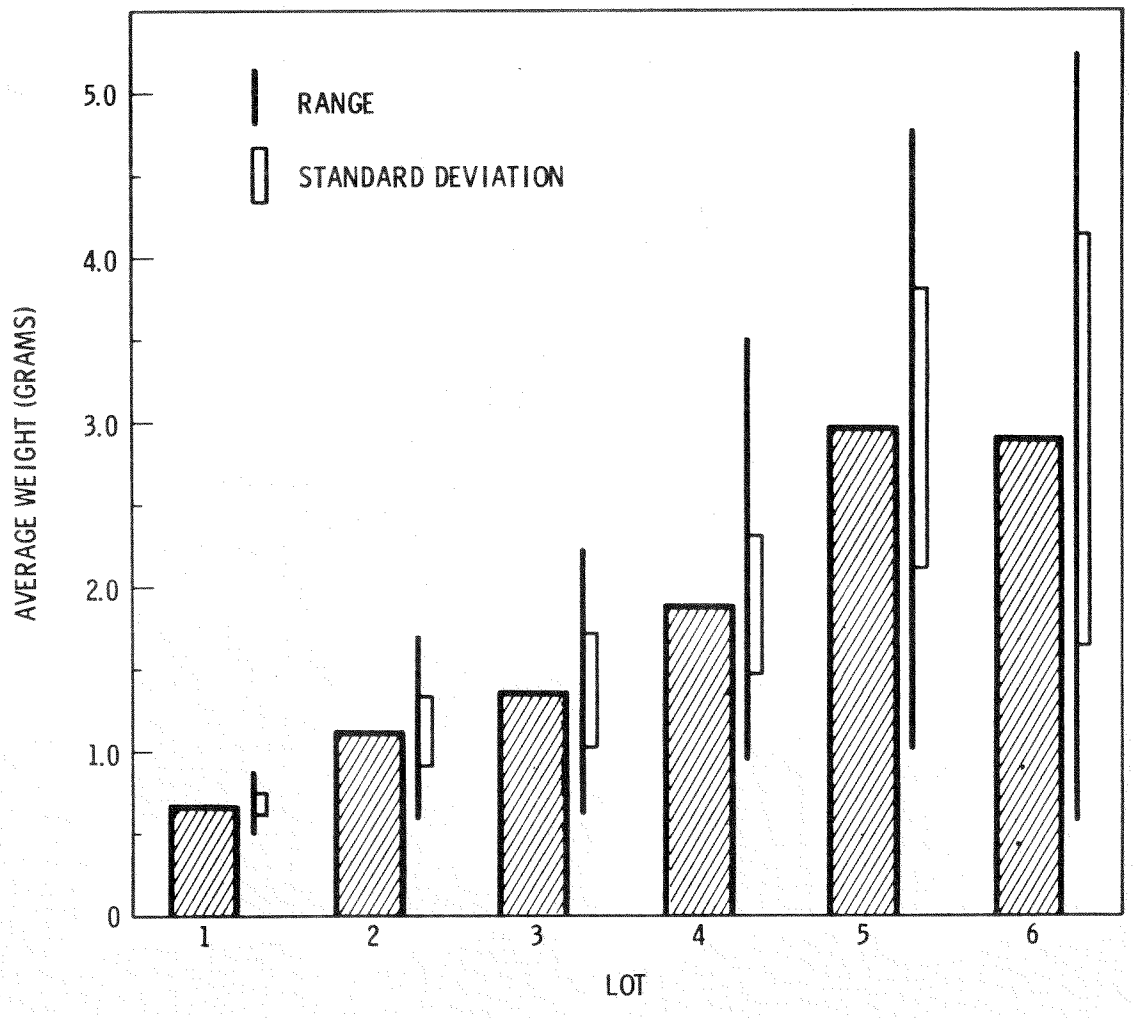

FIGURE 5. AVERAGE WEIGHT, RANGE AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES I (OCTOBER 30 SPAWNING)

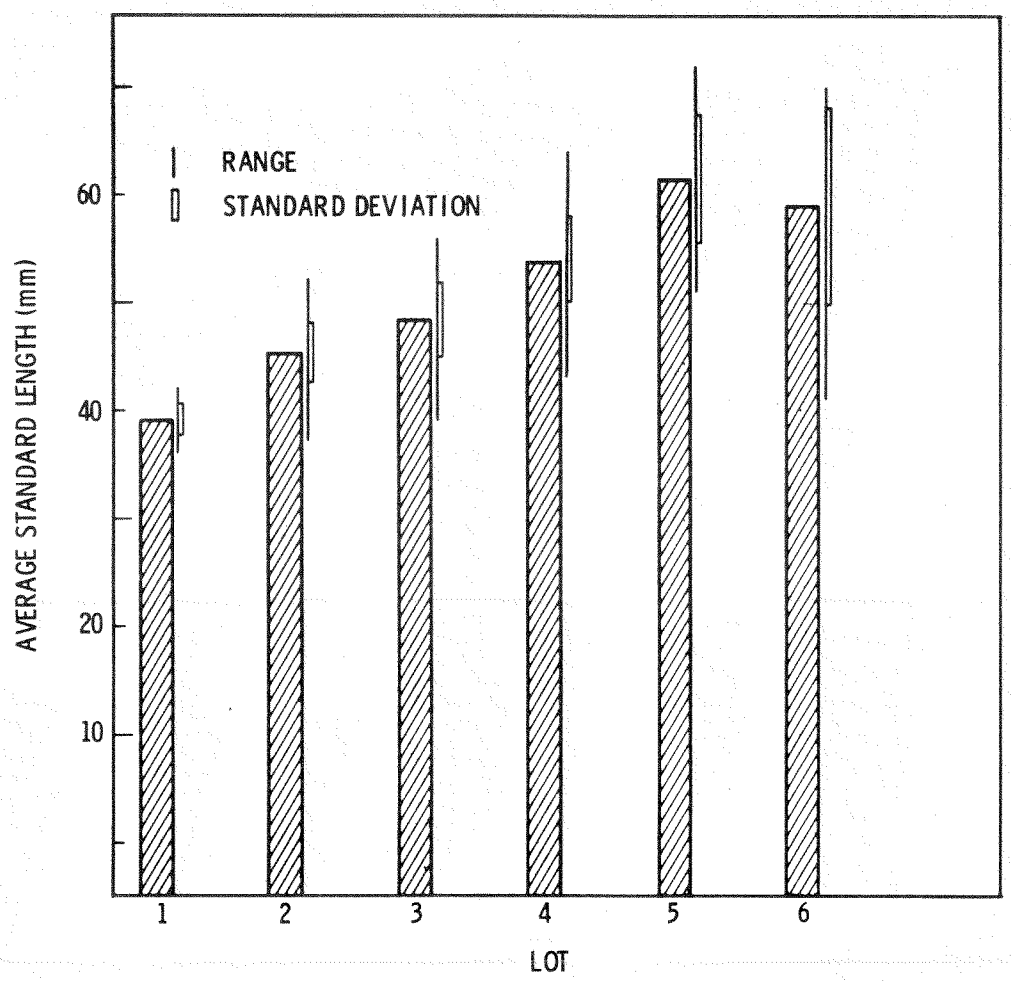

FIGURE 6. AVERAGE LENGTH, RANGE AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES I (OCTOBER 30 SPAWNING)

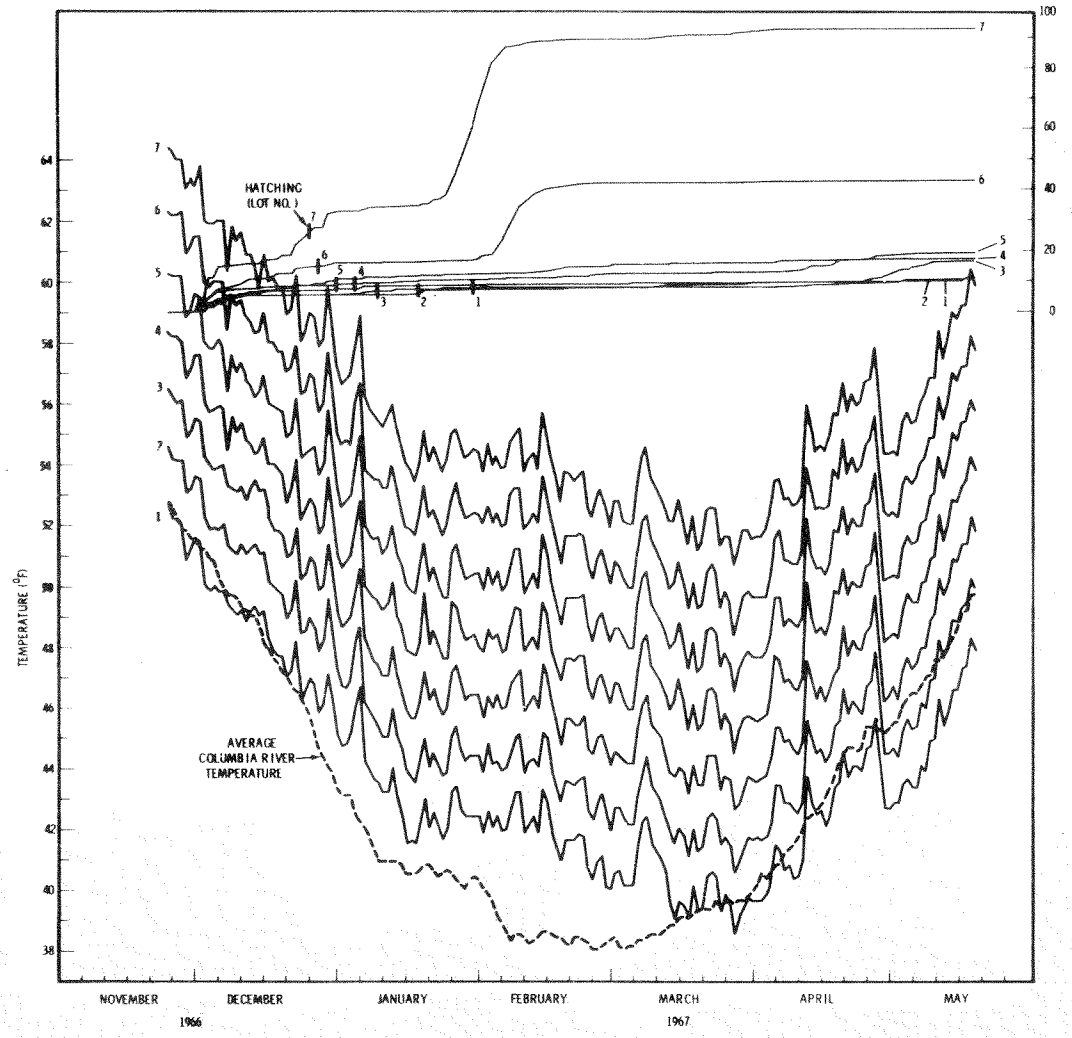

FIGURE 7. DAILY AVERAGE TEMPERATURES AND CUMULATIVE MORTALITIES, SERIES II (NOVEMBER 14 SPAWNING)

