Fishery Data Series No. 91-8

Fecundity of Chinook Salmon, Tanana River, Alaska

by

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[1] This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-5, Study C, Job No. 8-1.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Fecundity was estimated for 49 chinook salmon *Oncorhynchus tshawytscha* collected from the Tanana River in 1989. Regression analysis was used to estimate the relationship between length (measured from mid-eye to fork of tail) and fecundity. Predicted fecundities ranged from 7,400 eggs (length = 770 millimeters) to 13,400 eggs (length = 1,070 millimeters). Mean fecundities for chinook salmon that spent three, four, or five years in the ocean were 8,500, 9,100, and 11,900 respectively. There was a significant trend of increased fecundity with age. However, mean fecundities for chinook salmon that spent three or four years in the ocean were not significantly different.

KEY WORDS: chinook salmon, *Oncorhynchus tshawytscha*, Tanana River, fecundity at length, fecundity at age.

INTRODUCTION

Chinook salmon *Oncorhynchus tshawytscha* migrating through the Yukon River and returning to tributary systems to spawn support important commercial, personal use, sport, and subsistence fisheries in Alaska and in Canada. The commercial and subsistence harvests of chinook salmon in the Yukon River drainage are among the largest in Alaska. In addition, sport fisheries for chinook salmon occur in many tributaries to the Yukon River, including the Chena, Salcha, Anvik, Kaltag, Nulato, and Andreafsky rivers and tributaries to the Koyukuk River. Management of these fisheries is complex. More than 100 populations of spawning chinook salmon have been documented throughout the drainage (Geiger and Andersen 1982) and chinook salmon are harvested in one manner or another throughout most of the drainage. These fisheries are managed to allow harvest yet prevent over-harvest. Managers determine harvest levels based on estimates of potential productivity of prior year escapements. Abundance of spawners in tributary systems has varied several fold in different years. Male to female ratios of spawning populations has varied from 1:1 to 10:1 in different spawning populations. Thus both abundance and composition of spawners are important considerations when estimating sustainable yields.

The fecundity of individuals that contribute to a spawning population is also important because it is related to the potential reproductive capacity of that population. Prior researchers have found that the number of eggs produced by individual chinook salmon is related mainly to size (length). For *Oncorhynchus* the relationship between length and fecundity is considered linear (Rounsefell 1957). Large chinook salmon generally produce more eggs than small chinook salmon. Therefore, in addition to numbers and sex composition of spawning stocks, the reproductive capacity of populations is also effected by their size composition. Two populations with equal numbers of spawners and the same sex composition could have very different reproductive capacities if their size compositions are substantially different.

To effectively estimate the reproductive capacity of spawning populations of chinook salmon, knowledge of abundance, sex composition, size composition, and the relationship between size and fecundity is required. Abundance and age-sex-size composition have been estimated for several populations of chinook salmon that spawn in the Yukon River drainage (summarized by Barton 1984). Prior attempts to estimate the relationship between length and fecundity for populations of chinook salmon in the Yukon River drainage resulted in differing conclusions. Weidner (1972) found a relationship between length and fecundity from a small sample (n = 12) of chinook captured at three locations in the Yukon River drainage near the villages of Nenana, Rampart, and Tanana (Figure 1). Bigler (1982) found no relationship between length and fecundity for chinook salmon captured at the mouth of the Yukon River (n = 89).

Because size of chinook salmon generally increases with age, attempts have also been made to estimate the relationship between age and fecundity. Results were mixed. For one data set the relationship was negative; mean fecundity decreased as age increased (Geiger 1965). For another data set the relationship was weakly positive (Bigler 1982). Review of data on the

