# EFFECTS OF THE MINIMUM MESH SIZE REGULATION ON PRODUCTION OF BEAR RIVER LATE RUN SOCKEYE SALMON

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# EXECUTIVE SUMMARY

A minimum gillnet mesh size regulation for the Alaska Peninsula commercial fishing management area (Area M) has been in place since at least Alaska Statehood. Although, mesh size selectivity exists for virtually all gillnet fisheries, generally commercial fishers determine the mesh size that maximizes catch per unit of effort and hence harvest of abundant size and age classes. In the case of a minimum mesh size, this is presumed not to be the case and thus has a potentially negative impact on quality of the escapements.

Length-at-age data from the Bear River late run escapement and from North Peninsula catches (excluding Nelson Lagoon) 1985-1990, were evaluated for detecting the level and direction of selectivity of the minimum mesh size regulation prior to regulation changes that relaxed the minimum mesh size restriction in portions of the North Peninsula in 1992 and 1996. As a means to quantify the potential current state of selection, we used several different scenarios that required the fewest number of assumptions and allowed us to make inferences on sockeye stocks still affected by a minimum mesh restriction. This approach, as opposed to direct comparison between pre- and post- regulatory change, was necessary as length-at-age data from commercial catches after 1990 were not collected, and separating pre- and post- regulation changes on biological attributes from those caused by selection of gillnets would be extremely difficult.

Tests of mean length-at-age by year between the catch and subsequent escapement were statistically different from one another, in some cases by as much as 49 mm (10%). In all years a significant difference in length between the catch and escapement were found, therefore substantiating gillnet selection was occurring during 1985-1990 on late run Bear River sockeye salmon. We also found that for several of the hypothetical examples applied to the Bear River length-at-age data, as many as 660 million additional eggs could be available within the escapements when employing realized exploitation rates by age class on sockeye salmon from Bristol Bay.

We show that heavy selective pressure was occurring on the late Bear River sockeye salmon stock during the years 1985-1990. The subsequent regulatory changes instituted in 1992 and 1996 have probably alleviated some of this problem (about 69% of the 1996-97 average harvest of Bear River sockeye occurs within the Bear River Section after 1 August) for the late Bear River sockeye stock. However, it is likely that similar selective pressures as those found operating on the Bear River late run stock are being exacted on other North Peninsula sockeye stocks (e.g. early run Bear River, Ilnik, Sandy, and Meshik Rivers). Unfortunately, the limitations of existing catch data collection (no length-at-age data collected after 1990) and escapement sampling (Ilnik R. sampling began in 1991 and Sandy R. in 1994) preclude stock specific analyses from being conducted.

# INTRODUCTION

The Alaska Peninsula commercial salmon fishery management area is subdivided into the South Peninsula and North Peninsula areas each managed separately. The North Alaska Peninsula is comprised of two fishing districts: the Northwestern District spans the coastline from Cape Sarichef to Moffet Point and the Northern District extends from Moffet Point to Cape Menshikof (Figure 1). In accordance with Alaska Board of Fisheries (BOF) regulation, legal gear types permitted within the Northern and Northwestern Districts are purse seine, hand purse seine, and drift and set gillnet gear. Largely because of long standing allocative disputes and concerns regarding harvests of migratory sockeye salmon of non-local origin, the Alaska Peninsula Management Area (Area M) has a minimum mesh size of 5.25" stretch mesh (133.4 mm) regulation in place for both drift and set gillnet gears within many fishing areas.

During the 1992 BOF meeting, the minimum mesh size regulation was removed after 20 July within the Bear River Section of the Northern District. This was done to provide better control of surplus production beyond biological escapement requirements. The 20 July date was inserted assuming that after this date, the Bear Lake late run sockeye stock dominated area harvests (ADF&G 1992). During the 1996 BOF meeting, this restriction was further eased by expanding the date to the entire season and inclusion of the Port Moller Bight and Nelson Lagoon Sections, again with the intent of enabling the area manager to meet biological escapement goals for the Bear, Nelson, and Sandy Rivers sockeye stocks.

Selectivity of a particular gear type is predicated on the fact that an exploited fish population is composed of a highly variable grouping of individuals differing in age, size, sex, and in some cases maturation stage. Therefore, gear or size of gear (gillnet mesh size) allows for unequal probability of capture among members of a population based upon size (Hamley 1975).

The gillnet as applied to the commercial harvest of sockeye salmon has long been known to affect biological properties (age, size, and sex composition) of both catches and escapements (Gilbert 1927; Barnaby 1944; Mathisen 1962; Burgner 1964; *among others*). Documentation of affects upon size and age composition of commercial sockeye catches and escapements (Peterson 1954, 1966; Todd and Larkin 1971; Rogers 1987), sex composition of catches ( Ishida 1963) and escapements (Mathisen 1962; Larkin and McDonald 1968) have been reported. Generally, Ricker (1972) points out that selection by a commercial fishery gear type that may alter genetically controlled traits (e.g. length-at-age) should be minimized.

The objectives of this study were:

1) determine if evidence of gillnet selectivity exists within the drift gillnet fishery on late run Bear River sockeye salmon;
2) if there is selection occurring due to the minimum mesh size regulation, how is it affecting biological attributes (size at age and sex composition) of the escapement;
3) and how gillnet selectivity might it be impacting the potential number of eggs available for spawning deposition.

# METHODS

## *Data Sources*

### Size-at-age Data

An intensive sockeye salmon age, length, and sex composition sampling program was instituted by the Alaska Department of Fish and Game (ADF&G) for commercial catch areas and escapements within the North Alaska Peninsula during 1985 (McCullough 1987). The commercial catch samples were collected within districts and sections where a fishery was being prosecuted on a weekly basis with a desired sample size of 600 scales per week per area (for age determination). This sample size allows for estimation of age class proportions within ± 4.0% with 95% certainty ($\alpha$=0.05; Thompson 1987). Fish lengths (mid-eye to fork-of-tail) were measured from each fish sampled for age, and recorded to the nearest mm; mean length was estimated for each age class along with standard error (Zar 1984). Determination of sex was via examination of external morphological characteristics.