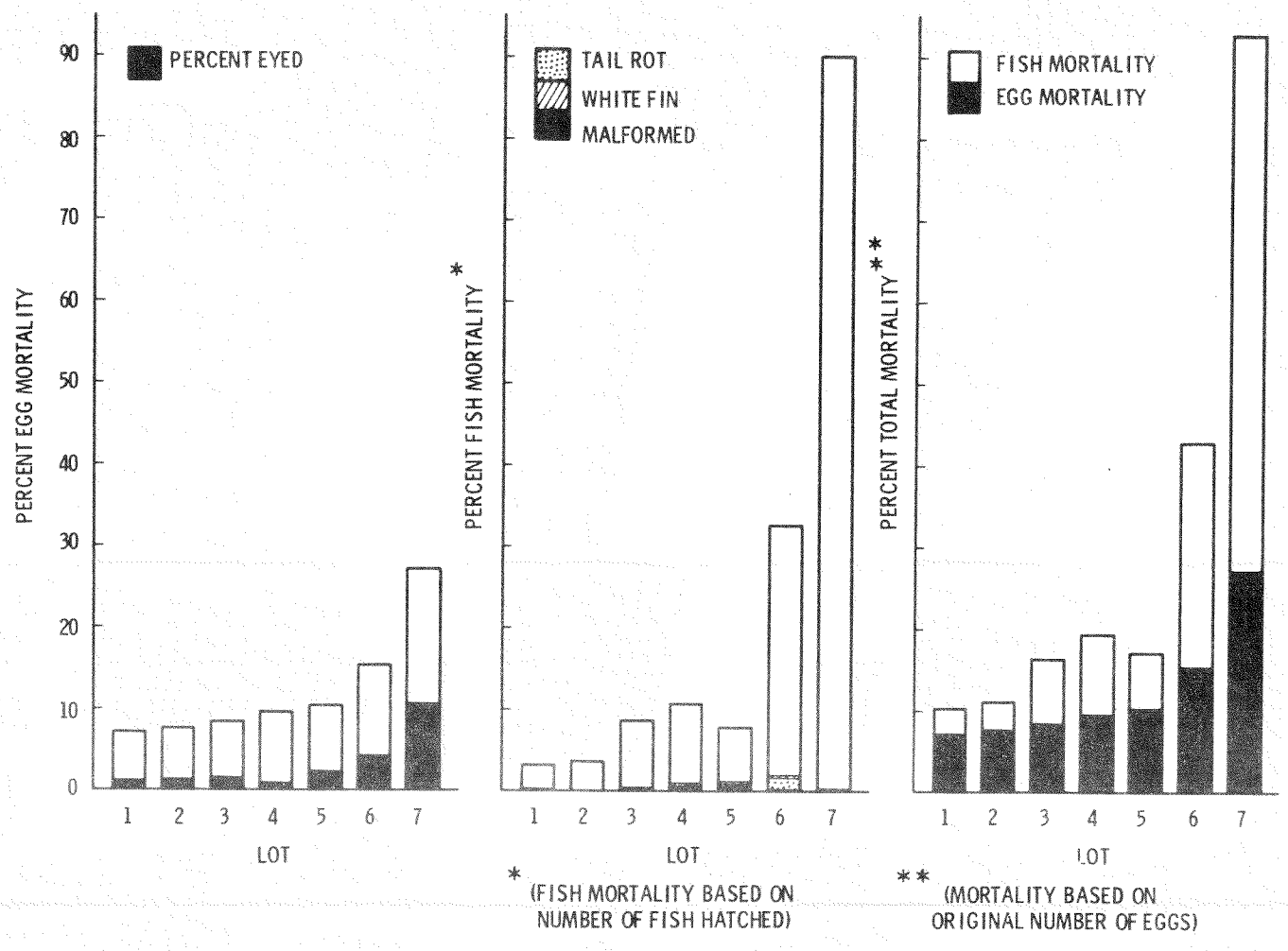

FIGURE 8. MORTALITY OF DIFFERENT STAGES AND TOTAL TERMINAL MORTALITY FOR YOUNG CHINOOK SALMON, SERIES II (NOVEMBER 14 SPAWNING)

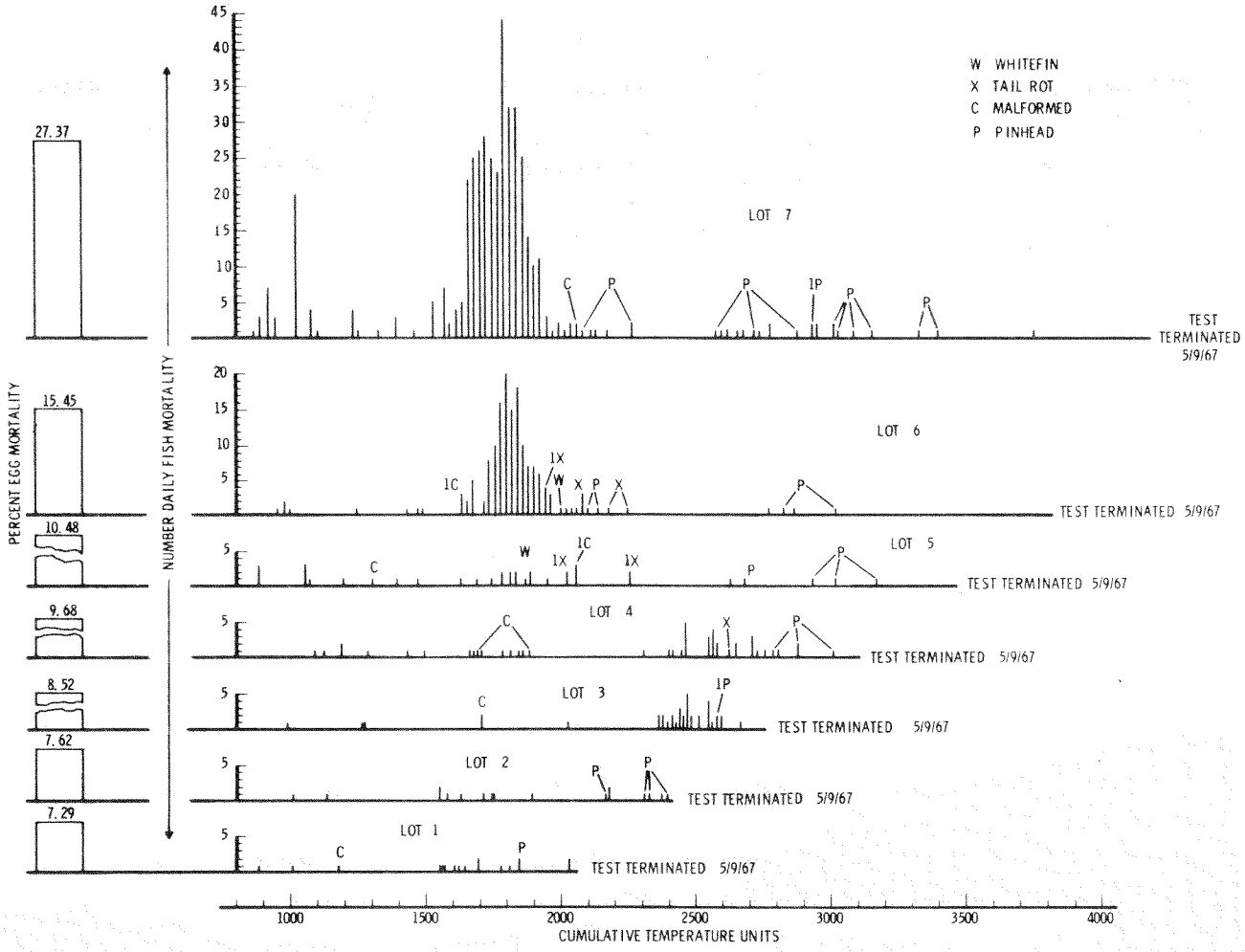

FIGURE 9. RELATIONSHIP OF MORTALITY TO STAGE OF DEVELOPMENT, SERIES II (NOVEMBER 14 SPAWNING)