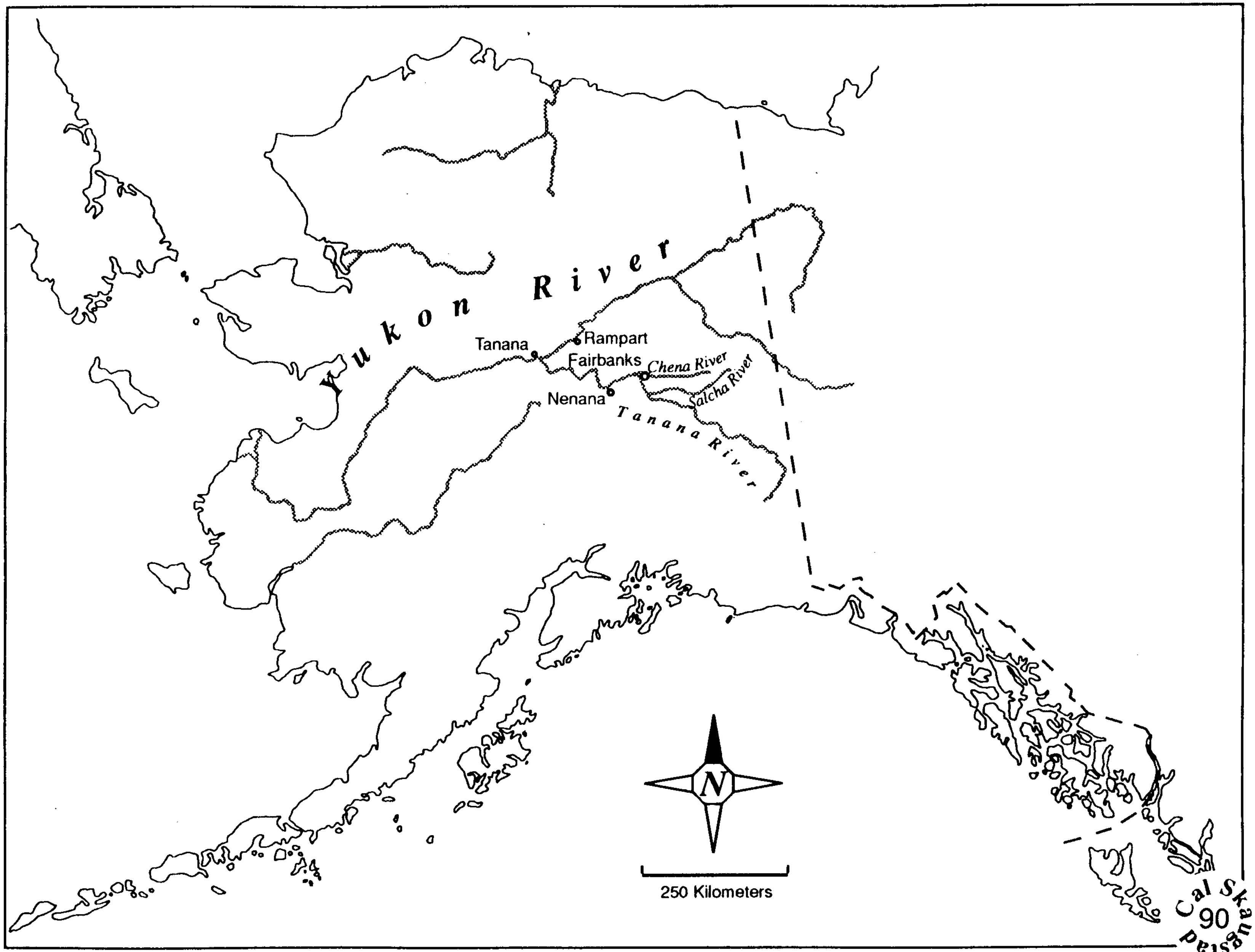

Figure 1. Location of Yukon, Tanana, Chena, and Salcha Rivers.

fecundity of chinook salmon in the Yukon River drainage by Barton (1981[1] and 1983[2]) led to the conclusion that Yukon River chinook salmon did not demonstrate measurable differences in fecundity for different ages. Yet, chinook salmon captured in the Nushagak District of Bristol Bay (Nelson and Biwer 1969), and in locations outside Alaska (Healey and Heard 1984) generally show a positive relationship between age and fecundity.

Data on chinook salmon fecundity (reviewed by Rounsefell 1957 and Healey and Heard 1984) show significant differences in fecundity for populations throughout their range. Bigler probably found no relationship between length and fecundity and a weak relationship between age and fecundity because chinook salmon captured at the mouth of the Yukon River were from populations that were returning to natal streams located in widely diverse portions of the Yukon River drainage.

The objective of this study was to estimate the relationships between length and fecundity and the relationship between age and fecundity for chinook salmon that spawn in the Tanana River drainage. These relationships can be used to estimate the reproductive capacity of populations of chinook salmon that spawn in portions of the Tanana River drainage. This information is of use in the estimation of sustainable yields.