Escapement age, length, and sex composition sampling consisted of collecting 240 scales per week from system specific escapements from about 1 June through 25 August, annually. This sample size effectively allows for simultaneously estimating the age composition of the escapement by week at $\alpha$=0.10 within ± 6.5% of the true proportions. All catch and escapement data by area and system have been previously reported (McCullough 1987, 1989a, 1989b, 1989c, 1990; Murphy 1992)

Escapement numbers were extracted from the Westward Regional escapement database, catch numbers cited were obtained from the ADF&G, CFMDD statewide fish ticket (harvest receipt) database. Both catch and escapement biological attribute data were extracted from the ADF&G regional databases compiled based upon calculations reported in Blackburn (1993).

### Length-Fecundity Data

Sockeye salmon length-fecundity at age data were obtained from three systems two of which are within Bristol Bay. Age 2.2 and 2.3 length-fecundity data from Bear River was collected during 1996 at the escapement counting weir from both the early and late runs by ADF&G and University of Washington field personnel. Generally, a single scale, fish length (to nearest mm), weight (to nearest gram), and left and right egg skeins from each fish were collected. A sample of 60 fish were targeted for collection during 1-2 July and again during 22-23 August, 1996. Fecundity for each fish sampled was estimated after the field season from previously frozen egg skeins (K. Ramstad, University of Washington, Fisheries Research Institute, Seattle, personal communication).

Data were also obtained from historical records of sockeye salmon length-fecundity from Pick Creek and the Agulukpak River from the Wood River Lakes system within Bristol Bay, specific to age-1.2 and -1.3 fish (D. Rogers, University of Washington, Fisheries Research Institute, Seattle, personal communication). Sample collection was performed similar to what was previously outlined for Bear River sockeye salmon length-fecundity data.

There were two additional sources of information which we used for evaluating gillnet selection. The first was matching up the weighted average length of the Bear River sockeye salmon runs 1985-90 with a series of gillnet selectivity curves generated from data extracted from Holt (1963). The second was comparing the coefficient of variation (CV) of the Bear River return with the proportion of 3-ocean age sockeye within the escapement and also variability in escapement magnitude versus proportion of 3-ocean fish within the escapement, after Rogers (1987).

### *Data Analyses*

After condensing the length-at-age data for the dominant age classes (1.2, 1.3, 2.2, and 2.3) by sex, time period (week; post-1 August), and year (1985-1990) for both North Peninsula catch (excluding Nelson Lagoon) and Bear River late run escapement, statistical tests (ANOVA; Systat 1996) were performed on mean length using a significance level ($\alpha$) of 0.05. These tests were employed to address the hypothesis that gillnet selection was/was not occurring and if so, to what extent.

A fundamental assumption with length-fecundity data is that fecundity varies with length and hence will also vary with age. We tested the dependence of fecundity on length (age-1.2, -1.3,-2.2, and -2.3) to see if statistically significant differences exist. If there is no difference between length-fecundity by age class then a single length-fecundity relationship can be used to estimate fecundity regardless of age; conversely if there is significant difference, then fecundity estimates should be generated using an age specific relationship.

As a measure of the impact gillnet selection has on length-at-age of the escapement, we employed mean size of females for estimating the potential number of eggs transported into the system. For comparison, three different examples were derived in an attempt to show what the potential changes to egg production could be and compared them to the benchmark (standard) of 1985-90 escapement data. The standard for comparison was constructed from the escapement average length-at-age for females by year, then estimating number of eggs per female at mean length. We then derived numbers of eggs by age class and finally summed over all age classes for an annual total. The three examples employed were: 1) keeping all of the standard variables constant, then adjusting the mean length of females in the escapement so that it matched that of the run; 2) holding all variables constant, adjusting the length of females to match the run, and adjusting the sex ratio of the escapement for each age class to be 1.0:1.0; and 3) keeping the mean length-at-age similar to the run, and applying age and sex specific exploitation rates as reported in Rogers (1987).

# RESULTS

The tests conducted on mean length-at-age between the catch areas and escapement, for all years and age classes were statistically significant (Appendix A.). These tests essentially confirm the assertion that the minimum 5.25" stretch mesh regulation for the 1985-1990 Bear River late run sockeye stock was in fact highly selective towards larger fish. Differences in weighted mean length between the reconstructed run and escapement for all years ranged from a low of 7 mm (1%; 1986) to a high of 24 mm (4%; 1989). Comparisons of the weighted mean lengths between the catch and the subsequent escapements show a more pronounced difference ranging from a low of 27 mm (5%; 1988) to a high of 49 mm (10%; 1989 and 1990; Table 1). These dramatic changes in length composition for the Bear River late run, after the fishery had occurred, can also be observed using length frequency plots for all years, however we show only the 1985 and 1990 data (Figures 2 and 3).

Tests of the significance between length and fecundity resulted in detectable differences for each of the relationships by age class when compared to all age classes (Full model) combined. Therefore, the all age classes combined model was used to estimate fecundity from mean length for each of the age classes (Appendix B.1). Using this model also had the added advantage of increased sample size and being able to incorporate a wider range of lengths.

In placing the observed gillnet selectivity into perspective (number of potential eggs lost from the spawning escapement), there was an average of 1% difference (range 0.0 to 1.0%) in numbers of potential eggs within the spawning escapement between the standard (1985-90 data) and the scenario referenced as example 1 (size composition of the escapement matched the run; Table 2). Comparison of the standard to example 2 (all variables held constant but sex ratio adjusted to 1:1) resulted in differences ranging from 0% to 27%; the upper value translating into 177 million eggs foregone from the escapement. Contrasting the standard and example 3 (using age and sex specific exploitation rates from Bristol Bay) showed the most drastic change with percentages ranging from 43% to upwards of 230%. These differences suggest that from 188 to 666 million eggs (example 3 estimated eggs minus standard) could have been added to the Bear River system under these conditions.

The weighted average length of the Bear River sockeye salmon run for all years ranged from 520 mm to 558 mm (Table 1). When comparing these lengths to the selectivity curves constructed for mesh sizes ranging from 4 5/8 inches to 5 3/8 inches (Holt 1963, Regier and Robson 1966; Appendix C.1) a majority of the weighted mean lengths (5 out of 6) matched gillnet mesh sizes of 4 7/8 to 5 1/8 inch stretch mesh.

We also compared sockeye salmon return variability of the Bear River late run versus the 3-ocean fish within the escapement and variability in escapement magnitude and proportion of 3-ocean age sockeye within the escapements to similar Wood River data (1953-1979). For both relationships the Bear Lake data (1981-1990 Brood Years) was less variable than that found for Wood River sockeye, however the CV's (~40% and 50% respectively; Appendix C.2) were not outliers and possibly with a similar sample size would have shown a better fit.