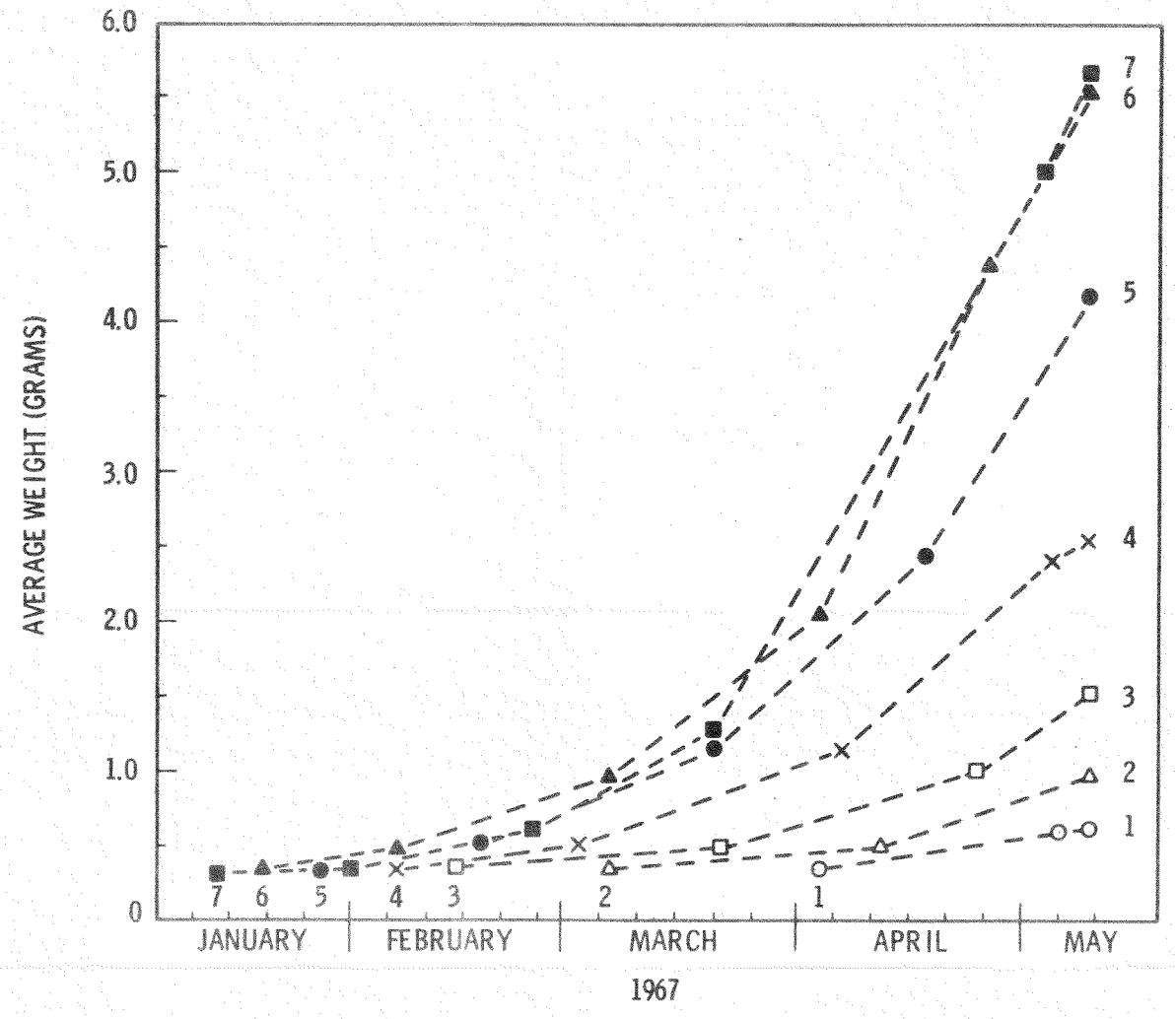

FIGURE 10. INCREASE IN WEIGHT OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES II (NOVEMBER 14 SPAWNING)

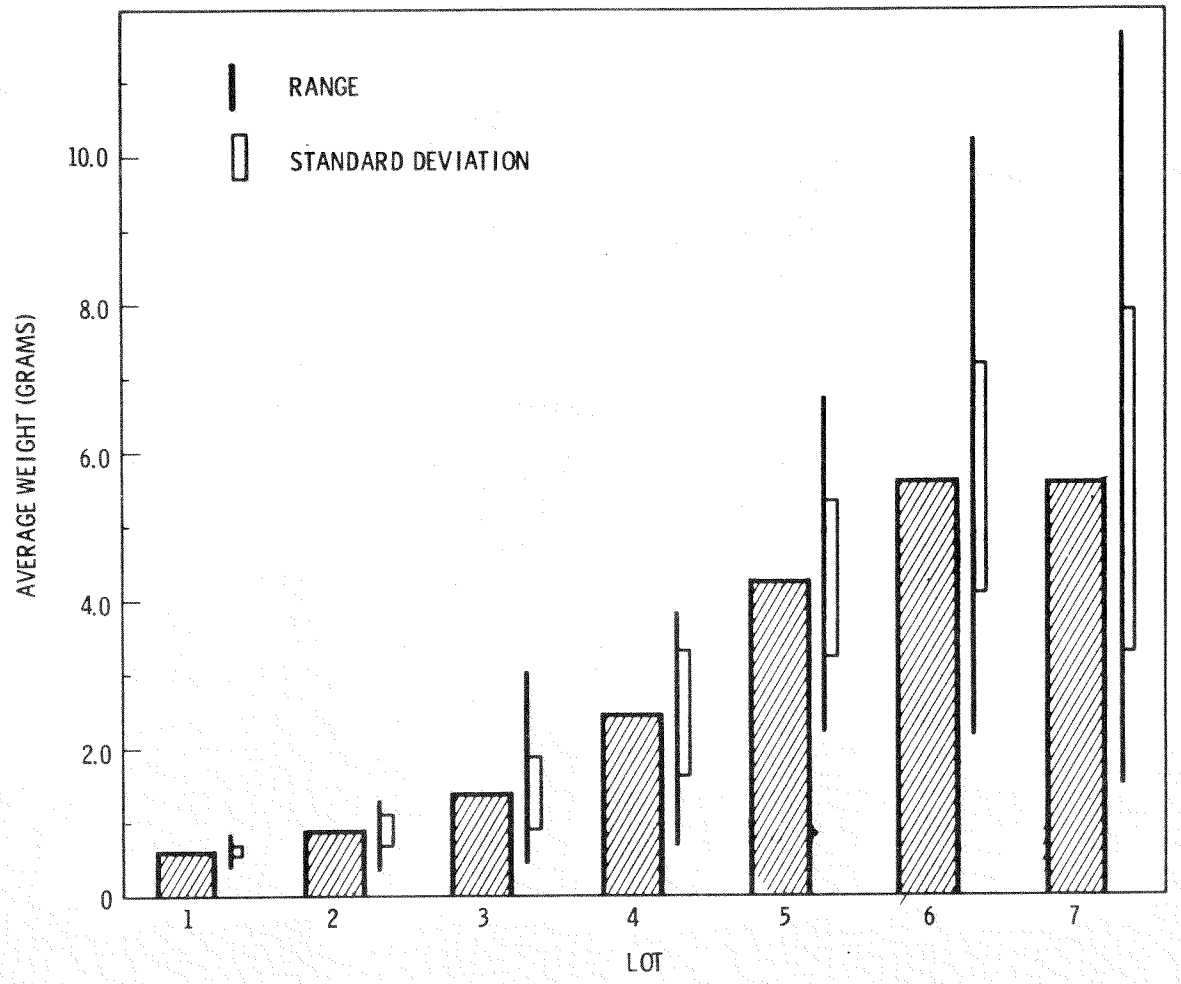

FIGURE 11. AVERAGE WEIGHT, RANGE AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES II (NOVEMBER 14 SPAWNING)

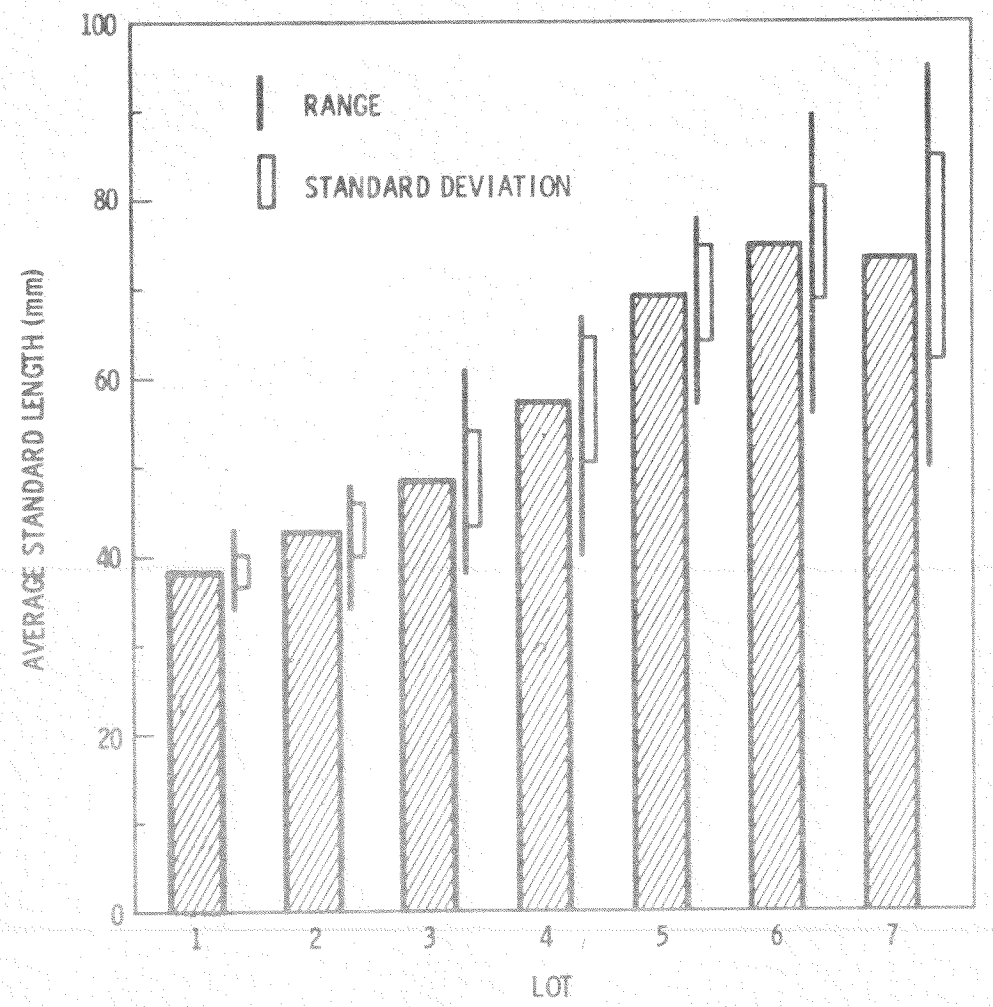

FIGURE 12. AVERAGE LENGTH, RANGE AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES II (NOVEMBER 14 SPAWNING)

