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ABUNDANCE, EGG PRODUCTION, AND AGE-SEX-SIZE COMPOSITION OF THE CHINOOK SALMON ESCAPEMENT IN THE SALCHA RIVER, 1989[1]

By

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TABLE OF CONTENTS

	Page
LIST OF TABLES	iii
LIST OF FIGURES	iv
list of appendices	v
ABSTRACT	1
INTRODUCTION	2
MATERIALS AND METHODS	4
Capture and Marking	4
Recovery	4
Abundance Estimator	6
Tag Loss	6
Age, Sex, and Size Composition	6
Egg Production From Escapement	7
Effects of Electrofishing	8
Aerial Survey	10
RESULTS	10
Tests of Assumptions for a Petersen Estimator	10
Gear Bias	10
Closed Population	10
Abundance Estimate	17
Tag Loss	17
Age, Sex, and Size Composition	17
Population Egg Production	17
Effects of Electrofishing	23
Aerial Survey	23
DISCUSSION	23

TABLE OF CONTENTS (Continued)

ACKNOWLEDGEMENTS... 26

LITERATURE CITED... 26

APPENDIX A... 28

LIST OF TABLES

Table		Page
1.	Description of equipment, control settings, and limnological measurements made while electrofishing....	5
2.	Mean fecundities by age for chinook salmon from the Tanana River, 1989......................................	9
3.	Number of male and female chinook salmon that were recovered during carcass sampling......................	11
4.	Number of chinook salmon that were captured during electrofishing (marking event) and carcass survey (recovery event) by length category...................	12
5.	Number of marked chinook salmon carcasses that were recovered by river section...........................	13
6.	Number of chinook salmon that were marked during the first and second marking events and recaptured during carcass sampling....................................	14
7.	Number of marked and unmarked chinook salmon collected during carcass sampling by river section...............	15
8.	Capture and recapture history of marked chinook salmon by river section....................................	16
9.	Estimates of the proportions and abundance of female and male chinook salmon by age class......................	18
10.	Estimated length-at-age of chinook salmon	20
11.	Estimated egg production of Salcha River chinook salmon by length, 1989......................................	21
12.	Estimated egg production of Salcha River chinook salmon, 1989...	22
13.	Abundance of live and dead chinook salmon counted during aerial surveys of the Salcha River, 1989........	24

LIST OF FIGURES

Figure		Page
1.	Salcha River study area................................	3
2.	Distributions of the lengths of chinook salmon captured during (A) both marking events, (B) the carcass survey, and (C) marked chinook salmon recovered during the carcass survey....................	19

LIST OF APPENDICES

Appendix | Page

A1. Statistical tests for analyzing data from a mark-recapture experiment for gear bias and evaluating the assumptions of a two-event mark-recapture experiment... 29

ABSTRACT

In 1989, the number of adult chinook salmon *Oncorhynchus tschawytscha* that returned to spawn in the Salcha River near Fairbanks, Alaska, was estimated using a mark-recapture experiment. A river boat equipped with electrofishing gear was used to capture 218 chinook salmon in early August. Captured chinook salmon were marked with jaw tags, finclipped, and released. In mid August, 330 chinook salmon carcasses were collected. Twenty-one of these carcasses had been marked. The estimate of abundance was 3,294 (standard error = 630). The ratio of females to males was about 1.1 to 1. During aerial surveys, the highest count of chinook salmon was 2,333; about 71 percent of the mark-recapture point estimate. The estimate of egg production for the 1989 escapement was 16.63 million eggs (standard error = 1.85 million).

KEY WORDS: chinook salmon, *Oncorhynchus tschawytscha*, Salcha River age-sex-size composition, aerial survey, fecundity, egg production, tag loss.

INTRODUCTION

The complex nature of the exploitation of stocks of Yukon River chinook salmon *Oncorhynchus tschawytscha* requires that accurate estimates of escapement be made in a number of major spawning streams. During a 1,540 km migration from the ocean to their spawning grounds in the Salcha River, chinook salmon must pass through five different fishing sub-districts in the Yukon and Tanana rivers. Commercial, subsistence, and personal use fishing occur in each sub-district. There is also a popular sport fishery at the mouth of the Salcha River. Chinook salmon returning to the Salcha River contribute to all these fisheries.

To perpetuate the stocks of chinook salmon, fishery managers set harvest levels for the various fisheries in each sub-district such that a desired number of chinook salmon are allowed to reach their spawning grounds. Harvest levels for the current year are based on estimates of the number of chinook salmon that enter the Yukon River along with results from prior years of the number of chinook salmon that were harvested and the number of chinook salmon that reached their spawning grounds.

One method that a fishery manager has of evaluating the effect of the harvest level on the stocks of chinook salmon is to estimate the number of chinook salmon that successfully reach their spawning grounds. When the number of chinook salmon is less than a desired level then the harvest level was probably too high. This information can be used in the future to better estimate the harvest level that will allow a desired number of chinook salmon to reach spawning habitat.