METHODS

Fecundity in this study is defined as the number of eggs carried by a female. The reproductive capacity of a population is the sum of the number of eggs carried by each fish that reaches the spawning grounds. This study does not address the number of eggs that are actually spawned or that actually hatch.

To better estimate the relationship between length and fecundity, sampling was stratified by length categories and sample sizes were increased toward the upper and lower categories (Table 1). Sample sizes for the upper length categories were larger than the lower length categories because a review of prior studies indicated that there is often greater variation in the relationship between length and fecundity for larger fish.

Chinook salmon were captured from the Tanana River near Nenana using a fish wheel which was operated during periods when commercial fishing was allowed. Forty-nine chinook salmon were captured from 15 to 25 July, 1989 (Table 1). The fish were measured to the nearest millimeter from mid-eye to fork of tail (MF). Three scales were removed from each fish midway between the dorsal fin and lateral line directly below the posterior margin of the dorsal fin. Scales were placed on gum cards. Impressions of the scales were made on 0.5 mm acetate using a Carver press at 138,900 KPa (20,000 psi) heated to 90° C for 30 seconds. The scale impressions were sent to the Division of

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[1] Barton, L. H. Unpublished Memorandum dated April 10, 1981. ADFG, Commercial Fisheries Division, 1300 College Rd., Fairbanks, Ak 99701.

[2] Barton, L. H. Unpublished Memorandum dated February 28, 1983. ADFG, Commercial Fisheries Division, 1300 College Rd., Fairbanks, Ak 99701.

Table 1. Planned and actual sample sizes for this study.

Strata	Length Category (mm)	Sample Size: Planned	Actual
1	750 - 799	8	8
2	800 - 849	8	10
3	850 - 899	4	4
4	900 - 949	4	8
5	950 - 999	12	12
6	1,000+	12	7
Total		48	49

Commercial Fisheries, Anchorage where the annuli were counted to determine the age of the fish (Appendix A1).

Ovaries were removed from each fish, placed in plastic bags, and put on ice for transport to Fairbanks where they were stored in a freezer. About three months later, the ovaries were thawed and weighed. Five sub-samples of approximately 100 eggs each were taken from one ovary from each fish. The sub-samples were placed in individual tared jars, weighed, and covered with Gilson's fluid (Nielsen and Johnson 1983) for two to five days. The jars were turned periodically to allow the fluid to reach all eggs in the sub-sample. The sub-samples were then removed and rinsed with water. The hardened eggs in each sub-sample were separated from the ovary membrane and counted. Fecundity was estimated as follows:

$$\hat{f}_{ij} = \frac{(G_j)(Egg_{ij})}{g_{ij}}; \qquad (1)$$

where:

$\hat{f}_{ij}$ = estimated fecundity of fish j based on sub-sample i;

G_j = weight (g) of ovaries from fish j;

Egg_{ij} = number of eggs in sub-sample i from fish j; and,

g_{ig} = weight (g) of sub-sample i from fish j.

Examination of a scatter plot of length versus fecundity indicated there was a positive linear relationship and did not show increasing variance with increasing length (Figure 2). The bootstrap technique (Efron 1982) and linear regression analysis were then used to determine the statistical relationship between length and fecundity. To implement the bootstrap technique, a computer program was created that randomly selected one of the 49 fish (with replacement) and then randomly selected one of five ovary sub-samples (with replacement) until five sub-samples were selected (Appendix A2). A bootstrap sample consisted of selecting 49 fish and selecting five ovary sub-samples for each fish. For each bootstrap sample, simple linear least squares regression was used to estimate the y-intercept (a) and slope (b). Five hundred bootstrap samples were made. The overall estimates of the y-intercept and slope were calculated as follows:

$$\hat{\alpha} = \frac{\sum_{b=1}^{B} \hat{\alpha}_b}{B}; \qquad \hat{\beta} = \frac{\sum_{b=1}^{B} \hat{\beta}_b}{B} \qquad (2)$$