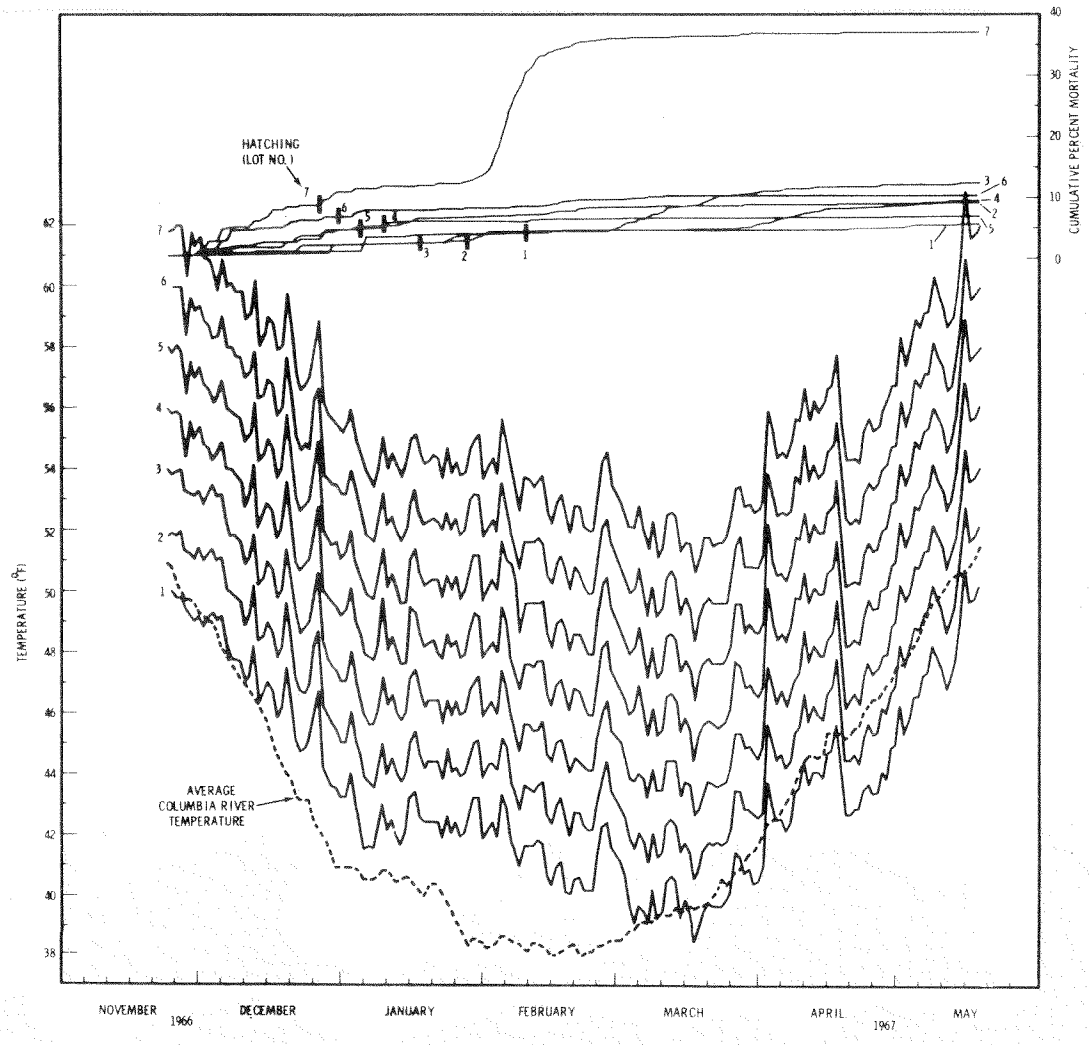

FIGURE 13. DAILY AVERAGE TEMPERATURES AND CUMULATIVE MORTALITIES, SERIES III (NOVEMBER 23 SPAWNING)

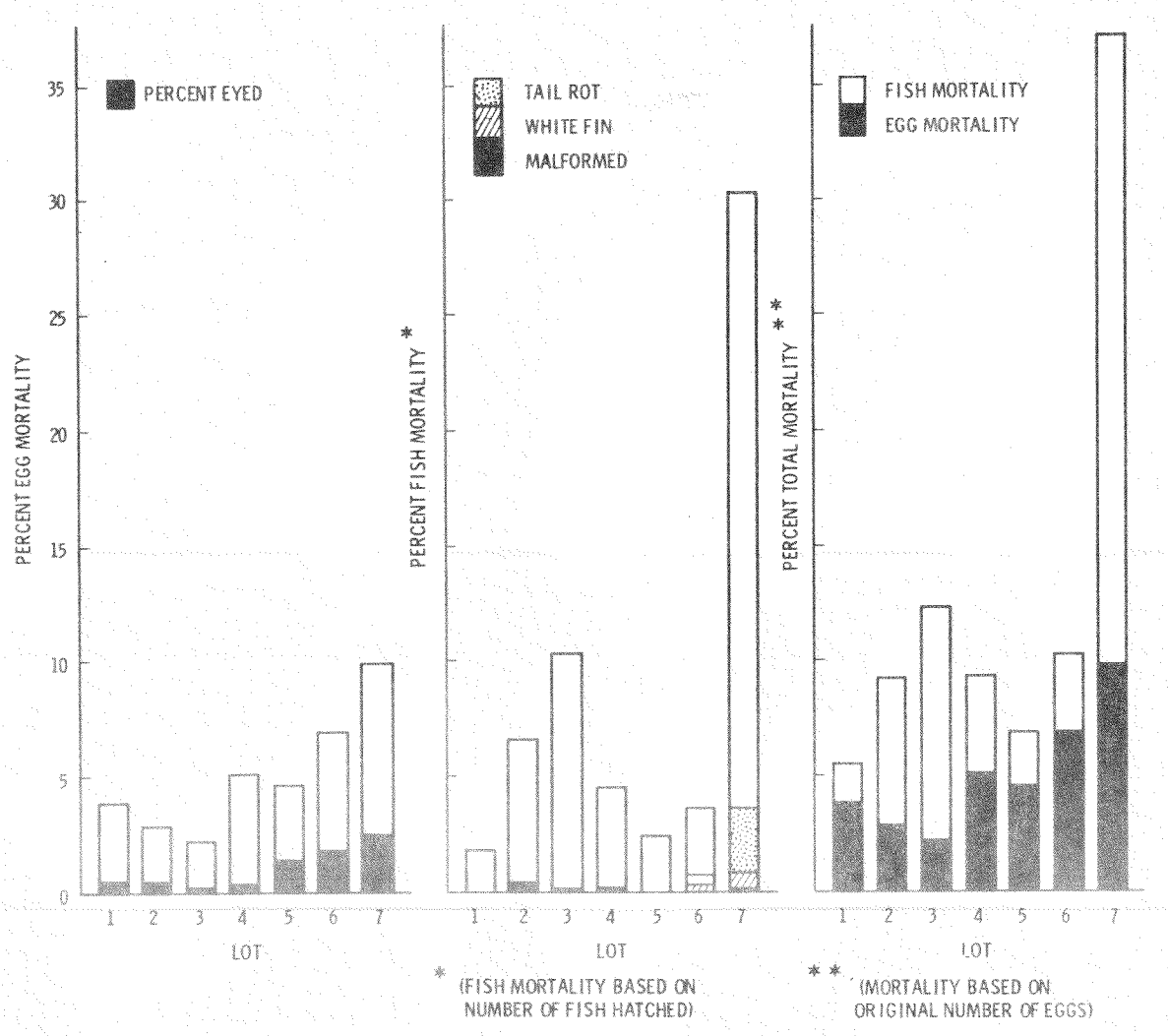

FIGURE 14. MORTALITY OF DIFFERENT STAGES AND TOTAL TERMINAL MORTALITY FOR YOUNG CHINOOK SALMON, SERIES III (NOVEMBER 23 SPAWNING)

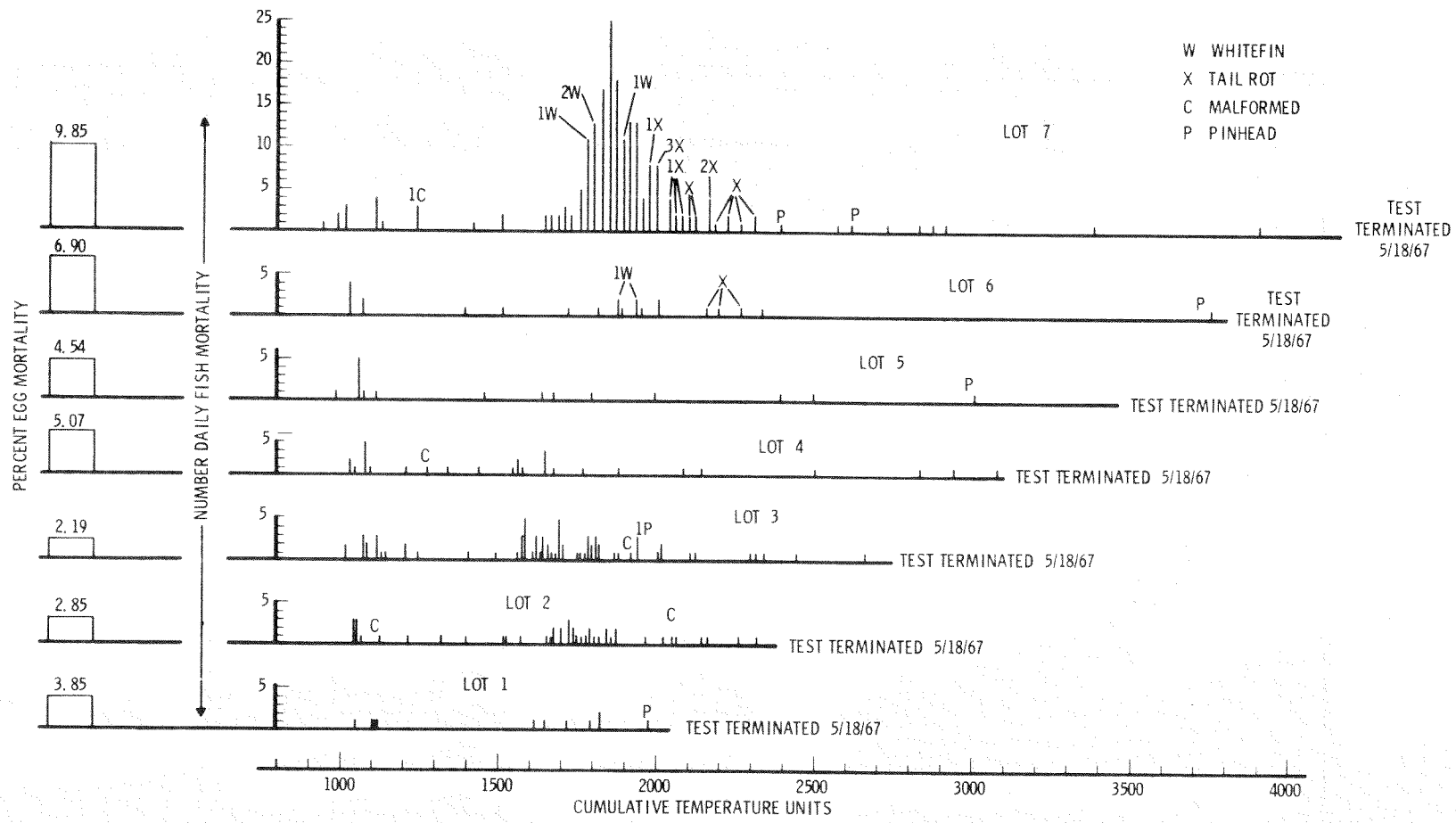

FIGURE 15. RELATIONSHIP OF MORTALITIES TO STAGE OF DEVELOPMENT, SERIES III (NOVEMBER 23 SPAWNING)