The Salcha River is a 250 km long clear runoff river flowing into the Tanana River about 60 km east of Fairbanks (Figure 1). From 1972 to 1988, the number of mature chinook salmon counted in the Salcha River during aerial surveys has ranged from 391 to 6,757 (Barton 1984, Skaugstad 1988, 1989). These counts indicate it is one of the most important chinook salmon producing streams in the entire Yukon River drainage. Only a portion of the entire spawning population is usually present during a single aerial survey and the number of chinook salmon counted is also affected by weather, water level, water clarity, and overhanging vegetation. Skaugstad (1988 and 1989) found that the number of large (presumably mature) chinook salmon counted during an aerial survey of the Salcha River in 1987 and 1988 was about 40% and 61%, respectively, of the estimated abundance from mark-recapture experiments. Barton (1987a, 1987b) found that the number of mature chinook salmon counted during an aerial survey was less than 20% of the estimated abundance based on mark-recapture experiments in the Chena River (near Fairbanks) and fish counts through a weir in Clear Creek (near Nenana).

The goal of this project was to determine what portion of the chinook salmon spawning in the Salcha River is typically observed during an aerial survey. The specific objectives in 1989 were to estimate:

1. The abundance of spawning chinook salmon in the Salcha River;

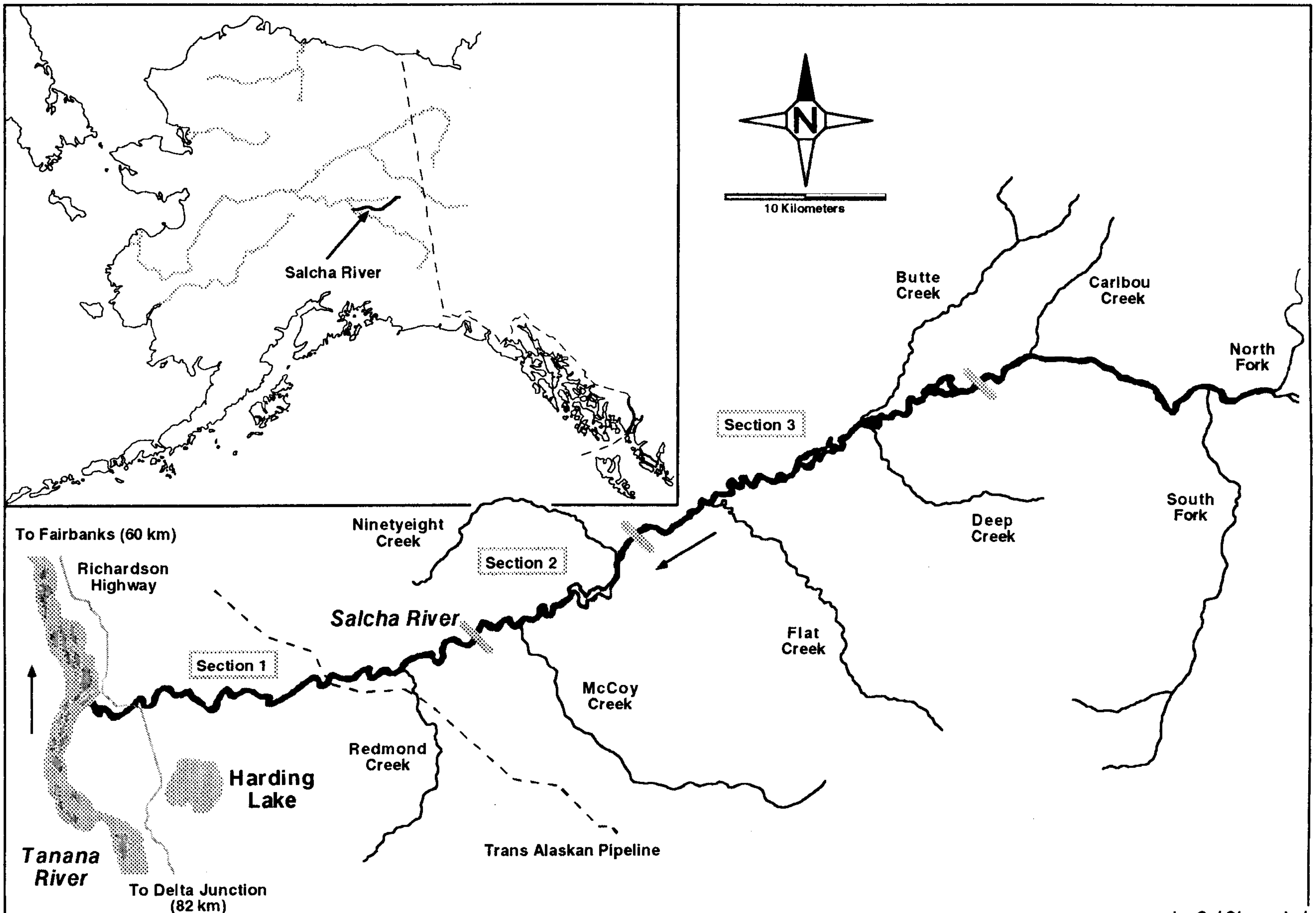

Figure 1. Salcha River study area.

2. the proportion of the population of chinook salmon that was counted in the Salcha River during an aerial survey; and,

3. the age, sex, and size composition, and total fecundity of the escapement of chinook salmon in the Salcha River.