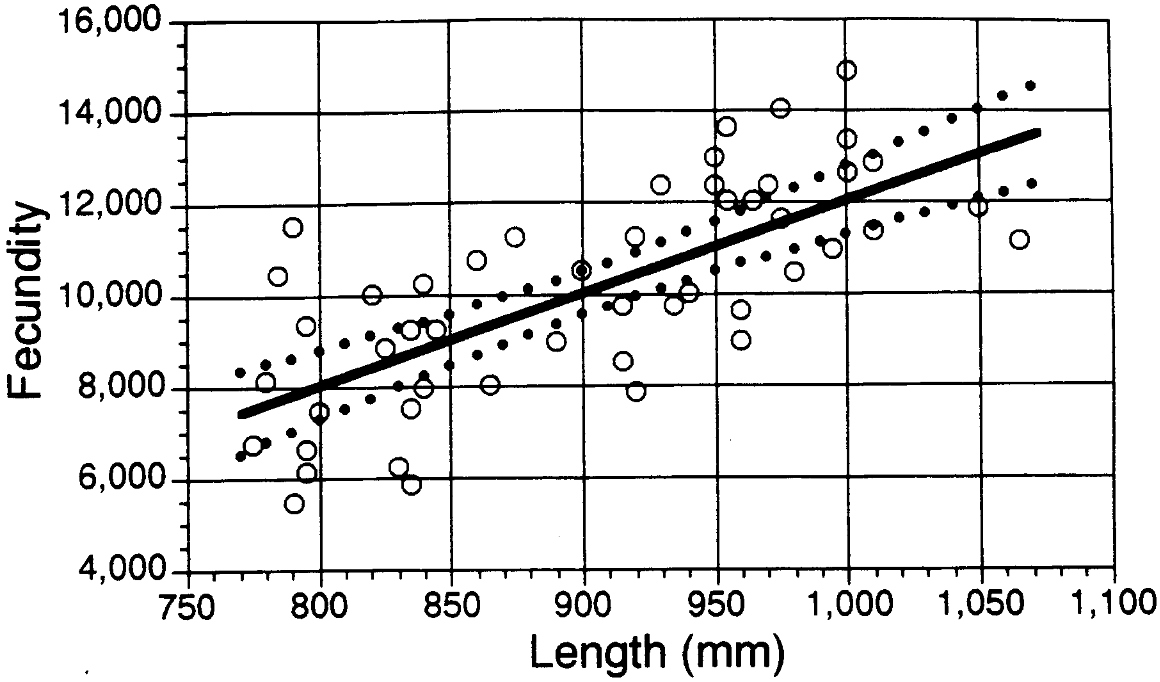

Figure 2. Length (mid-eye to fork of tail) versus fecundity of individual chinook salmon and the fitted regression line with 95 % confidence for means intervals developed from bootstrapping.

$$V(\hat{\bar{\alpha}}) = \frac{\sum_{b=1}^{B}(\hat{\alpha}_b - \hat{\bar{\alpha}})^2}{B-1} \quad ; \quad V(\hat{\bar{\beta}}) = \frac{\sum_{b=1}^{B}(\hat{\beta}_b - \hat{\bar{\beta}})^2}{B-1} \qquad (3)$$

where:

$\hat{\bar{\alpha}}, \hat{\bar{\beta}}$ = estimate of the mean (y-intercept or slope);

α_b, β_b = estimate of y-intercept or slope for the bth bootstrap sample; and,

B = number of bootstrap samples (500).

Predictions of fecundity for a given length were estimated as follows:

$$\hat{F}_j = \hat{\bar{\alpha}} + \hat{\bar{\beta}} L_j \qquad (4)$$

$$V[\hat{F}_j] = MSE \left\{ 1 + \frac{1}{n} + \frac{(L_j - \bar{L})^2}{\sum L_i^2 - (\sum L_i)^2/n} \right\} \qquad (5)$$

where:

$\hat{F}_j$ = fecundity of fish;

L_j = length of fish j;

$\bar{L}$ = mean length of 49 fish;

L_i = length of one of the 49 fish;

n = sample size; and,

MSE = mean square error from the bootstrapped regression.

Mean fecundity for each fish was estimated as follows:

$$\hat{\bar{F}}_j = \frac{\sum \hat{f}_{ij}}{m} \qquad (6)$$

$$V(\hat{\bar{F}}_j) = \frac{\sum(f_{ij} - \hat{\bar{F}}_j)^2}{m(m-1)} \qquad (7)$$

where:

$\hat{\bar{F}}_j$ = estimated mean fecundity of fish j based on sub-sample i;

$V(\hat{\bar{F}}_j)$ = estimated variance of mean fecundity of fish j; and,

m = sample size for ovaries from fish j.