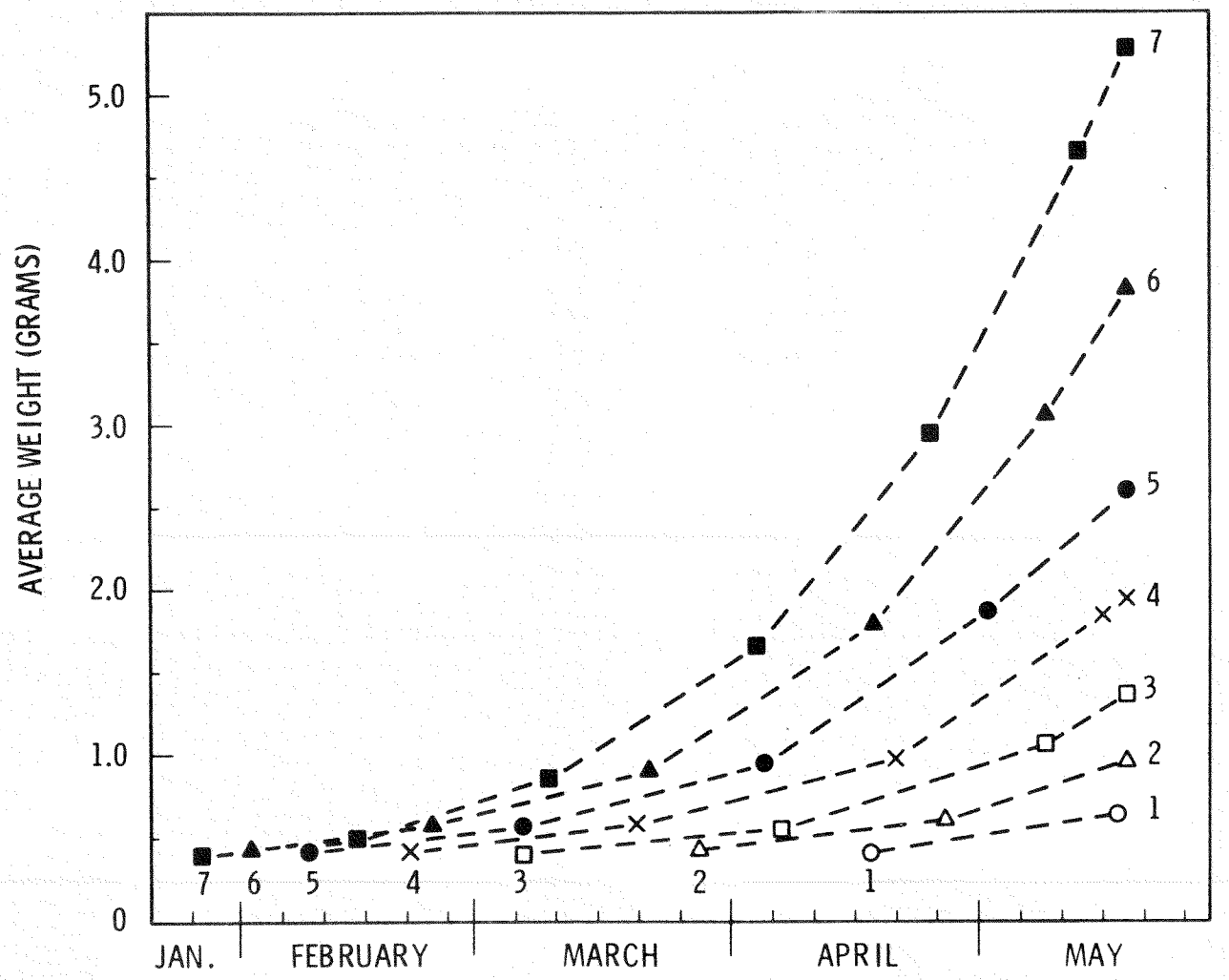

FIGURE 16. INCREASE IN WEIGHT OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES III (NOVEMBER 23 SPAWNING)

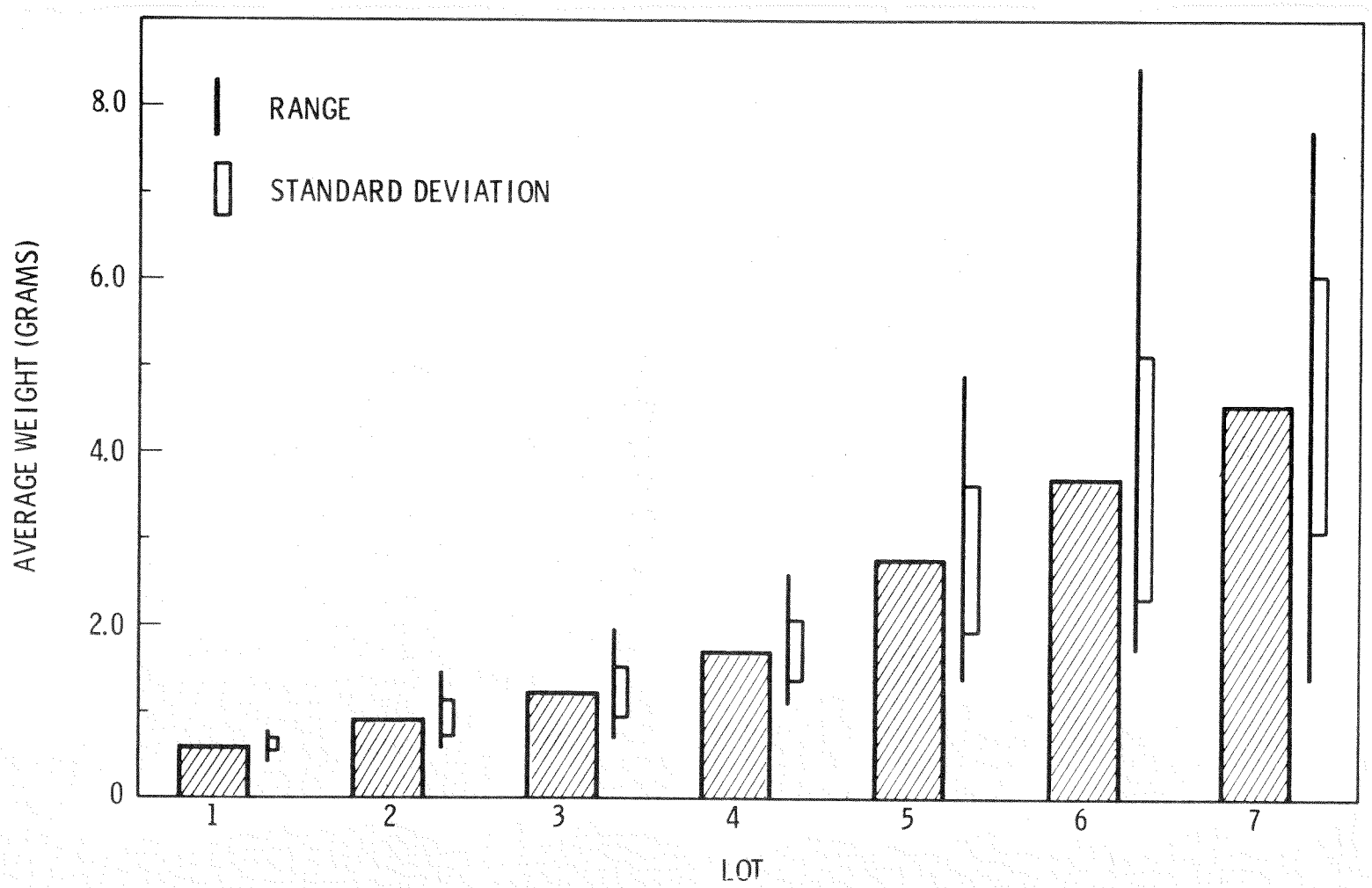

FIGURE 17. AVERAGE WEIGHT, RANGE AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES III (NOVEMBER 23 SPAWNING)

