FISHERY DATA SERIES NO. 90-13

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

By

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August 1990

[1] This investigation was jointly financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-5, Job No. C-8-1 and through the United States - Canada Pacific Salmon Treaty, Yukon River, Cooperative Agreement Number NA90AA-H-FM010.

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ABSTRACT

In 1989, the number of adult chinook salmon *Oncorhynchus tschawytscha* that returned to spawn in the Chena River near Fairbanks, Alaska, was estimated using a mark-recapture experiment. A riverboat equipped with electrofishing gear was used to capture 311 chinook salmon in early August. Captured chinook salmon were marked with jaw tags, finclipped, and released. In mid-August, 337 chinook salmon carcasses were collected. Forty-six of these carcasses had been marked. The estimate of abundance was 2,666 (standard error = 249). The estimates of the number of females and males were 1,039 (standard error = 194) and 1,627 (standard error = 156), respectively. During aerial surveys, the highest count of live and dead chinook salmon was 1,180, about 44 percent of the mark-recapture point estimate. The estimate of egg production for the 1989 escapement was 9.81 million eggs (standard error = 0.80 million).

KEY WORDS: chinook salmon, *Oncorhynchus tschawytscha*, Chena 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 1,440 km migration from the ocean to their spawning grounds in the Chena River, chinook salmon pass through five different fishing sub-districts. Commercial, subsistence, and personal use fishing occur in each of these sub-districts. There is also a popular sport fishery in the lower 72 km of the Chena River. Chinook salmon returning to the Chena River contribute to all these fisheries.

To perpetuate the fisheries and stocks of chinook salmon, fishery managers set harvest levels in each sub-district with the goal of allowing a desired number of chinook salmon 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 reach their spawning grounds. When the number of chinook salmon is less than a desired level then the harvest level was considered too high. This information can be used in the future to establish improved harvest levels.

The Chena River is a 200 km long clear runoff river flowing into the Tanana River about 5 km west of Fairbanks (Figure 1). From 1974 to 1983 the highest annual count of mature chinook salmon in the Chena River during aerial surveys has ranged from less than 500 to more than 2,500 (Barton 1984). However, only a portion of the population is usually present during a single aerial survey and the number of chinook salmon counted is influenced by weather, water level, water clarity, and overhanging vegetation. Skaugstad (1988, 1989, and In press) found that numbers of mature chinook salmon counted during aerial surveys of the Salcha River in 1987, 1988, and 1989 were about 40, 61, and 71%, respectively, of the estimated abundance from mark-recapture experiments. Barton (1987a and 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 proportion of the chinook salmon spawning population in the Chena River is counted during an aerial survey. The specific objectives in 1989 were to estimate:

1. the abundance of the population of spawning chinook salmon;

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

3. the age and sex composition of the escapement of chinook salmon.