Mean fecundity at age was estimated as follows:

$$\hat{\bar{F}}_a = \frac{\sum_{j=1}^{t} \hat{\bar{F}}_{ja}}{t} \qquad (8)$$

$$V(\hat{\bar{F}}_a) = \frac{\sum^{j} (\hat{\bar{F}}_{ja} - \hat{\bar{F}}_a)^2}{t(t-1)} \qquad (9)$$

where:

$\hat{\bar{F}}_a$ = mean fecundity at age a;

$\hat{\bar{F}}_{ja}$ = mean fecundity of fish j at age a;

$V(\hat{\bar{F}}_a)$ = variance of mean fecundity at age a;

t = sample size at age a; and,

a = number of years spent in the ocean.

A linear contrast was used to test for a positive linear trend (general linear model procedure using SAS[3] computer program). Analysis of variance was used to determine if mean fecundities for each age were equal. Age was based on the number of years a fish spent in the ocean. One fish that spent two years in fresh water was not used in the analysis of variance. All other fish spent one year in fresh water. A multiple comparison procedure (Tukey test, Zar 1984) was used to determine which mean fecundities were significantly different.

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[3] SAS Institute Inc. SAS Circle Box 8000, Cary, NC 27512-8000.

RESULTS

In this study, there was a significant positive linear relation between fecundity and length. For the regression of fecundity against length, the slope and y-intercept were 20 and -7,940, respectively. The coefficient of determination (R^2) was 0.49 and the slope was significantly different from 0 ($p < 0.001$, Table 2). Predicted fecundities for chinook salmon varied between 7,400 eggs (length = 770 mm MF) and 13,400 eggs (length = 1,070 mm MF; Table 3).

The range of fecundities at age 4 almost completely overlapped both ages 3 and 5 and mean fecundity generally increased with age (Figure 3). Results of the linear contrast showed the trend was significant ($p = 0.014$, Table 4). Analysis of variance indicated that the mean fecundity of at least one age was significantly different ($p = 0.001$, Table 5). Multiple comparison showed that the mean fecundity of fish that spent three or four years in the ocean were not significantly different; however, the mean fecundity of fish that spent five years in the ocean was significantly different from the mean fecundity of fish that spent three or four years in the ocean (Table 6).

DISCUSSION

The observed relationship between length and fecundity and age and fecundity of chinook salmon captured in the Tanana River near Nenana (1989) may be the result of the sample containing only chinook salmon from a limited geographical area. Except for the Chena and Salcha rivers there are no other major spawning sites in other clearwater tributaries to the Tanana River upstream of Nenana. This is in contrast to samples collected at the mouth of the Yukon River which probably included individuals from several diverse geographical areas.

There are two reasons why it is more appropriate to use the relationship between length and fecundity than the relationship between age and fecundity in estimating fecundity for chinook salmon. Although there were trends of increased fecundity with length and age, the difference between mean fecundities for ages 3 and 4 was not significant. The error associated with aging chinook salmon from scale samples may be the reason the difference between mean fecundities was not significant for ages 3 and 4. Sometimes the outer annulus of the scale has been absorbed by the time carcasses are collected on the spawning grounds. This is especially true for older fish (Clark 1987). The result is that older fish are more likely to be under aged which would inflate the estimate of the mean fecundity for younger age categories. Age 4 and 5 chinook salmon may have been categorized as age 3 if outer annuli were missing. Also, the effort required to obtain length data is less than that required for age data.

It may not be appropriate to use the relationship between length and fecundity of chinook salmon captured in the Tanana River to estimate the fecundity of chinook salmon captured outside the Tanana River drainage. Because significant differences in fecundity were found between chinook salmon that return to different rivers (Healey and Heard 1984), the relationship between

Table 2. Regression analysis for the relationship between fecundity and length (mid-eye to fork of tail) of chinook salmon sampled from the Tanana River near Nenana, 1989.

Regression Statistics:

	Estimates	Standard Errors
a (intercept)	-7,940	
b (slope)	20	0.25
regression		1,630

Coefficient of Determination: 0.49

Analysis of Variance:

	df	SS	MS	F	P
Regression	1	1.26E8	1.26E8	48.7	< 0.001
Error	46	1.25E8	2.66E6		
Total	47	2.51E8			

Table 3. Estimated fecundities for chinook salmon, Tanana River, 1989.