MATERIALS AND METHODS

Capture and Marking

Adult chinook salmon were captured from 2 August through 8 August using a riverboat equipped with electrofishing gear (Clark 1985, Table 1). The chinook salmon were stunned using pulsating direct current electricity, dipped from the river with long handled nets and placed in an aerated holding box. Since past aerial surveys of the Salcha River have shown that few chinook salmon spawn above Caribou Creek (Fred Andersen pers. comm[1]), only the lower 97 km of the Salcha River, between the confluences of the Salcha River with Caribou Creek and the Tanana River, were sampled (Figure 1). The sample area was divided into three sections. The length of each section was based on the estimated number of chinook salmon present (from aerial surveys), and the number of chinook salmon that could be captured and tagged in one day. During the first marking event, one pass was made through sections 1, 2, and 3 on 2, 3, and 4 August, respectively. Each pass through a section started at the upstream end of the section. During the second marking event, one pass was again made in all three sections. Sections 1 and 2 were sampled on 7 August and Section 3 was sampled on 8 August.

All captured chinook salmon were tagged, finclipped, measured, and released. A uniquely numbered metal tag was attached to the lower jaw of each fish. A combination of adipose, pectoral, and pelvic fin clips was used to identify the location and period of capture. Length was measured from mid-eye to fork-of-tail (ME-FK) to the nearest 5 mm. Sex was determined from observation of body morphology.

Recovery

Tags were recovered from chinook salmon carcasses from the same three river sections in which electrofishing was performed. Carcasses were collected starting with section 1 and ending with section 3 on 11, 12, and 13 August, respectively.

One pass was made through each section in a drifting riverboat starting at the upstream end of each section. Carcasses were collected with long handled spears. The carcasses were measured and examined for jaw tags and fin clips. Sex was determined from observation of body morphology. Three scales were removed from each carcass for age analysis.

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[1] Andersen, Fred. 1987. Personal Communication. Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701.

Table 1. Description of equipment, control settings, and limnological measurements made while electrofishing.

Generator characteristics:	4,000 KW, 60 Hz, 120 V
VVP:	Coffelt (no model number) Manufactured around 1967.
Pulse duration:	2.5 milliseconds (ms).
Duty cycle:	50%
Frequency:	40 pulses per second (pps).
Voltage:	100 - 250 volts (peak).
Amperage:	2 - 4 amperes.
Cathode:	The boat served as the cathode.
Anode:	16 mm (5/8 in) diameter flexible electrical conduit.
Water conductivity:	90 - 120 microsiemens/cm^3.

Abundance Estimator

Data collected from the mark-recapture experiment were investigated with a series of statistical tests (described in Appendix A1) to determine the appropriate unbiased estimator. The abundance of adult chinook salmon was calculated using a Petersen estimator.

The unbiased Petersen estimator (described by Chapman 1951, cited in Seber 1982):

$$\hat{N}^* = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1 \qquad (1)$$

$$V(\hat{N}^*) = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \qquad (2)$$

where:

$\hat{N}^*$ = the estimated abundance of chinook salmon;

n_1 = the number of chinook that were marked;

n_2 = the number of chinook salmon carcasses; and,

m_2 = the number of chinook salmon carcasses with marks.

Tag Loss

The proportion of tags lost during the study was estimated using:

$$\hat{p}_t = n_u/n_r \qquad (3)$$

$$V(\hat{p}_t) = \hat{p}_t(1-\hat{p}_t)/(n_r-1) \qquad (4)$$

where:

$\hat{p}_t$ = the proportion of tags lost;

n_u = the number of recaptured fish without jaw tags; and,

n_r = the total number of marked fish recaptured.

Age, Sex, and Size Composition

The proportion of females and males by ocean age and associated variances were estimated using:

$$p_i = \hat{a}_i/n \qquad (5)$$

$$V(\hat{p}_i) = \hat{p}_i(1-\hat{p}_i)/(n-1) \qquad (6)$$

where:

$\hat{p}_i$ = the estimated proportion of females (or males) of ocean age i;

a_i = the number of females (or males) of ocean age i sampled;

n = the total number of females and males sampled; and,

i = the ocean age (1, 2, 3, 4, and 5).

The abundance of females (or males) of ocean age i in the population was estimated using:

$$\hat{N}_i = \sum\hat{p}_i(\hat{N}) \qquad (7)$$

The variance of the product N_i was estimated using Goodman's (1960) exact variance of products:

$$V(\hat{N}_i) = \sum[\hat{N}^2V(\hat{p}_i)+\hat{p}_i^2V(\hat{N})-V(\hat{p}_i)V(\hat{N})] \qquad (8)$$

<u>Egg Production From Escapement</u>

Predictions of fecundity for a given length were estimated as follows (McCracken and Skaugstad in press):

$$\hat{\bar{F}} = a + b(L) \qquad (9)$$

$$V(\hat{\bar{F}}) = MSE \left\{ \frac{1}{49} \; \frac{(L_j - \hat{\bar{L}})}{\sum L_j^2 - (\sum L_j)^2} \right\} \qquad (10)$$

where:

$\hat{\bar{F}}$ = estimate of the mean fecundity for length L;

MSE = mean square error;

L_j = length of fish j; and,

$\hat{\bar{L}}$ = mean length of the 49 fish that were collected.

For each age the mean fecundity for each fish was estimated as follows (McCracken and Skaugstad in press):

$$\hat{\bar{F}}_j = \frac{\sum \hat{f}_{ij}}{5} \qquad (11)$$

where:

$\hat{\bar{F}}_j$ = estimated mean fecundity of fish j based on sub-sample i (i = 1 to 5).