## DISCUSSION

The findings from the length-at-age analyses confirmed that during 1985-1990, the minimum mesh size regulation of 5.25" stretch mesh was exacting a high degree of selective pressure on the larger late run sockeye salmon destined for Bear River. The differences of 27 to 49 mm in mean length between the catch and subsequent escapement was evidence that selection was occurring. This situation was similar to what was reported to have been occurring in Bristol Bay from the late 1800's through the mid-1950's (Mathisen 1971). There is also evidence that selection for 3-ocean age fish was higher than for 2-ocean age fish thus potentially impacting the quality of the Bear River late run escapement. Both Rogers (1987) and Mathisen (1971) reported that there were periods when 3-ocean age fish were experiencing a higher level of selection than the smaller 2-ocean age fish within Bristol Bay as well. Further evidence exists that the Port Moller offshore test fishery catch of sockeye has been on the average 10 mm larger, and the percentage of 2-ocean age fish about 8% less than the sockeye salmon harvested by commercial gear within Bristol Bay (Helton 1991; Eggers and Fried 1984). The current mesh size employed by the test fishery is 5.0" stretch mesh while in Bristol Bay mesh sizes used for sockeye vary by district but generally range from 4 ½ to 5 1/8 inch stretch mesh.

The implications for impact to the quality (egg numbers or stock specific production) of the escapement is evident from the various examples given relative to the estimated number of eggs from the standard escapement. Converse to the minimum mesh size of 5.25" regulation that exists within Area M, the Bristol Bay area regulations impose mesh size ceilings for time and area protection of various salmon species. For the protection of sockeye and coho salmon a maximum mesh size of 4.75" stretch mesh is invoked which is the smallest mesh size permitted and is a full ½ inch smaller than the minimum used where this regulation still applies. It is interesting that this mesh size closely approximates what might be the optimum mesh size for harvesting Bear River sockeye salmon, and given that other North Peninsula stocks have similar length-at-age distributions, for these stocks as well. This observation supports our use of the exploitation rates from Rogers (1987). If the Bear River stock was exposed to similar exploitation rates as those found within Bristol Bay by age class and sex, an average increase of upwards of 300 million additional eggs could be available within the escapement from the late run Bear River stock.

Although the Bear Lake data set was less extensive than that from Bristol Bay for comparing relative variability of the sockeye salmon return to the proportions of 3-ocean age sockeye, the fact that the coefficients of variation were approaching those from Rogers (1987) suggest that similar levels of variability do exist within North Peninsula sockeye returns. Rogers (1987) points out that if ocean age is an inherited trait then the selection of 3-ocean age fish could have been cause for reduced production during the earlier years of the Bristol Bay fishery. He points out that sockeye populations with variable age at maturity are more stable numerically than those with a more static and consistent age composition which implies that age, and hence size, selective fisheries would tend to induce larger interannual variability in the runs to these systems. This situation could be in existence for North Peninsula sockeye stocks.

Unfortunately an adequate biological sampling (age, size and sex composition) program was not instituted for North Peninsula catches and escapements until 1985; size at age data prior to 1985 are limited. This makes long term comparisons similar to those of Rogers (1987) for the sockeye stocks of the North Peninsula limited in scope. Additionally, termination of size sampling of commercial catches post 1990 places severe restrictions on the types of analyses that can be conducted on data collected during 1992-1996, for determining the level of selection post-1991 that might have changed for the Bear River stock.

Regardless of the data limitations that exist, we feel reasonably confident that gillnet selection similar to what was exacted on the late Bear River run during 1985-1990 is still partially in existence for Bear River late run fish and for other North Peninsula sockeye salmon stocks not affected by the regulatory changes instituted during 1992 and 1996. This can be interpreted to mean that there is some level of production suppression operating on these stocks as a function of the minimum mesh size regulation. Invariably what can be stated from these analyses is that 5.25" stretch mesh is not the optimum mesh size for harvesting late Bear River sockeye salmon nor other similar size fish from other North Peninsula sockeye stocks.

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Table 1. Sockeye salmon mean lengths by run segment, sex, and age class from the Bear River late run, and commercial catches from Harbor Point to Cape Seniavin and Cape Seniavin to Strogonof Point fishing areas, 1985-1990.

| Year | Run Segment | Sex | Length-at-Age (mm) 1.2 | 1.3 | 2.2 | 2.3 | Overall weighted average length (mm) | Difference [a] Absolute (mm) | relative (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1985 | Total Run | All | 514 | 567 | 513 | 564 | 529 | | |
| | | Females | 512 | 558 | 513 | 560 | | | |
| | Catch | All | 517 | 567 | 523 | 567 | 538 | 9 | 2% |
| | | Females | 514 | 558 | 520 | 562 | | | |
| | Escapement | All | 467 | 548 | 490 | 542 | 495 | -34 | -6% |
| | | Females | 478 | 549 | 499 | 544 | | | |
| 1986 | Total Run | All | 482 | 568 | 517 | 571 | 544 | | |
| | | Females | 487 | 558 | 519 | 567 | | | |
| | Catch | All | 492 | 568 | 526 | 572 | 550 | 7 | 1% |
| | | Females | 496 | 558 | 524 | 568 | | | |
| | Escapement | All | 451 | 566 | 493 | 565 | 511 | -33 | -6% |
| | | Females | 462 | 566 | 503 | 563 | | | |
| 1987 | Total Run | All | 507 | 580 | 499 | 579 | 558 | | |
| | | Females | 499 | 573 | 502 | 574 | | | |
| | Catch | All | 515 | 581 | 518 | 581 | 569 | 11 | 2% |
| | | Females | 502 | 574 | 509 | 575 | | | |
| | Escapement | All | 462 | 570 | 481 | 568 | 519 | -39 | -7% |
| | | Females | 479 | 569 | 495 | 566 | | | |
| 1988 | Total Run | All | 510 | 572 | 502 | 549 | 535 | | |
| | | Females | 508 | 565 | 505 | 564 | | | |
| | Catch | All | 513 | 573 | 522 | 548 | 543 | 8 | 2% |
| | | Females | 510 | 566 | 520 | 566 | | | |
| | Escapement | All | 460 | 568 | 474 | 555 | 508 | -27 | -5% |
| | | Females | 470 | 555 | 483 | 552 | | | |
| 1989 | Total Run | All | 469 | 580 | 509 | 581 | 538 | | |
| | | Females | – | 568 | 507 | 571 | | | |
| | Catch | All | 475 | 581 | 543 | 585 | 562 | 24 | 4% |
| | | Females | 0 | 569 | 530 | 574 | | | |
| | Escapement | All | 453 | 559 | 473 | 561 | 489 | -49 | -9% |
| | | Females | 475 | 539 | 482 | 553 | | | |