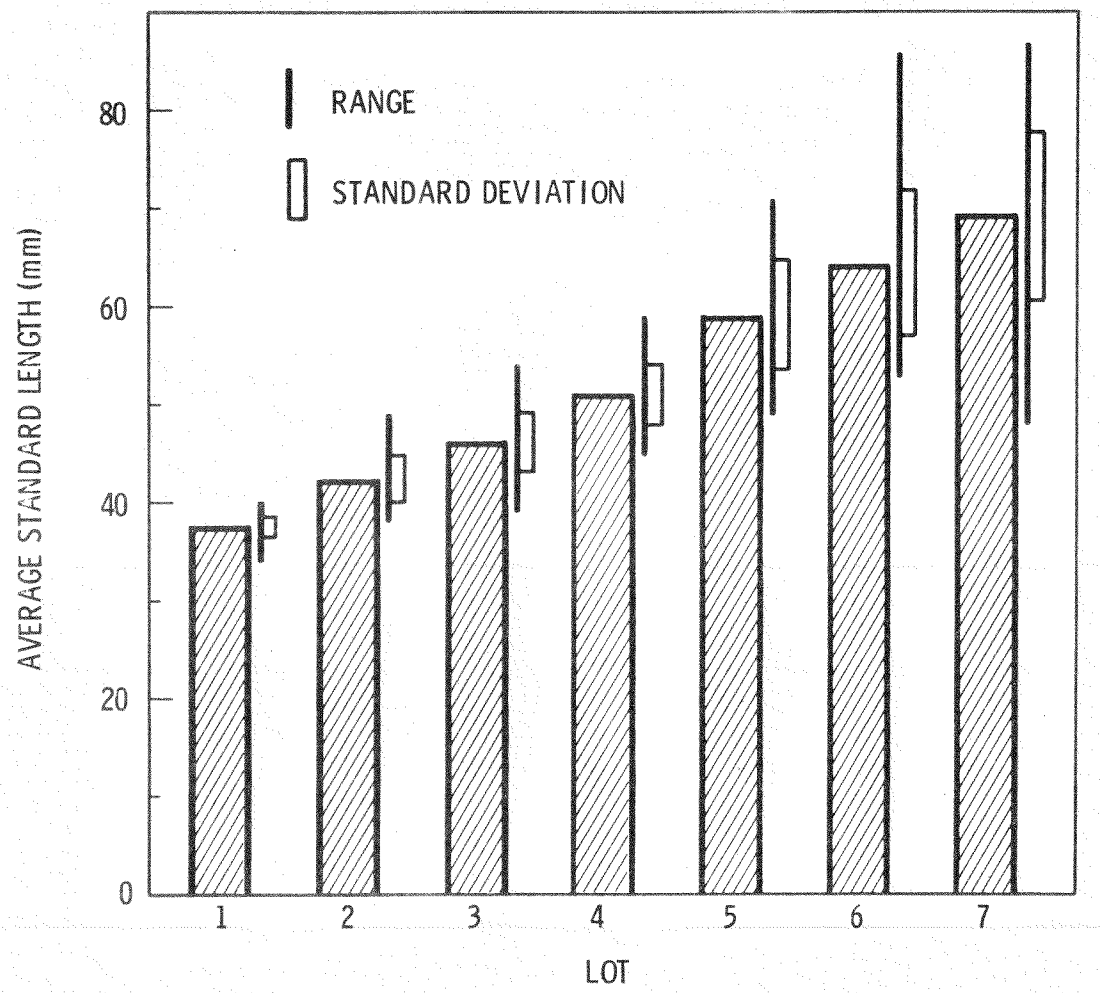

FIGURE 18. AVERAGE LENGTH, RANGE, AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES III (NOVEMBER 23 SPAWNING)

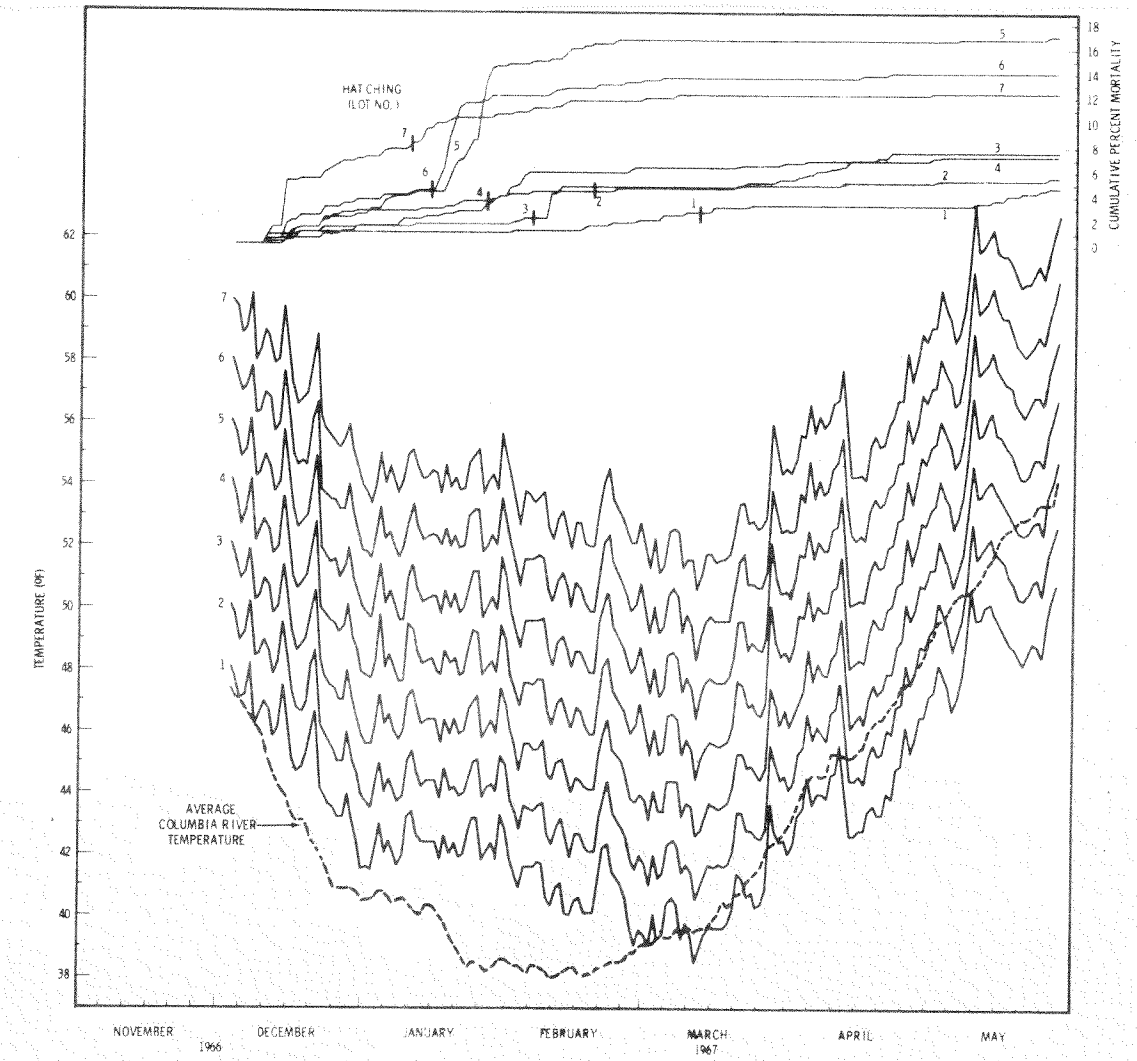

FIGURE 19. DAILY AVERAGE TEMPERATURES AND CUMULATIVE MORTALITIES, SERIES IV (DECEMBER 8 SPAWNING)

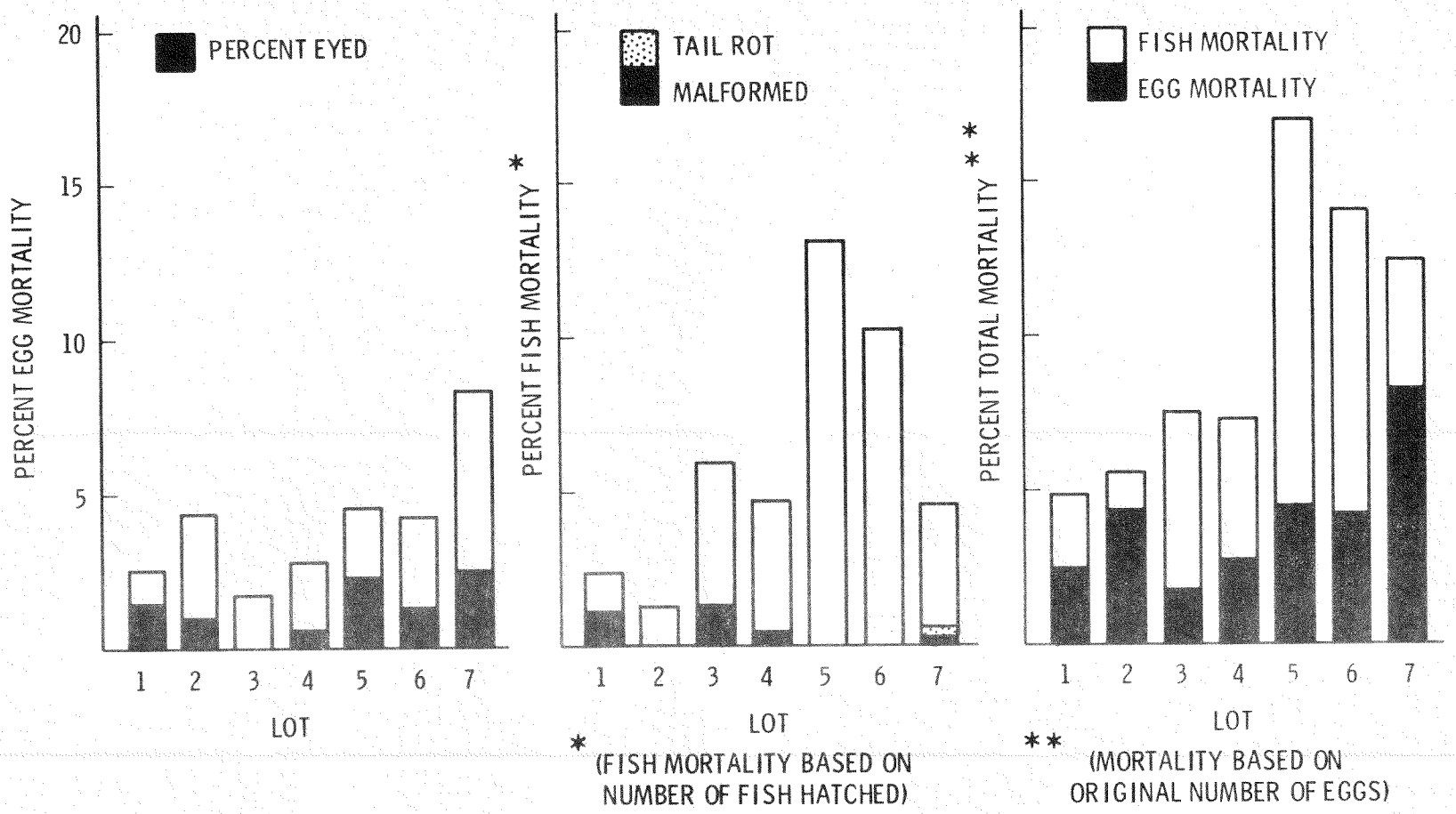

FIGURE 20. MORTALITY OF DIFFERENT STAGES AND TOTAL TERMINAL MORTALITY FOR YOUNG CHINOOK SALMON, SERIES IV (DECEMBER 8 SPAWNING)