The total egg production of the spawning chinook salmon was estimated using:

$$\hat{E} = \sum \hat{N}_i \hat{F}_i; \qquad (12)$$

$$\hat{V}(\hat{E}) = \sum \hat{V}(\hat{N}_i \hat{F}_i); \text{ and} \qquad (13)$$

$$V(\hat{N}_i \hat{F}_i) = \hat{N}_i^2 V(\hat{F}_i) + \hat{F}_i^2 V(\hat{N}_i) - V(\hat{N}_i)V(\hat{F}_i) \qquad (14)$$

where:

$\hat{E}$ = the production of eggs from the spawning chinook salmon population;

$\hat{N}_i$ = the estimated number of females of ocean age i (or length i);

$\hat{F}_i$ = the mean fecundity for females of ocean age i (or length interval i) as determined by McCracken and Skaugstad (In press) for chinook salmon in the Tanana River drainage (Table 2);

$V(\hat{E})$ = the variance of the population egg production;

$V(\hat{F}_i)$ = the variance of the mean fecundity for females of ocean age i;

$V(\hat{N}_i)$ = the variance of the estimated number of females of ocean age i (or length interval i).

Effects of Electrofishing

Carcasses of females were examined for eggs and the presence or absence of a mark (jaw tag or fin clip). The presence of a mark indicated that a fish was shocked and captured. A fish with no mark may have not been shocked or may have been shocked but not captured. The volume of eggs in a carcass was subjectively categorized as empty to 1/4 full or greater than 1/4 full. A test for a significant difference in the volume of eggs between marked and unmarked carcasses was based on the chi-squared statistic. The null hypothesis was no difference in the volume of eggs between marked and unmarked carcasses.

Table 2. Mean fecundities by age for chinook salmon from the Tanana River, 1989[a].

Age[b]	Sample Size	Fecundity	
		Mean	SE
1.3	4	8,547	818
1.4	25	9,120	424
1.5	11	11,869	457

[a] Data taken from McCracken and Skaugstad (In press).
[b] European formula "x.y" where "x" is the number of freshwater age annuli and "y" is the number of ocean annuli. Total age equals x + y + 1.

Aerial Survey

Personnel from the Fairbanks office of the Division of Commercial Fisheries of the Alaska Department of Fish and Game counted the number of live and dead adult chinook salmon in the Salcha River on 12, 18, and 30 July. Counts were made from low flying, fixed-wing aircraft. Barton (1987c) described the methods used by the Division of Commercial Fisheries for these aerial surveys.

RESULTS

During 2 through 8 August, 218 chinook salmon were captured, tagged, fin clipped, and released. Five chinook salmon were killed during the capture event. From 11 August through 13 August, 330 carcasses were collected and examined for tags and fin clips. Of those carcasses examined, 21 were marked.

Tests of Assumptions for a Petersen Estimator

The following results were based on a series of statistical tests (described in Appendix A1) on data from the mark-recapture experiment.

Gear Bias:

Although the rate of recovery was greater for females (0.10) than for males (0.09), there was no significant gear bias by sex ($\chi^2 = 0.049$, df = 1, P = 0.83; Table 3). Therefore, sex was ignored and estimates of abundance were not stratified by sex.

Tests for gear bias by size (length) showed that differences in length distributions were not significant for (A) fish marked during electrofishing and later recaptured during the carcass survey ($\chi^2 = 3.08$, df = 2, P = 0.21; Table 4) or (B) all fish captured during electrofishing and all carcasses collected during the carcass survey ($\chi^2 = 1.54$, df = 2, P = 0.46; Table 4).

Closed Population:

The rate of recovery of marked chinook salmon was not significantly different between (A) river sections ($\chi^2 = 1.25$, df = 2, P = 0.54; Table 5) or (B) marking period ($\chi^2 = 0.42$, df = 1, P = 0.52; Table 6).

The number of marked and unmarked chinook salmon collected during the carcass survey were collected and marked in proportion to their abundance in each river section ($\chi^2 = 1.92$, df = 2, P = 0.38; Table 7).

The chi-square statistic could not be used to evaluate the level of mixing of marked chinook salmon that occurred between river sections. More than half of the expected values in the contingency table were less than five. In chi-square analyses of contingency tables, it is recommended that no expected value be less than one and no more than 20% of the expected values be less than five (Cochran 1954). However, casual examination indicates that there was little or no mixing of marked fish between river sections (Table 8).

Table 3. Number of male and female chinook salmon that were recovered during carcass sampling.

	Males	Females	Total
Recovered	8	13	21
Not recovered	84	123	197
Total released	92	126	218
Recovery rate	0.09	0.10	0.10

Table 4. Number of chinook salmon that were captured during electrofishing (marking event) and carcass survey (recovery event) by length category.

	0 - 700 mm	701 - 900 mm	901 +
Electrofishing	19	123	76
Carcass survey	26	191	93
Recaptured	1	16	4

Table 5. Number of marked chinook salmon carcasses that were recovered by river section.

	River Section			
	Lower	Middle	Upper	Total
Recovered	11	5	5	21
Not recovered	88	69	48	205
Total marked	99	74	53	226
Recovery rate	0.11	0.07	0.09	

Table 6. Number of chinook salmon that were marked during the first and second marking events and recaptured during carcass sampling[a].

	First	Second	Total
Recaptured	14	7	21
Not recaptured	117	80	197
Total released	131	87	218
Recovery rate	0.11	0.08	0.10

[a] The first marking event was 2, 3, and 4 August; the second marking event was 7 and 8 August.