-Continued-

Table 1. (page 2 of 2)

| Year | Run Segment | Sex | Length-at-Age (mm) 1.2 | 1.3 | 2.2 | 2.3 | Overall weighted average length (mm) | Difference [a] Absolute (mm) | relative (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1990 | Total Run | All | 466 | 550 | 492 | 567 | 520 | | |
| | | Females | 480 | 550 | 496 | 561 | | | |
| | Catch | All | 508 | 551 | 510 | 569 | 537 | 17 | 3% |
| | | Females | 501 | 550 | 507 | 563 | | | |
| | Escapement | All | 441 | 535 | 464 | 547 | 470 | -49 | -10% |
| | | Females | 468 | 547 | 478 | 545 | | | |

[a] Calculated differences are between overall weighted average lengths of the total run by year and the catch or escapement.

Table 2. Estimated number of sockeye salmon eggs potentially foregone within the late run Bear River escapement based on the fecundity-length model, realized gillnet selectivity, and several hypothetical changes to the escapement and catch compositions.

| | Number of Eggs (In Millions) | | | | Relative Difference from Standard | | |
|---|---|---|---|---|---|---|---|
| Year | Standard | Example 1 [a] | Example 2 [b] | Example 3 [c] | Example 1 | Example 2 | Example 3 |
| 1985 | 475 | 478 | 472 | 1,224 | 1% | 0% | 158% |
| 1986 | 289 | 291 | 327 | 955 | 1% | 13% | 230% |
| 1987 | 212 | 213 | 249 | 471 | 0% | 17% | 122% |
| 1988 | 329 | 331 | 364 | 669 | 1% | 11% | 104% |
| 1989 | 431 | 436 | 496 | 619 | 1% | 15% | 43% |
| 1990 | 661 | 667 | 838 | 1,243 | 1% | 27% | 88% |

[a] Numbers of females stayed the same but mean size of escapement similar to run.

[b] Number of females stayed the same but mean size of escapement similar to run and proportion of females to males was equal (i.e. 50/50)

[c] Number of females stayed the same but mean size of escapement similar to run and appying exploitation rates found by Rogers 1987.

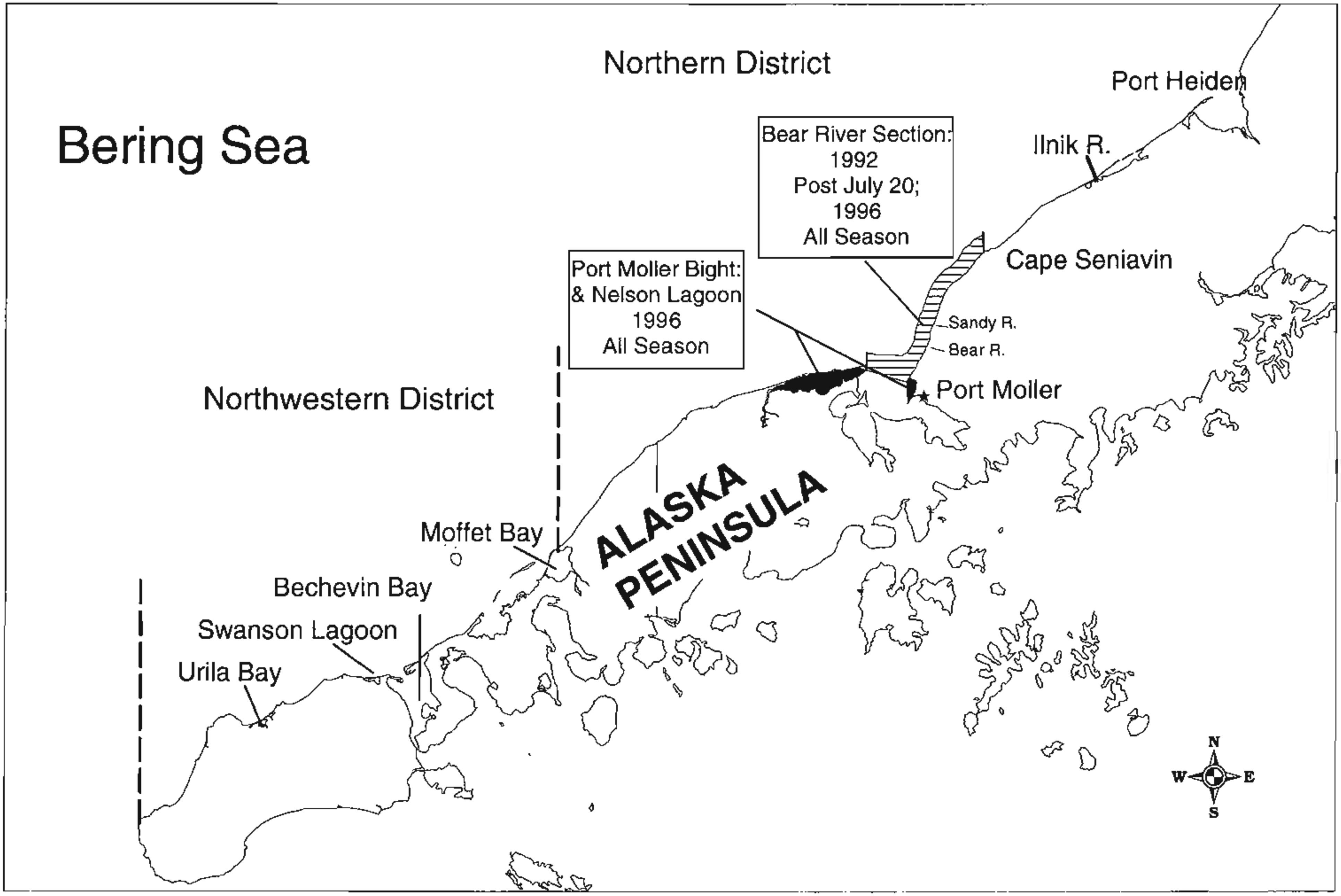


Figure 1. Map of the North Alaska Peninsula showing commercial fishing areas where gillnet regulations have been modified.