Fork Length (mm)	Mean Fecundity	SE
770	7,400	1,691
780	7,600	1,685
790	7,800	1,679
800	8,000	1,674
810	8,200	1,669
820	8,400	1,665
830	8,600	1,661
840	8,800	1,657
850	9,000	1,654
860	9,200	1,652
870	9,400	1,650
890	9,600	1,649
890	9,800	1,648
900	10,000	1,648
910	10,200	1,648
920	10,400	1,648
930	10,600	1,650
940	10,800	1,651
950	11,000	1,653
960	11,200	1,656
970	11,400	1,659
980	11,600	1,663
990	11,800	1,667
1,000	12,000	1,672
1,010	12,200	1,677
1,020	12,400	1,683
1,030	12,600	1,689
1,040	12,800	1,695
1,050	13,000	1,702
1,060	13,200	1,710
1,070	13,400	1,718

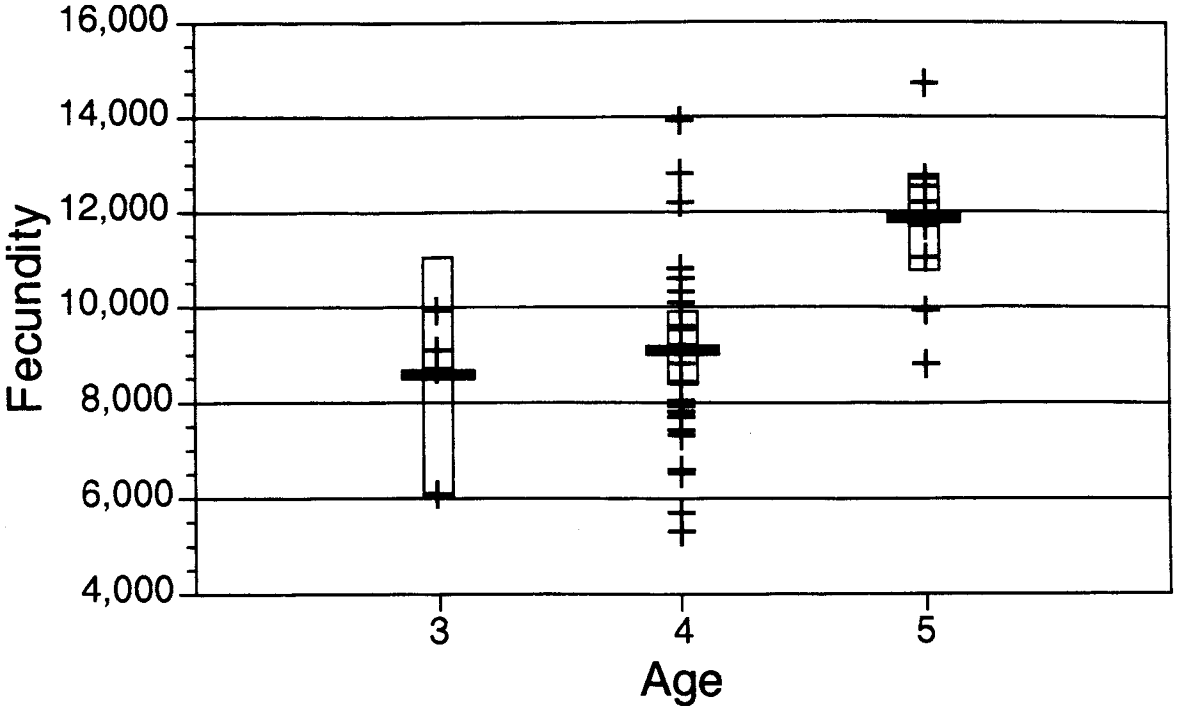

Figure 3. Number of years spent in ocean versus fecundity of individual chinook salmon. Means and 95% confidence intervals are represented by horizontal bars and vertical rectangles; individual data points are represented by crosses.

Table 4. Fecundity by age for chinook salmon sampled from the Tanana River near Nenana, 1989.

Age[a]	Sample Size	Mean	SE	95 Percent Confidence Intervals	
				Lower	Upper
3	4	8,500	822	6,900	10,200
4	25	9,100	424	8,500	9,800
5	11	11,900	460	10,900	12,900

[a] Number of years spent in ocean.