Table 7. Number of marked and unmarked chinook salmon collected during carcass sampling by river section.

	River Section			
	Lower	Middle	Upper	Total
Marked	11	5	5	21
Unmarked	115	94	100	309
Total collected	126	99	105	330
Recovery rate	0.09	0.05	0.05	0.06

Table 8. Capture and recapture history of marked chinook salmon by river section[a].

River Section Where Marks Were Released	River Section Where Marks Were Recaptured: Lower	Middle	Upper	Total	Number Marked	Number Not Recaptured
Lower	11	0	0	11	94	83
Middle	0	4	0	4	73	69
Upper	0	1	5	6	51	45
Total	11	5	5	21	218	297
Unmarked Carcasses	115	94	100	309		
Total Carcasses	126	99	105	330		

[a] These data were used to estimate abundance of chinook salmon with Darroch's estimator.

Abundance Estimate

Abundance of adult chinook salmon was estimated to be 3,294 (SE = 630). Abundance of females was estimated to be 1,704 (SE = 484) and abundance of males was estimated at 1,590 (SE=427; Table 9).

Tag Loss

Of the 330 chinook salmon that were examined for marks during the carcass survey, 21 were marked with both a jaw tag and a fin clip. Therefore, the estimated proportion of jaw tags lost was zero.

Age, Sex, and Size Composition

Age data were obtained from chinook salmon during the carcass survey. These fish spent one to five years in the ocean and nearly all fish spent one year in freshwater (Table 9). The dominant age class for females was 1.4 (brood year 1983) and for males was 1.3 and 1.4 (brood years 1984 and 1983). About 87% of the females were age 1.4 or older and about 88% of the males were age 1.3 or 1.4 (Table 9).

Sex and length data were obtained from all chinook salmon during both marking events and during the carcass survey. Of 218 chinook salmon that were captured during the marking events, 126 were females and 92 were males, for a sex ratio of 1.36 to 1. During carcass sampling, 171 females and 139 males were collected, for a sex ratio of 1.23 to 1. Using the Petersen method of abundance estimation, the ratio of females to males was 1.13 to 1. Females comprised about 52% of the population and males comprised about 48% of the population. The similarity between these sex ratios show that females and males were collected in proportion to their abundances and there was little or no sex bias during electrofishing and the carcass survey. These results agree with those found during the tests for gear bias.

Lengths of females ranged from 760 mm to 1,020 mm while males ranged in length from 470 mm to 1,070 mm (Figure 2). While chinook salmon less than 700 mm were predominantly males, there was no consistent trend for females to be larger on average than males by age (Table 10).

Population Egg Production

The estimate of egg production based on length (ME-FT) was 16.6 million eggs (SE = 1.85 million; Table 11). The estimate of egg production based on ocean age was 16.1 million eggs (SE = 4.50 million; Table 12). Age 1.4 females accounted for about 71% of the population egg production.

Table 9. Estimates of the proportions and abundance of female and male chinook salmon by age class.

Age Class	Sample Size	Proportion	Standard Error	Abundance	Standard Error
Females:					
1.1					
1.2					
1.3	18	0.13	0.03	224	95
1.4	100	0.73	0.04	1,244	464
1.5	19	0.14	0.03	236	99
Sub-totals	137	1.00		1,704	484
Males:					
1.1	1	0.01	0.01	19	19
1.2	9	0.11	0.03	170	84
1.3	46	0.55	0.06	871	354
1.4	28	0.33	0.05	530	223
1.5	0				
Sub-totals	84	1.00		1,590	427
Sexes combined:					
1.1	1	0.01	0.01	19	19
1.2	9	0.04	0.01	170	84
1.3	64	0.29	0.03	1,095	319
1.4	128	0.57	0.03	1,774	407
1.5	19	0.09	0.02	236	99
Total	221	1.00		3,294	645