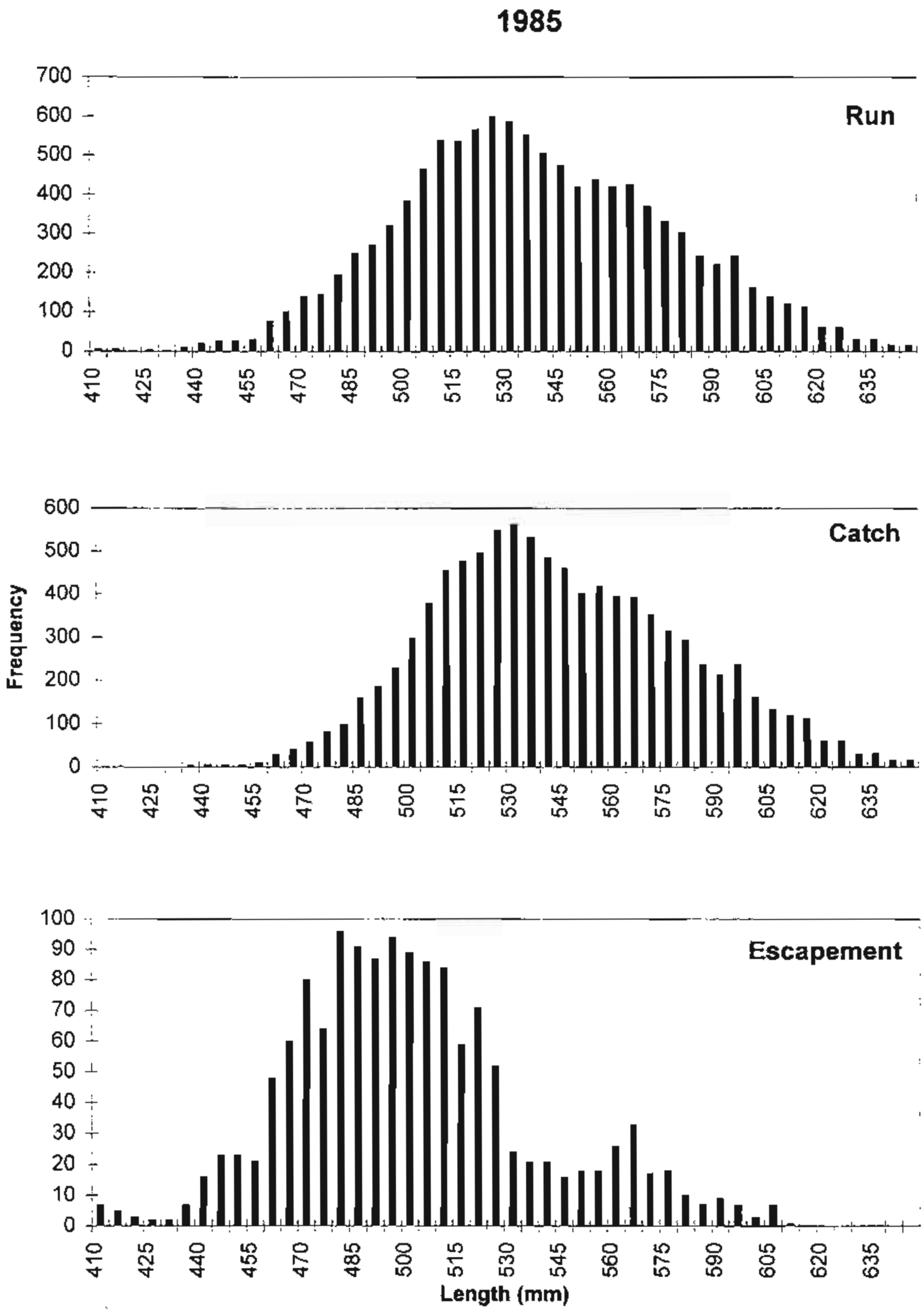


Figure 2. Distributions of sockeye salmon lengths (all age classes combined) from the reconstructed run, Harbor Point to Strogonof Point commercial catch, and escapement, late run Bear River, 1985.