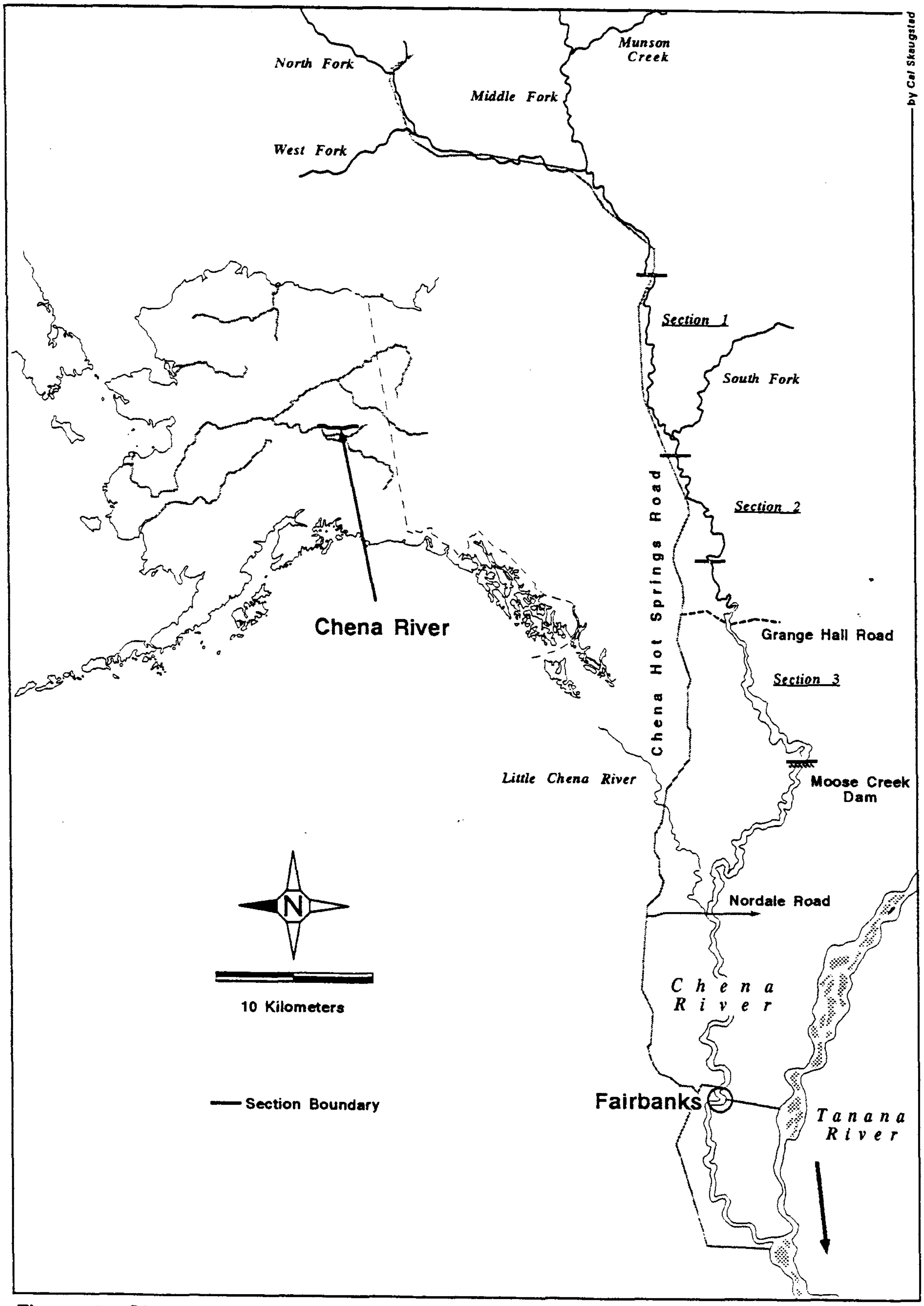

Figure 1. Chena River study area.

In addition, the length composition and total egg production of the escapement of chinook salmon in the Chena River were estimated.

MATERIALS AND METHODS

Capture and Marking

Adult chinook salmon were captured from 27 July through 4 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. An area of the river from about 72 km to 145 km (measured from the mouth) was sampled in this manner. Past aerial surveys of the Chena River have shown that almost all of the chinook salmon spawn in this area (Andersen pers. comm.[1]). The sample area was divided into three sections (Figure 1). The length of each section was based on an estimate of the 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 27, 28, and 29 July, respectively. Each pass through a section started at the upstream boundary. During the second marking event, one pass was again made in all three sections (sections 1, 2, and 3 were sampled on 2, 3, and 4 August, respectively).

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 8, 9, and 10 August, respectively. Starting at the upstream end, one pass was made through each section in a drifting riverboat. Carcasses were collected with long handled spears. The carcasses were measured and examined for jaw tags and fin clips. The sex was determined from observation of body morphology. Three scales were removed from each carcass for age analysis.