Table 5. Analysis of variance of fecundity by age for chinook salmon sampled from the Tanana River near Nenana, 1989.

Source Of Variation	D.F.	Sum Of Squares	Mean Square	F	P
Between groups	2	65,192,331	32,596,166	8.66	0.001
Within groups	37	139,285,418	3,764,471		
Total (corrected)	39	204,477,750			

Table 6. Multiple range analysis of fecundity by age for chinook salmon sampled from the Tanana River near Nenana, 1989.

Comparison of Ocean Years	Difference Between Means	Results of Analysis
5 vs 3	3,323	Significant
5 vs 4	2,757	Significant
3 vs 4	566	Not Significant

Alpha	0.05
Confidence	0.95
D.F.	37
MSE	3,848,616

length and fecundity and age and fecundity should be investigated for chinook salmon that return to other major tributaries of the Yukon River to determine if regional differences exist.

ACKNOWLEDGEMENTS

Tim Balch, Bill Busher, and Suzie Lozo operated the fish wheel and collected the ovary samples. Staff from the Alaska Department of Fish and Game, Division of Commercial Fisheries in Anchorage determined the age of the fish. This study and report were made possible by partial funding provided by the U.S. Fish and Wildlife Service through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-5, Job Number C-8-1.

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APPENDIX A

Appendix A1. Length, age, and estimated number of eggs.

Fish	Length (mm)	Age[a]	Estimated Number Of Eggs	
			Mean	SE
1	835	4	7,500	91
2	845	4	9,200	110
3	790	3[b]	11,500	280
4	915	4	8,500	160
5	975	NA[c]	11,600	300
6	920	NA	11,200	190
7	935	4	9,700	540
8	860	4	10,700	520
9	940	5	10,000	380
10	865	4	8,000	70
11	970	5	12,300	460
12	930	5	12,300	410
13	1,010	5	12,800	510
14	900	NA	10,500	230
15	980	4	10,400	220
16	915	4	9,700	260
17	920	4	7,800	180
18	840	4	7,900	160
19	890	4	8,900	140
20	875	NA	11,200	360
21	785	4	10,400	650
22	975	4	14,000	1,010
23	795	4	6,600	80
24	830	3	6,200	240
25	1,010	NA	11,300	360
26	800	4	7,400	160
27	965	5	12,000	750
28	950	4	12,900	170
29	820	3	10,000	140
30	825	3	8,800	250
31	835	3	9,200	440
32	960	4	9,600	330
33	960	5	8,900	260
34	995	4	10,900	350
35	955	NA	13,600	220
36	840	4	10,200	180
37	835	4	5,800	190
38	795	4	9,300	240
39	1,000	5	12,600	430
40	1,065	5	11,100	90
41	955	5	12,000	250
42	775	4	6,700	96
43	780	4	8,100	320
44	950	4	12,300	350
45	1,000	5	14,800	350
46	790	4	5,400	95
47	795	NA	6,100	87
48	1,050	5	11,800	240
49	1,000	NA	13,300	320

[a] Number of years spent in the ocean.

[b] This individual spent 2 years in freshwater. All other chinook salmon spent 1 year in freshwater.

[c] Not ageable.

Appendix A2. Computer program written in BASIC for regression analysis using the bootstrap procedure[a].

```
REM------------------CHINOOK SALMON FECUNDITY
REM------------------BASIC PROGRAM - KINGEGG2
OPTION BASE 1
RANDOMIZE TIMER
N=49:        REM----Number of fish
NBOOT=500:   REM----Number of bootstrap samples
DIM EGGDATA%(49,6)
OPEN "A:EGGDATA.PRN" FOR INPUT AS #1
OPEN "A:BOOTOUT1.PRN" FOR OUTPUT AS #2
OPEN "A:BOOTPRED.PRN" FOR OUTPUT AS #3

REM------------------DATA INPUT
FOR FISH=1 TO N
INPUT #1, EGGDATA%(FISH,1), EGGDATA%(FISH,2), EGGDATA%(FISH,3),
          EGGDATA%(FISH,4), EGGDATA%(FISH,5), EGGDATA%(FISH,6)
NEXT FISH
CLOSE #1

REM------------------DRAW A BOOTSTRAP SAMPLE
FOR BOOT=1 TO NBOOT
SUMXY=0
SUMX=0
SUMYAVG=0
SUMYAVG2=0
SUMX2=0

REM------------PICK A FISH
FOR B1=1 TO N
FISH% = INT(RND*N)+1

REM--------PICK EGG SAMPLE
SUMY=0
FOR B2 = 1 TO 5
EGG% = INT(RND*5)+2
SUMY = SUMY + EGGDATA%(FISH%,EGG%)
NEXT B2
SUMX = SUMX + EGGDATA%(FISH%,1)
SUMX2 = SUMX2 + EGGDATA%(FISH%,1)^2
SUMYAVG = SUMYAVG + SUMY / 5:      REM--------AVERAGE FECUNDITY
SUMYAVG2 = SUMYAVG2 + (SUMY / 5)^2
SUMXY = SUMXY + EGGDATA%(FISH%,1) * SUMY / 5
NEXT B1
```