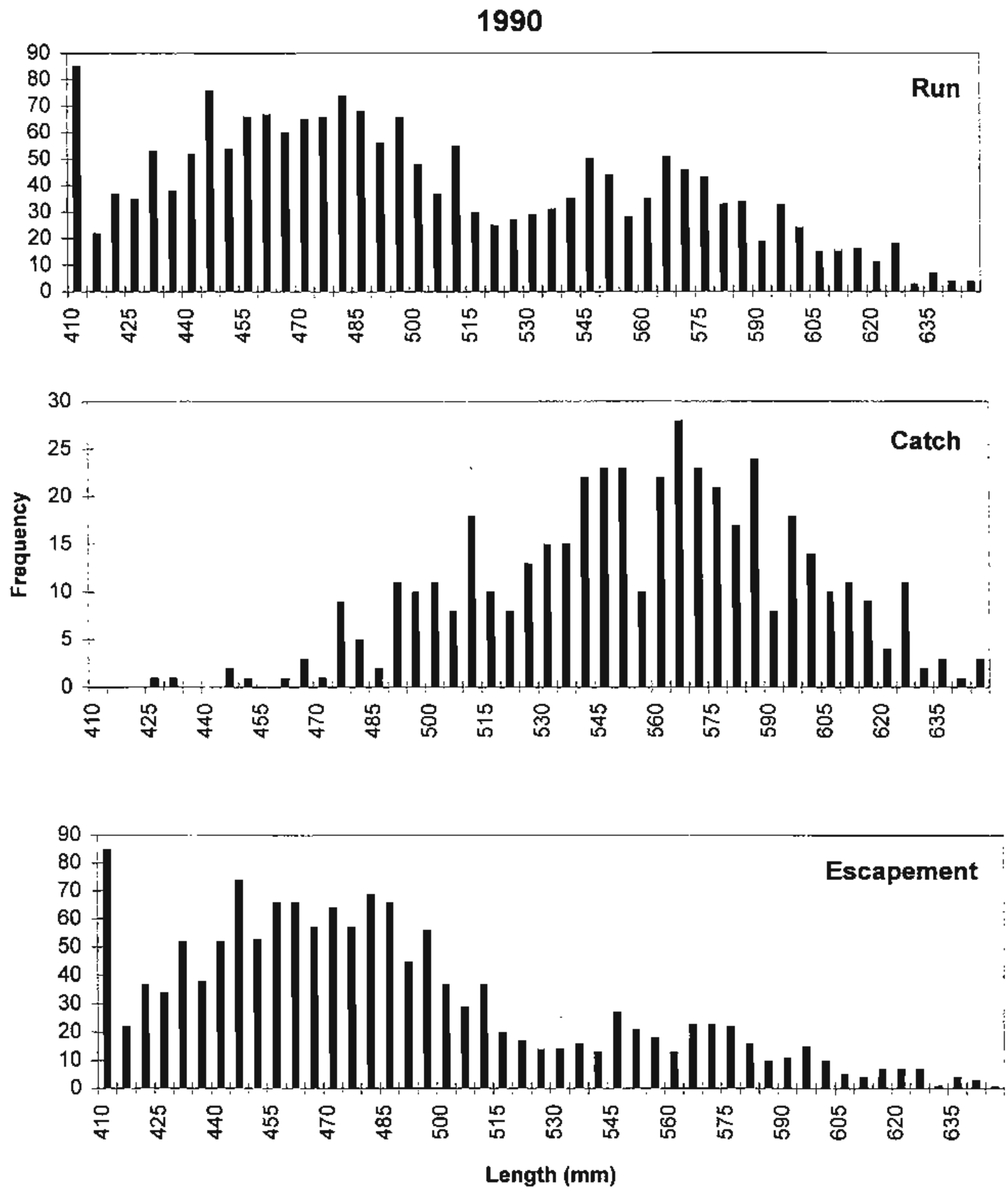


Figure 3. Distributions of sockeye salmon lengths (all age classes combined) from the reconstructed run, Harbor Point to Strogonof Point commercial catch, and escapement, late run Bear River, 1990.

# APPENDIX

Appendix A. Tests of differences between length at age for escapement versus catch.

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A two factor (age and sample location) analysis of variance (ANOVA) was used to test for differences in mean length among age classes, sample location, and the interaction of age class and sample location. A total of 6 analyses were conducted to test for differences in length categories for each year (1985-1990). Post-hoc multiple comparisons were made using the Tukey method (Kleinbaum et al. 1987 page 365) to discover which combinations of age/location were significantly different. The levels within each factor were: AGE (1.2, 1.3, 2.2, and 2.3) and LOCATION (Bear River escapement, catch from Harbor Point to Cape Seniavin, and catch from Cape Seniavin to Stogonof Point).

For each year three hypotheses were tested:

$H_1$: the mean lengths of fish sampled from each location are equal;

$H_2$: the mean lengths of fish sampled from each age class are equal;

$H_3$: the mean lengths of fish sampled from each age class and location combination are equal (e.g. age 1.2 catch Cape Seniavin to Harbor Point vs. age 2.2 Bear River Escapement).

As shown in the following ANOVA summary tables, all of the hypotheses were rejected in every year ($p<0.001$). The 864 comparisons revealed that all but 85 were significantly different. Of these 85 non-significant comparisons, nearly half (42) were comparing fish of equal saltwater age.

**1985** Analysis of Variance Table

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| LOCATION | 576,421.9 | 2 | 288,210.9 | 357.9 | 0.000 |
| AGE | 3,155,745.6 | 3 | 1,051,915.1 | 1,306.5 | 0.000 |
| LOCATION*AGE | 49,683.0 | 6 | 8,280.5 | 10.3 | 0.000 |
| | | | | | |
| Error | 8,919,415.2 | 11,078 | 805.1 | | |

**1986** Analysis of Variance Table

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| LOCATION | 238,588.2 | 2 | 119,294.1 | 140.3 | 0.000 |
| AGE | 6,830,109.7 | 3 | 2,276,703.2 | 2,678.3 | 0.000 |
| LOCATION*AGE | 276,246.8 | 6 | 46,041.1 | 54. 2 | 0.000 |
| | | | | | |
| Error | 9,824,149.6 | 11,557 | 850.1 | | |

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**1987** Analysis of Variance Table

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| LOCATION | 663,025.9 | 2 | 331,512.9 | 373.9 | 0.000 |
| AGE | 1.21737E+07 | 3 | 4,057,896.4 | 4,576.7 | 0.000 |
| LOCATION*AGE | 262,190.2 | 6 | 43,698.4 | 49.3 | 0.000 |
| | | | | | |
| Error | 1.04234E+07 | 11756 | 886.6 | | |

**1988** Analysis of Variance Table

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| LOCATION | 104,329.9 | 2 | 52,164.9 | 57.4 | 0.000 |
| AGE | 2,241,546.1 | 3 | 747,182.1 | 822.7 | 0.000 |
| LOCATION*AGE | 251,080.8 | 6 | 41,846.8 | 46.1 | 0.000 |
| | | | | | |
| Error | 3,895,345.4 | 4,289 | 908.2 | | |

**1989** Analysis of Variance Table

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| LOCATION | 121,280.9 | 2 | 60,640.5 | 54.9 | 0.000 |
| AGE | 172,174.7 | 3 | 57,391.6 | 51.9 | 0.000 |
| LOCATION*AGE | 84,391.4 | 6 | 14,065.3 | 12.7 | 0.000 |
| | | | | | |
| Error | 2,904,139.8 | 2629 | 1,104.7 | | |

**1990** Analysis of Variance Table

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| LOCATION | 145,654.6 | 2 | 72,827.2 | 51.4 | 0.000 |
| AGE | 757,689.3 | 3 | 252,563.1 | 178.3 | 0.000 |
| LOCATION*AGE | 51,543.6 | 6 | 8,590.6 | 6.1 | 0.000 |
| | | | | | |
| Error | 2,661,502.3 | 1,879 | 1,416.4 | | |

Appendix B. Modeling of fecundity on length.

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We modeled the dependence of fecundity on length at age for the four dominant age classes 1.2, 1.3, 2.2 and 2.3 by the relationship:

$$F = \beta_0 + \beta_1 L + \beta_2 Z_1 + \beta_3 Z_2 + \beta_4 Z_3 + \beta_5 Z_1 L + \beta_6 Z_2 L + \beta_7 Z_3 L, \qquad (1)$$

where

$Z_1 = \{$ 1, if age 1.2; 0, otherwise,

$Z_2 = \{$ 1, if age 1.3; 0, otherwise, and

$Z_3 = \{$ 1, if age 2.2; 0, otherwise.