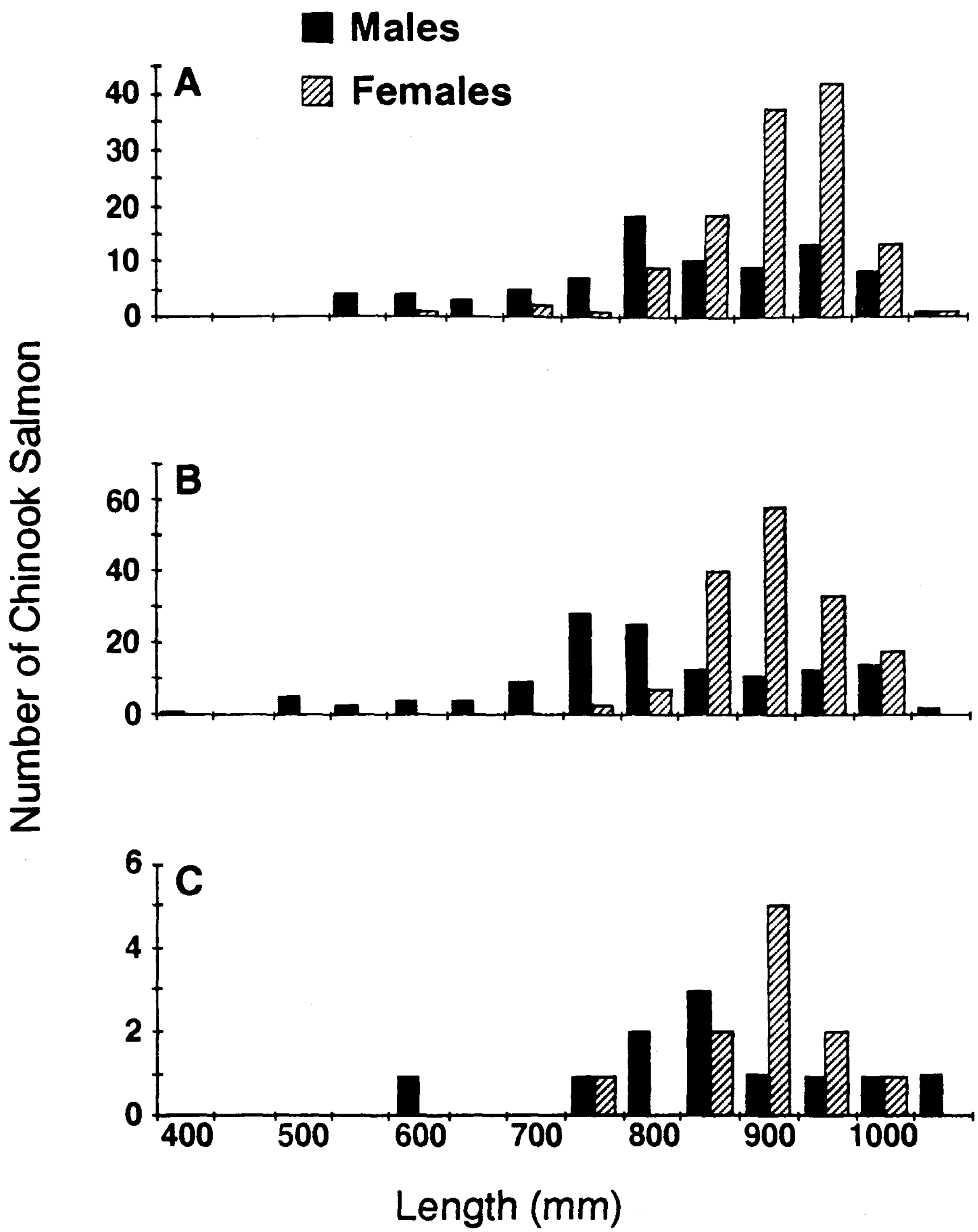

Figure 2. Distributions of the lengths of chinook salmon captured during: (A) both marking events, (B) the carcass survey, and (C) marked chinook salmon recovered during the carcass survey.

Table 10. Estimated length at age of chinook salmon.

Ocean Age	Sample Size	Length (mm) Mean	SE	Range
Females:				
1	0			
2	0			
3	18	850	8	760 - 890
4	100	880	5	750 - 1,010
5	19	960	8	880 - 1,020
Sub-total	137			
Males:				
1	1	370		
2	9	520	15	470 - 590
3	46	790	14	580 - 1,050
4	28	930	18	610 - 1,070
5	0			
Sub-total	84			
Females and males:				
1	1	370		
2	9	520	15	470 - 590
3	64	807	12	580 - 1,050
4	128	891	8	610 - 1,070
5	19	960	8	880 - 1,020
Total	221			

Table 11. Estimated egg production of Salcha River chinook salmon by length, 1989.

Length (mm)	Number of Fish	Fecundity (millions)	SE (millions)
740	10	0.07	0.07
750	20	0.14	0.11
760	10	0.07	0.07
770	0	0	
780	0	0	
790	20	0.16	0.12
800	40	0.32	0.19
810	50	0.41	0.23
820	50	0.42	0.23
830	90	0.77	0.37
840	110	0.97	0.44
850	100	0.90	0.42
860	130	1.20	0.53
870	100	0.94	0.44
880	149	1.44	0.63
890	159	1.57	0.68
900	100	1.00	0.47
910	60	0.61	0.32
920	90	0.94	0.45
930	100	1.06	0.50
940	50	0.54	0.30
950	60	0.66	0.35
960	10	0.11	0.11
970	70	0.80	0.40
980	60	0.70	0.37
990	10	0.12	0.12
1,000	30	0.36	0.23
1,010	20	0.24	0.18
1,020	10	0.12	0.12
	1,704	16.63	1.85[a]

[a] The standard error was calculated as the square root of the sum of the variances of the estimated fecundities for each length.

Table 12. Estimated egg production of Salcha River chinook salmon, 1989.

Age Class	Estimated Number of Females	Average Fecundity[a]	Estimated Number of Eggs (millions)	SE
1.3	224	8,500	1.91	0.83
1.4	1,244	9,100	11.34	4.26
1.5	236	11,900	2.80	1.18
Totals	1,704		16.06	4.50

[a] Average fecundities were rounded off to nearest hundred in the table.

Effects of Electrofishing

During the carcass survey only one female carcass was found that was more than 1/4 full of eggs. The carcass was not marked, therefore, the fish may or may not have been shocked during the marking events.

Aerial Survey

Counts of live and dead chinook salmon during aerial surveys on 12, 18, and 30 July were 177, 544, and 2,333 (Table 13). Survey conditions were rated "fair", "fair", and "good", respectively, on a scale of "poor, fair, good, and excellent". The maximum count on 30 July was about 71% of the point estimate from the mark-recapture experiment.