Abundance Estimator

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

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[1] Andersen, Fred. 1987. Personal Communication. ADFG, 1300 College Rd., Fairbanks, AK 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 ") dia. flexible electrical conduit.
Water conductivity:	150 microsiemens/cm^3.

location) and a Petersen estimator. The Darroch estimator (Darroch 1961, cited in Seber 1982) used is summarized below:

$$\hat{N}^{\sim} = \mathbf{n'M^{-1}a} \tag{1}$$

where:

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

$\mathbf{n'}$ = a vector of the number of carcasses of chinook salmon recovered in river sections 1, 2, and 3;

$\mathbf{M^{-1}}$ = a matrix of recovered tags by river section where chinook salmon were marked and then recovered; and,

$\mathbf{a}$ = a vector of the number of chinook salmon marked and released in river sections 1, 2, and 3.

The variance of $\hat{N}^{\sim}$ was obtained using resampling techniques on the capture history (Efron and Gong 1983; Buckland Unpublished[2]). The capture history was created in two adjacent columns. The first column was the river section where a fish was marked during electrofishing and the second column was the river section where a fish was collected during the carcass survey. The numbers 1, 2, and 3 in either column indicate the river section where each fish was marked and later collected. Each row represented the capture history of one fish. Zero was assigned in the appropriate column when a fish was unmarked or not recaptured. The capture history was then sampled 500 times. The size of each sample equaled the number of rows in the original capture history. The matrix **M** and the vectors **a** and **n'** were constructed from each sample of the capture history. The variance was then calculated as described by Buckland except the Darroch estimator was substituted for the Petersen estimator.

The unbiased Petersen estimator and associated sampling variance (described by Chapman 1951, cited in Seber 1982) used is summarized below:

$$\hat{N}^{*} = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1; \text{ and,} \tag{2}$$

$$\hat{V}(N^{*}) = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} . \tag{3}$$

where:

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

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[2] Buckland, S. T. Unpublished. Quantifying precision of mark-recapture estimates using the bootstrap. Inter American Tropical Tuna Commission, 8604 La Jolla Shores Drive, La Jolla, California 92093.

n_1 = the number of chinook salmon 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:

$$\hat{p}_t = n_u/n_r; \text{ and,} \tag{4}$$

$$V(\hat{p}_t) = \hat{p}_t(1-\hat{p}_t)/(n_r-1). \tag{5}$$

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:

$$\hat{p}_i = a_i/n; \text{ and,} \tag{6}$$

$$V(\hat{p}_i) = \hat{p}_i(1-\hat{p}_i)/(n-1). \tag{7}$$

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;

n = the total number of females and males; 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:

$$\hat{N}_i = \sum\hat{p}_i(\hat{N}) \tag{8}$$

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

$$\hat{V}(\hat{N}_i) = \sum[\hat{N}^2\hat{V}(\hat{p}_i)+\hat{p}_i^2\hat{V}(\hat{N})-\hat{V}(\hat{p}_i)\hat{V}(\hat{N})] \quad (9)$$

where:

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

N = the estimated number of females (or males) in the population; and,

p_i = the estimated proportion of females (or males) of ocean age i.

Population Egg Production

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

$$\hat{E} = \sum\hat{N}_i\hat{F}_i; \quad (10)$$

$$\hat{V}(E) = \sum V(\hat{N}_i\hat{F}_i); \quad (11)$$

$$\hat{V}(\hat{N}_i\hat{F}_i) = \hat{N}_i^2\hat{V}(\hat{F}_i)+\hat{F}_i^2\hat{V}(\hat{N}_i)-\hat{V}(\hat{N}_i)V(F_i) \quad (12)$$

where:

$\hat{E}$ = the total egg production for the spawning chinook salmon;

$\hat{N}_i$ = 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);

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

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

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

Effects of Electrofishing

To evaluate the effect of electrofishing on spawning chinook salmon, all 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 marked carcass with more than 1/4 of the eggs remaining was considered to have been injured from electrofishing. A test for a significant difference in the volume of eggs between marked and unmarked carcasses was based on the chi-squared statistic.