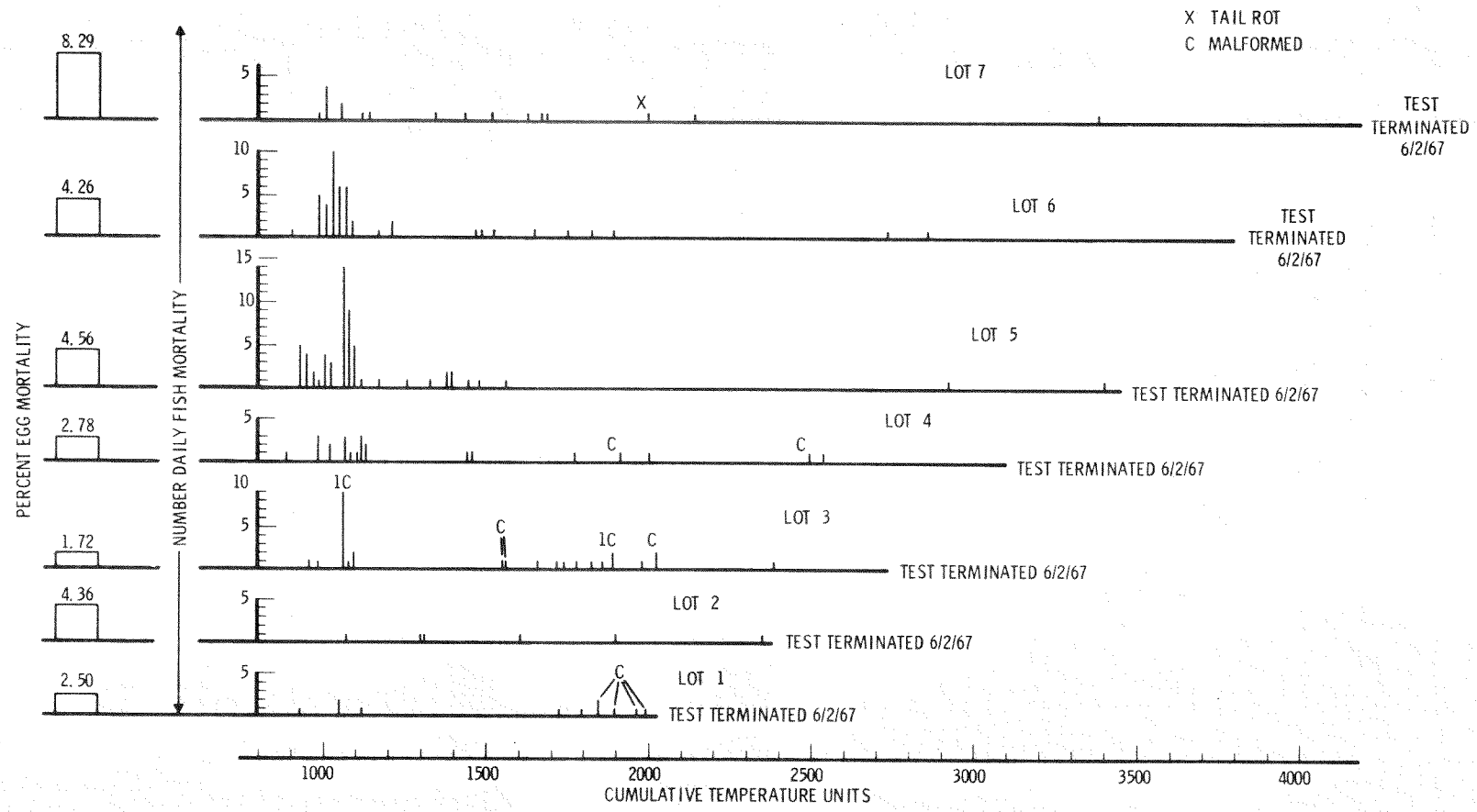

FIGURE 21. RELATIONSHIP OF MORTALITY TO STAGE OF DEVELOPMENT, SERIES IV (DECEMBER 8 SPAWNING)

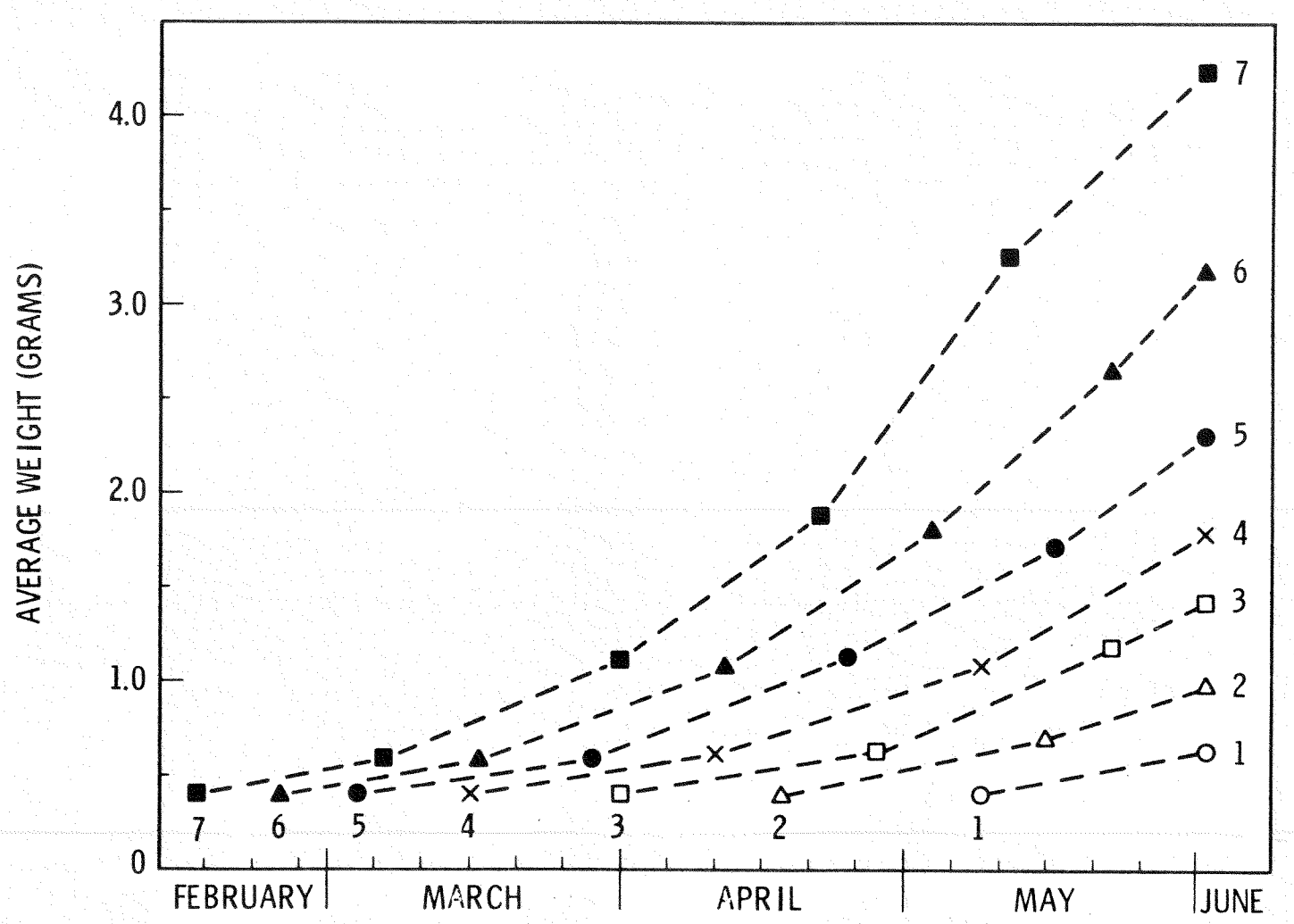

FIGURE 22. INCREASE IN WEIGHT OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES IV (DECEMBER 8 SPAWNING)