DISCUSSION

Examination of data from the mark-recapture experiment indicated that marked chinook salmon partially mixed between river sections. The recapture history of marked chinook salmon for other mark-recapture experiments on the Salcha River (Skaugstad 1988 and 1989) and the Chena River (Skaugstad In press) also showed partial mixing. Partial mixing is expected due to the experimental design and death of chinook salmon after spawning. When captured for marking, most chinook salmon had finished or nearly finished spawning and these fish were a few days from death. Dying fish would be less able to move upstream or maintain a stationary position and would probably drift downstream into areas with lower velocities and pools. Therefore, any mixing that occurred would be in a downstream direction.

The point estimates of egg production were similar for each method. However, the standard error was much less when the estimate of egg production was based on the relation between length and fecundity. Length may be a better indicator of fecundity simply because of the difficulty of estimating age from scales that were collected from carcasses. The estimated age may be less than the actual age because the outer annuli is sometimes lost through partial absorption of the scale (Yole 1975). The person examining the scale may not notice a missing annuli and incorrectly age the fish. Incorrect ages probably increase the variance of the estimate. Length is a better estimator of fecundity simply because there is little error in measuring the length of a fish.

A potential problem with using electricity to stun fish is the possibility of injury that may affect the probability of recapture. If chinook salmon suffer premature death from either electrofishing, handling during marking, or both, then there is a greater chance during the carcass survey that marked carcasses will be less available than unmarked carcasses. Carcasses are less likely to be collected if they are covered with silt, drift out of the study area, or decompose. Because of these factors, the probability of recovery of a carcass decreases with time. However, if marked and unmarked chinook salmon die within a short period after spawning, then the probabilities of recapture of marked and unmarked fish should be equal. This experiment was designed so that premature death would have little effect on the probability of recapture. The marking event occurs after most chinook salmon in the river have spawned

Table 13. Abundance of live and dead chinook salmon counted during aerial surveys of the Salcha River, 1989[a].

Date	Live	Dead	Total	Survey Conditions
12 July	177	0	177	Fair
18 July	544	0	544	Fair
30 July	2,096	237	2,333	Good

[a] Barton, Louis. 1989. Personal Communication. ADFG, Div. of Commercial Fisheries, 1300 College Rd., Fairbanks, AK 99701.

but are still alive. Collection of carcass occurs after most of the chinook salmon have died (about two weeks after the start of the first marking event). Therefore, due to the short period between events, any injury suffered during the marking event that may cause premature death should have little, if any, effect on the probability of recapture of marked fish. Based on three years of sampling, it has been shown that electrofishing is an efficient method of capturing chinook salmon. Very few fish have been killed and the potential harm to unspawned females is low because electrofishing was used after most of the females had spawned.

Since most chinook salmon had already spawned when marked, the ability of electroshocked (marked) females to spawn could not be tested. Because no marked female carcasses were found with greater than 25% of eggs retained, this suggests that electroshocking may not have impaired spawning success. This aspect is not judged to require further study.

In terms of the effects of pulsating direct current (d.c.) on egg viability, Maxfield et al. (1971) found that fecundity of rainbow trout and survival of eggs was not influenced by pulsating d.c. electrical shock. Godfrey (1957) found that while pink salmon eggs in the pre-eyed condition are susceptible to disturbance (including electrical shock) eggs buried under gravel were offered protection from the current of electrical fishing gear.

The abundance of adult chinook salmon was estimated using the pooled Petersen estimator which combines the mark-recapture data for the three river sections. Stratification of the estimate of abundance by river section was not necessary because the probability of capture was equal for marked and unmarked fish during the carcass survey.

The number of chinook salmon counted during an aerial survey is usually lower than estimates obtained from mark-recapture experiments for a number of reasons including: fish may still be arriving; fish may have died and been washed from the river; or not all of the fish present are visible because of weather conditions, water level, water clarity, and overhanging vegetation. For the Salcha River in 1987, 1988, and 1989 the most chinook salmon counted during aerial surveys were 40, 61, and 71%, respectively, of the abundance estimated from mark-recapture experiments. The higher proportions of chinook salmon counted in the Salcha River in 1988 and 1989 was probably due to better visibility during the aerial surveys in 1988 and 1989. During these aerial surveys, the Salcha River was clear and weather conditions did not hinder visibility which resulted in more of the population being seen and counted.

The goal of this project was to estimate the portion of the population of chinook salmon observed during an aerial survey. The estimate of the portion of the population observed can then be used to estimate the population abundance for past and future aerial surveys. The data from 1987, 1988, and 1989 showed that from 61 to 71% of the population was seen when visibility was "good" and about 40% of the population was seen when visibility was "poor". There are, however, too few data points to estimate a relationship between the population abundance, aerial survey counts, and the effect of visibility. This is the third year that an estimate of abundance from a mark-recapture experiment has been compared to a count from an aerial survey. Additional comparisons may refine the relationship between the proportion of the population observed during an aerial survey and the subjective evaluation of the aerial survey. However, variability in the numbers of chinook salmon seen from the air and in the ranking of survey conditions between different aerial observers would probably contribute greater variance to the relationship than could be corrected through additional comparisons.

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APPENDIX A

Appendix A1. Statistical tests for analyzing data from a mark-recapture experiment for gear bias and evaluating the assumptions of a two-event mark-recapture experiment.