The model provided in equation (1) allows for the length-fecundity data for each age class to be fit by a unique linear relationship and will be referenced as the full model. Conversely, the reduced model allows for a single linear relationship to be fit to data specific to a single age class and is represented as:

$$F = \beta_0 + \beta_1 L. \qquad (2)$$

Our interest was not with estimates of the parameters $\beta_2$ through $\beta_7$ but rather whether they differed significantly from zero. If this was the case then the full model (equation 1) reduces to equation (2) indicating that a single linear equation is adequate for describing the fecundity-length relationship regardless of age class. However if any of the parameters differ from zero, then a single relationship would improperly describe the fecundity-length relation for the different age classes. We tested the adequacy of the reduced model relative to the full model by analysis of variance (Partial F-test; Kleinbaum and Kupper 1978) with the null hypothesis being:

$H_0 : \beta_2 = \beta_3 = \ldots\ldots \beta_7 = 0,$

versus the alternative hypothesis,

$H_a : \beta_i \neq 0,$ for at least one i=2,3,...7.

The null hypothesis which supports the reduced model, allows for a single relationship for all age classes.

The tests conducted between each of the relationships describing fecundity on length provided an F=8.98 with 6 and 114 df ($p<0.001$). Based upon this, we rejected the null hypothesis of there being no significant differences of fecundity on length between age