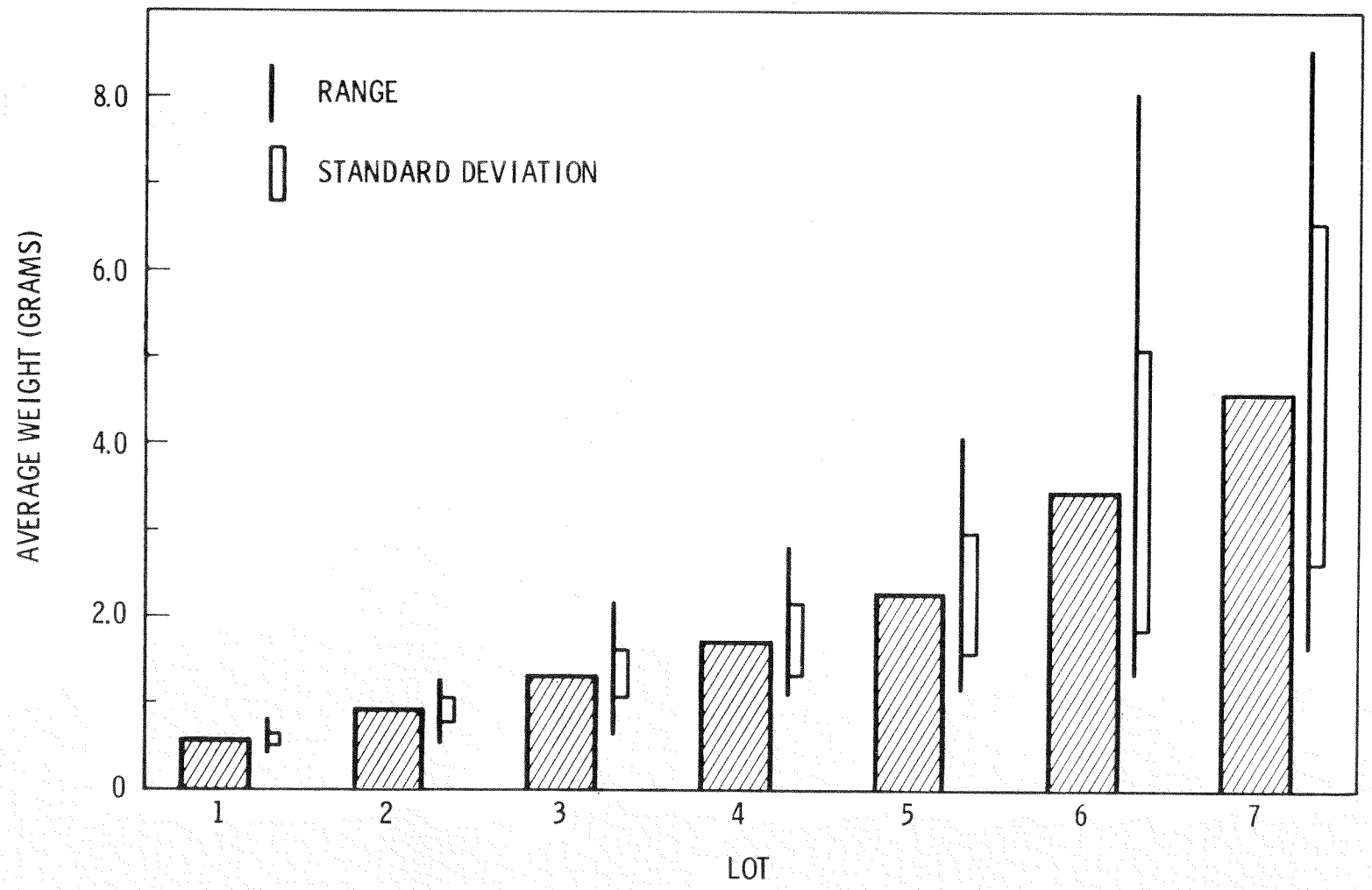

FIGURE 23. AVERAGE WEIGHT, RANGE AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES IV (DECEMBER 8 SPAWNING)

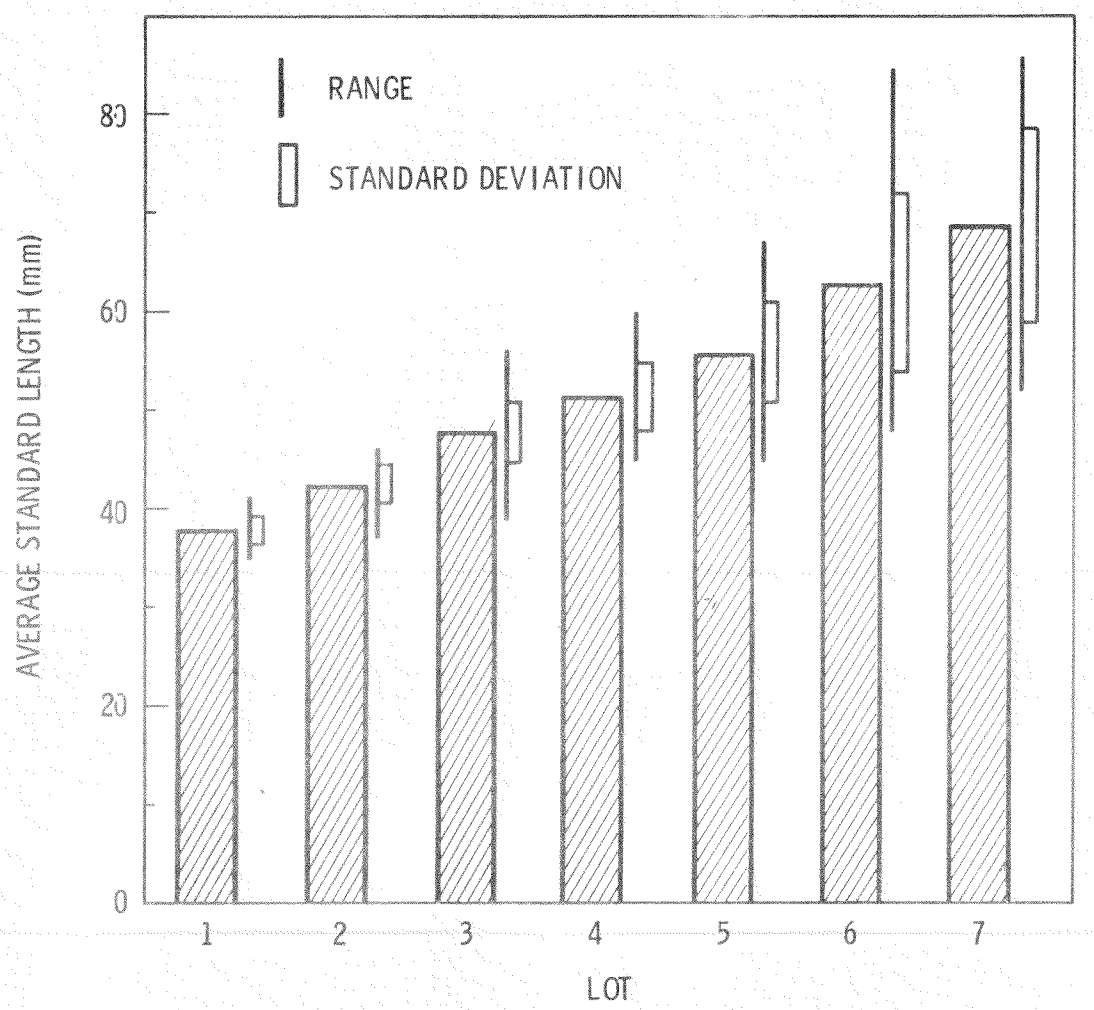

FIGURE 24. AVERAGE LENGTH, RANGE, AND STANDARD DEVIATION OF CHINOOK REARED UNDER DIFFERENT TEMPERATURE CONDITIONS, SERIES IV (DECEMBER 8 SPAWNING)

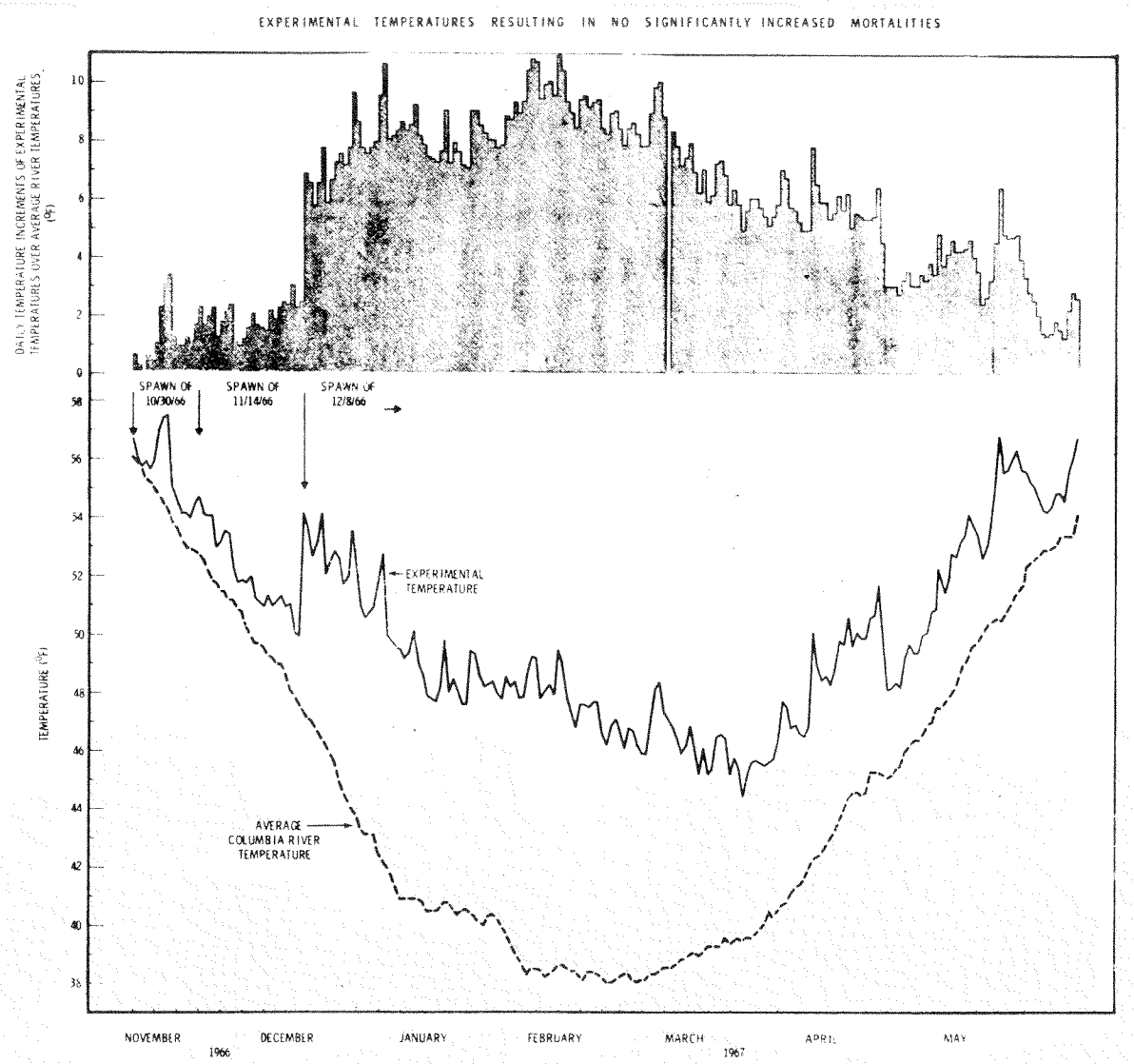

FIGURE 25. EXPERIMENTAL TEMPERATURES RESULTING IN NO SIGNIFICANTALLY INCREASED MORTALITIES

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