Gear Bias

The following statistical tests were used to analyze the data for significant bias due to gear selectivity by sex and length:

1. A test for significant gear bias by sex was based on a contingency table of the number of males and females that were and were not recaptured. The chi-square statistic was used to evaluate the bias.

If there was a significant gear bias by sex then the following tests were conducted separately for males and females.

2. Tests for significant gear bias by size were based on: (A) A chi-square goodness of fit test comparing the distributions of the lengths of all fish that were marked during electrofishing and all marked fish that were collected during the carcass survey; and, (B) A contingency table comparing the distributions of the lengths of all fish that were captured during electrofishing and all fish that were collected during the carcass survey. The null hypothesis is no difference between the distributions of lengths for Test A or for Test B.

For these two tests there are four possible outcomes:

Case I

Accept $H_o(A)$ Accept $H_o(B)$

There was no size-selectivity during the first sampling event (when fish were marked) or during the second sampling event (when carcasses were collected).

Case II

Accept $H_o(A)$ Reject $H_o(B)$

There was no size-selectivity during the second sampling event but there was size-selectivity during the first sampling event.

Case III

Reject $H_o(A)$ Accept $H_o(B)$

There was size-selectivity during both sampling events.

Case IV:

Reject $H_o(A)$ Reject $H_o(B)$

There was size-selectivity during the second sampling event; the status of size-selectivity during the first event was unknown.

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Depending on the outcome of the tests, the following procedures were used to estimate the abundance of the population:

Case I: Calculate one unstratified estimate of abundance, and pool lengths, sexes, and ages from both sampling events to improve precision of proportions in estimates of compositions.

Case II: Calculate one unstratified estimate of abundance, and only use lengths, sexes, and ages from the second sampling event to estimate proportions in compositions.

Case III: Completely stratify both sampling events, and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Pool lengths, ages, and sexes from both sampling events to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data.

Case IV: Completely stratify both sampling events and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Also, calculate a single estimate of abundance without stratification.

Case IVa: If the stratified and unstratified estimates of abundance for the entire population are dissimilar, discard the unstratified estimate. Only use the lengths, ages, and sexes from the second sampling event to estimate proportions in composition, and apply formulae to correct for size bias (*See* Adjustments in Compositions for Gear Selectivity) to data from the second event.

Case IVb: If the stratified and unstratified estimates of abundance for the entire population are similar, discard the estimate with the larger variance. Only use the lengths, ages, and sexes from the first sampling event to estimate proportions in compositions, and do not apply formulae to correct for size bias.

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Closed Population

The following two assumptions must be fulfilled:

1. Catching and handling fish does not affect the probability of their recapture when carcasses are collected; and,

2. Marked fish do not lose their mark.

The design of the experiment reduces the chance of failure of these two assumptions. Probability of recapture of marked fish is not likely to be affected by the capture method (electrofishing) used during the marking event because most of the marked and unmarked fish are dead before the recapture event.

For a mark-recapture experiment to be successful no marks should be lost. To reduce the chance of losing marks, all captured chinook salmon received a jaw tag and fin clip. Jaw tags are desirable because individual chinook salmon can be identified and allow the use of more powerful statistical tests. Jaw tags, however, sometimes detach and are lost (Skaugstad 1988 and 1989). To prevent the complete loss of a mark, fin clips were used as a second mark because they were less likely to be lost; the time between the marking and recovery events (maximum of three weeks) is too short for fins to regenerate. The disadvantage of using finclips is that individual chinook salmon could not be identified.

Of the following assumptions, only one must be fulfilled:

1. Every fish has an equal probability of being captured and marked;

2. Every fish has an equal probability of being collected during carcass surveys; or,

3. Marked fish mix completely with unmarked fish between electrofishing and carcass surveys.

To evaluate these three assumptions, the chi-square statistic was used to examine the following contingency tables. Results were used to determine the appropriate abundance estimator and if the estimate of abundance should be stratified by river section or marking period:

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1. The rate of recovery of marked fish during the carcass survey was the same for each (A) river section and (B) marking period. The number of marked fish recovered and not recovered during the carcass survey were arranged in two contingency tables. Columns 1, 2, and 3 in the first contingency table were the river sections. Columns 1 and 2 in the second contingency table were the periods that fish were marked.

2. To evaluate the degree of mixing of marked fish between river sections, the number of marked fish recovered and not recovered during the carcass survey were arranged in a contingency table. Rows 1, 2, and 3 were the river sections where fish were captured and marked during both marking events. Columns 1, 2, and 3 were the river sections where marked fish were recovered during the carcass survey. Column 4 was the number of marked fish captured and marked in each river section but not recovered during the carcass survey.

3. To evaluate if fish were captured and marked in proportion to the abundance in each river section, the number of marked and unmarked fish collected during the carcass survey were arranged in a contingency table. Columns 1, 2, and 3 were the number of marked and unmarked fish recovered during the carcass survey by river section. This test also indicates unequal mixing of marked and unmarked fish between river sections.

If Test 1 indicates that there was significant differences between the rates of recovery (river section or period), then a stratified Petersen estimator was used to estimate the abundance. If the differences were not significant, then a pooled Petersen estimator was used.

If Tests 2 and 3 indicate that there was no mixing, then a stratified Petersen estimator was used to estimate the abundance. If there was partial mixing, then a Darroch estimator was used. If there was complete mixing, then a pooled Petersen estimator was used.