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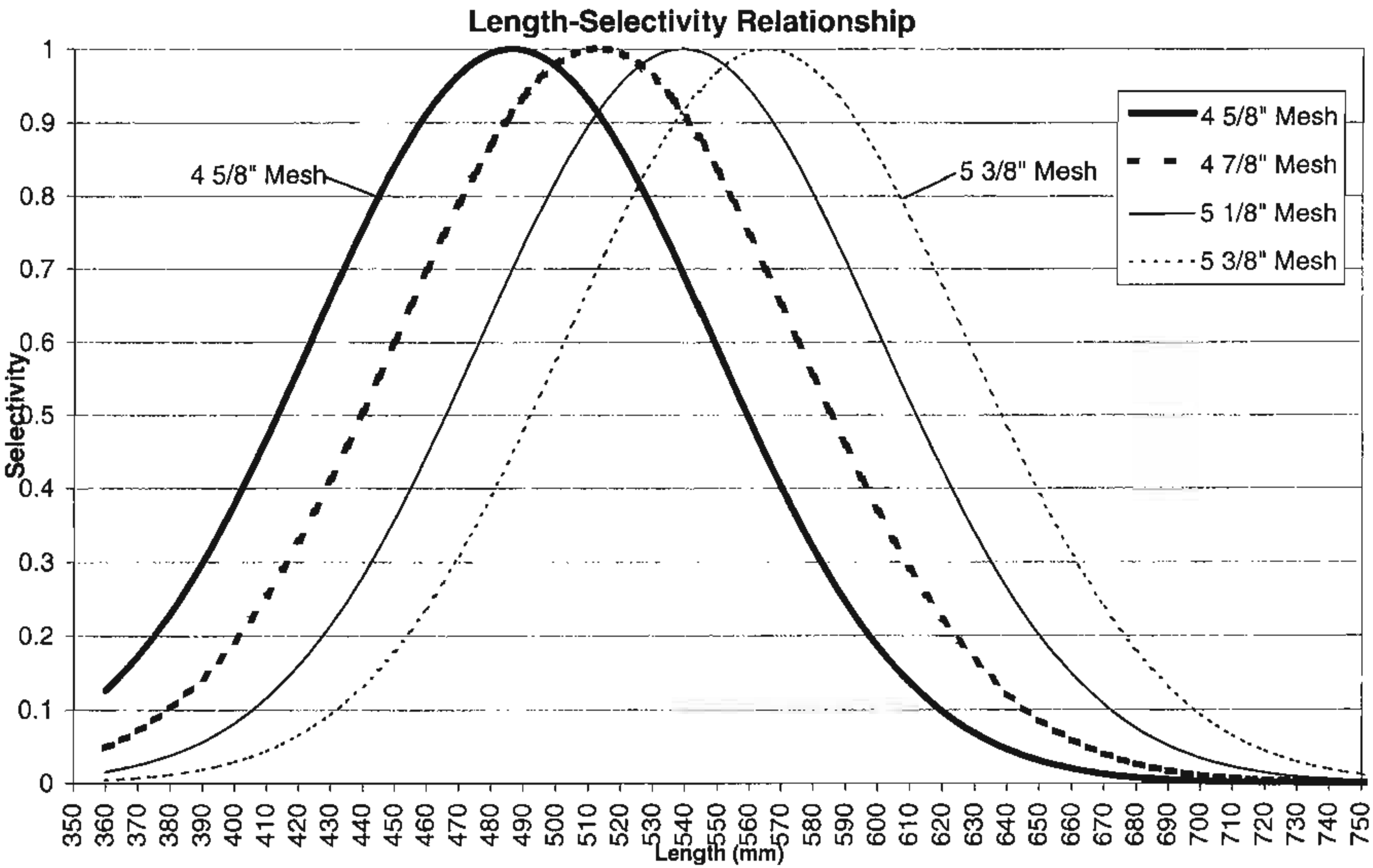
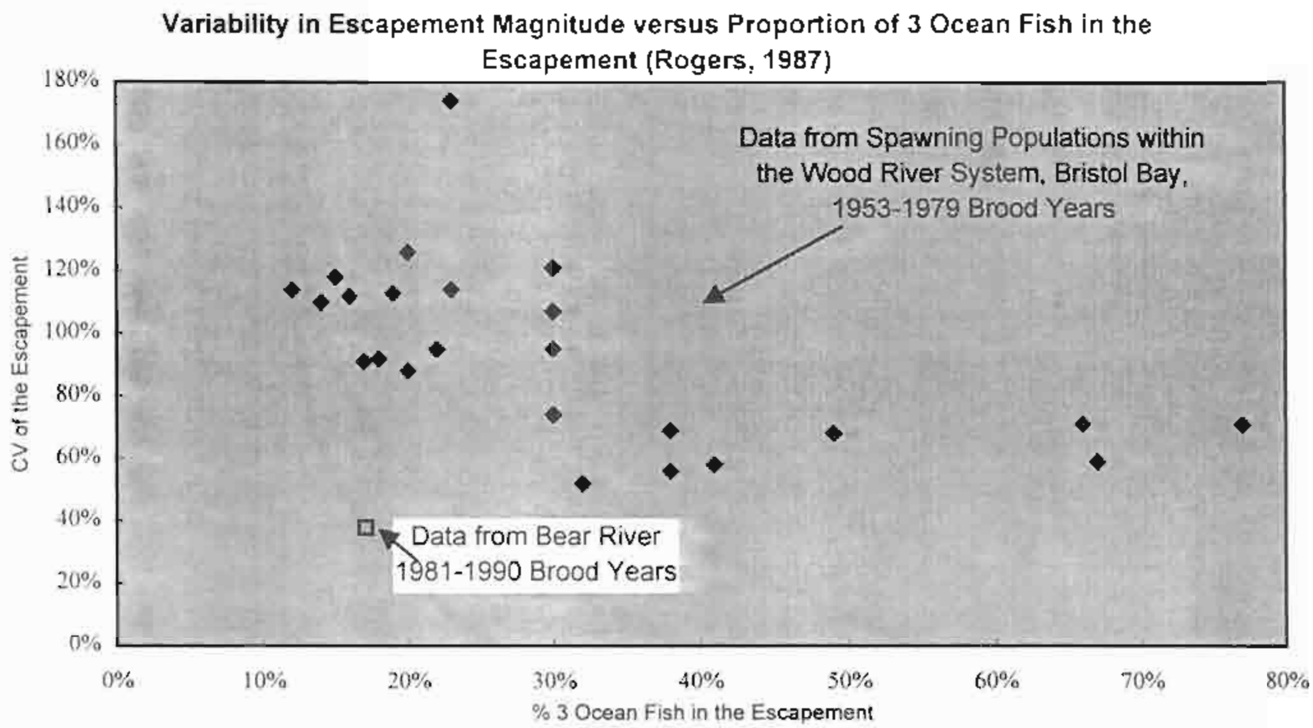
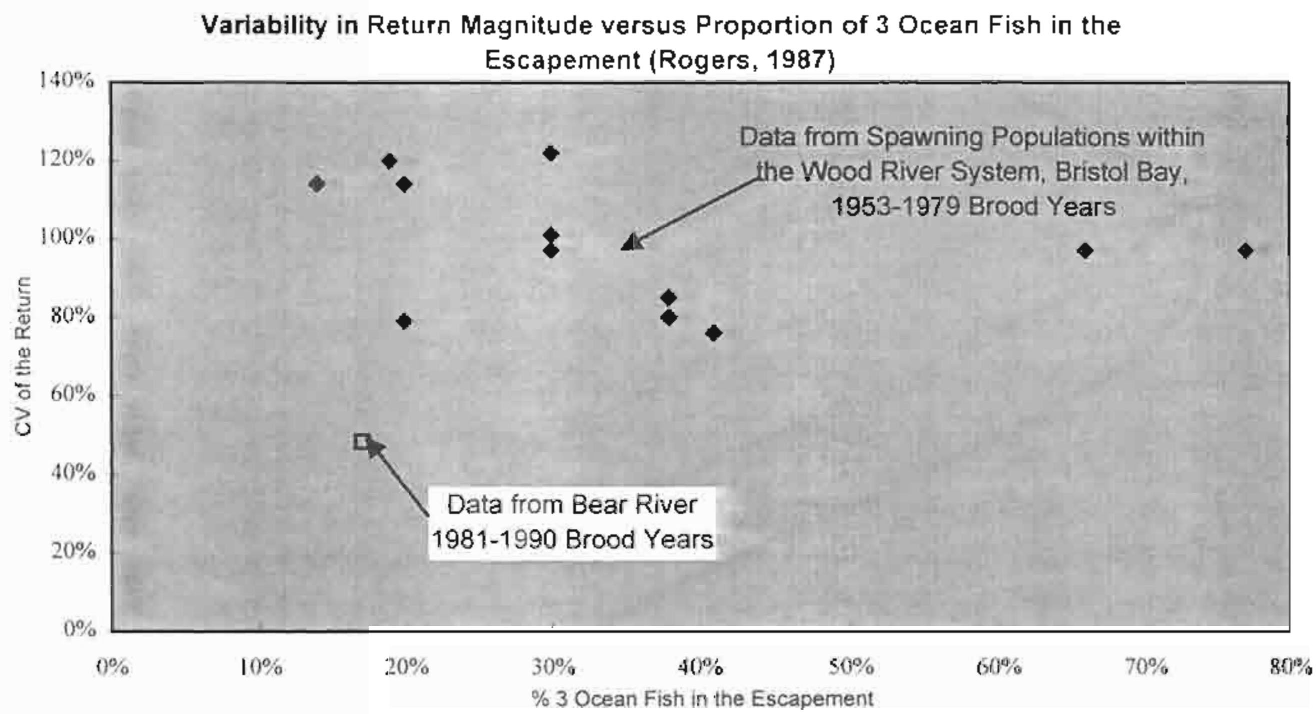
classes and accordingly, it does vary positively with length; however there was no single relationship that was applicable to all age classes. Therefore, female sockeye salmon fecundity was calculated for a specific age and mean length.

| Source | df | SS | MS | F | p-value |
|---|---|---|---|---|---|
| **Full model** | | | | | |
| Regression | 7 | $3.289 \times 10^7$ | 4698966.52 | 25.58 | 0.000 |
| Residual | 114 | $2.093 \times 10^7$ | 183675.51 | | |
| **Reduced Model** | | | | | |
| Regression | 1 | $2.30106 \times 10^7$ | $2.30106 \times 10^7$ | 89.59 | 0.000 |
| Residual | 120 | $3.08212 \times 10^7$ | 2.56842.918 | | |
| **Full \| Reduced** | | | | | |
| Regression | 6 | $0.9879 \times 10^7$ | $1.65 \times 10^6$ | | |
| Residual | 114 | $2.03939 \times 10^7$ | 183675.51 | 8.98 | 0.000 |




Appendix C.1. Various gillnet mesh size selectivity curves for sockeye salmon from the Skeena River, British Columbia, adapted from Holt (1963).




Appendix C.2. Graphics showing the variability in escapements and returns of sockeye salmon versus the proportion of 3-ocean age fish within the escapement from both Bristol Bay (1953-1979) and Bear River (1981-1990) stocks.