-Continued-

Appendix A2. (page 2 of 3).

```
REM-----------------LINEAR REGRESSION
REM B = slope
REM A = y-intercept
REM TSS = Total Sum of Squares
REM REGSS = Regression Sum of Squares
REM REGMS = Regression Mean Square
REM RESIDSS = Residual Sum of Squares
REM RESIDMS = Residual Mean Squares

B = (SUMXY - SUMX * SUMYAVG / N) / (SUMX2 - SUMX^2 / N)
A = SUMYAVG / N - B * SUMX / N
TSS = SUMYAVG2 - SUMYAVG^2 / N
REGSS = (SUMXY - SUMX * SUMYAVG / N)^2 / (SUMX2 - SUMX^2 / N)
REGMS = REGSS / (2 - 1)
RESIDSS = TSS - REGSS
RESIDMS = RESIDSS / (N - 2)
R2 = REGSS / TSS
F = REGMS / RESIDMS

REM------------SUMMATION
SUMA = SUMA + A
SUMB = SUMB + B
SUMTSS = SUMTSS + TSS
SUMREGSS = SUMREGSS + REGSS
SUMREGMS = SUMREGMS + REGMS
SUMRESIDSS = SUMRESIDSS + RESIDSS
SUMRESIDMS = SUMRESIDMS + RESIDMS
SUMR2 = SUMR2 + R2
SUMF = SUMF + F
PRINT "BOOT =";BOOT
PRINT "A =";A, "B =";B,
PRINT "TSS =";TSS, "REGSS =";REGSS, "RESIDSS =";RESIDSS
PRINT "REGMS =";REGMS, "RESIDMS =";RESIDMS
PRINT "R2 =";R2, "F =";F
PRINT
PRINT #2, BOOT;A;B;TSS;REGSS;RESIDSS;REGMS;RESIDMS;R2;F

REM-----------------PREDICTION OF Y
FOR L = 600 TO 1150 STEP 10
YPRED = A + L * B
PRINT #3, YPRED;
NEXT L:PRINT #3, CHR$(13)
NEXT BOOT
```

-Continued-

```
REM------------------BOOTSTRAP AVERAGES
A = SUMA / NBOOT
B = SUMB / NBOOT
TSS = SUMTSS / NBOOT
REGSS = SUMREGSS / NBOOT
REGMS = SUMREGMS / NBOOT
RESIDSS = SUMRESIDSS / NBOOT
RESIDMS = SUMRESIDMS / NBOOT
R2 = SUMR2 / NBOOT
F = SUMF / NBOOT

REM------------------PRINT TO SCREEN
PRINT "BOOTSTRAP MEANS"
PRINT "A =";A, "B =";B,
PRINT "TSS =";TSS, "REGSS =";REGSS, "RESIDSS =";RESIDSS
PRINT "REGMS =";REGMS, "RESIDMS =";RESIDMS
PRINT "R2 =";R2, "F =";F
PRINT:PRINT:PRINT

REM------------------PRINT TO PRINTER
LPRINT "BOOTSTRAP MEANS"
LPRINT "A =";A, "B =";B,
LPRINT "TSS =";TSS, "REGSS =";REGSS, "RESIDSS =";RESIDSS
LPRINT "REGMS =";REGMS, "RESIDMS =";RESIDMS
LPRINT "R2 =";R2, "F =";F
LPRINT:LPRINT:LPRINT

CLOSE #2: CLOSE #3
END
```

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