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

Age[b]	Sample Size	Fecundity Mean	Fecundity 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 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 Chena River on 12, 18, 22, and 30 July. Counts were made from low flying, fixed-wing aircraft. Barton (1987c) describes the methods used for aerial surveys.

RESULTS

During 27 July through 4 August, 311 chinook salmon were captured, tagged, fin clipped, and released. Three chinook salmon were killed during the capture event. From 8 August through 10 August, 337 carcasses were collected and examined for tags and fin clips. Of those carcasses examined, 46 were marked.

Tests of Assumptions for a Petersen Estimator

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

Gear Bias:

The rates of recovery were significantly different between male and female chinook salmon (males = 0.07; females 0.24; $\chi^2 = 17.80$, df = 1, $P < 0.01$; Table 3). Therefore, estimates of abundance were stratified by sex and the following statistical tests were performed separately for males and females.

Tests for gear bias by size (length) showed that differences in length distributions were not significant for fish marked during electrofishing and later recaptured during the carcass survey (males: $\chi^2 = 3.49$, df = 2, $P = 0.18$; females: $\chi^2 = 0.91$, df = 2, $P = 0.64$; Table 4). Differences in length distributions were significant between all males captured during electrofishing and all males collected during the carcass survey ($\chi^2 = 6.88$, df = 2, $P = 0.03$; Table 4). There was no significant difference between the length distributions of females captured during electrofishing and females collected during the carcass survey ($\chi^2 = 0.41$, df = 2, $P = 0.81$; Table 4).

Closed Population:

The rates of recovery of marked chinook salmon between river sections were not significantly different for males ($\chi^2 = 4.33$, df = 2, $P = 0.11$) or females ($\chi^2 = 1.34$, df = 2, $P = 0.51$; Table 5). The rates of recovery of marked chinook salmon between the first and second marking periods were not significantly different for males ($\chi^2 = 0.51$, df = 1, $P = 0.47$) or females ($\chi^2 = 1.98$, df = 1, $P = 0.16$; Table 6).

The number of marked and unmarked chinook salmon collected during the carcass survey indicated that chinook salmon were collected and marked in proportion to their abundance in each river section (males: $\chi^2 = 2.91$, df = 2, $P = 0.23$; females: $\chi^2 = 5.10$, df = 2, $P = 0.08$; Table 7).

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

	Males	Females	Total
Recovered	12	34	46
Not Recovered	158	107	265
Total Released	170	141	311
Recovery Rate	0.07	0.24	0.15

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 +
Males:			
Electrofishing	53	94	23
Carcass survey	28	61	30
Recaptured	3	5	4
Females:			
Electrofishing	2	90	49
Carcass survey	5	135	78
Recaptured	0	20	14

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

	River Section			
	Upper	Middle	Lower	Total
Males:				
Recovered	3	5	4	12
Not Recovered	50	89	19	158
Total Marked	53	94	23	170
Recovery Rate	0.06	0.05	0.17	
Females:				
Recovered	0	20	14	34
Not Recovered	2	70	35	107
Total Marked	2	90	49	141
Recovery Rate	0	0.22	0.29	

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
Males:			
Recaptured	7	5	12
Not Recaptured	108	50	158
Total Released	115	55	170
Recovery Rate	0.06	0.09	0.07
Females:			
Recaptured	16	18	34
Not Recaptured	65	42	107
Total Released	81	60	141
Recovery Rate	0.20	0.30	0.24

[a] The first marking event was 27, 28, and 29 July; the second marking event was 2, 3, and 4 August.

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

	River Section			
	Upper	Middle	Lower	Total
Males:				
Marked	1	4	7	12
Unmarked	37	26	44	107
Total Collected	38	30	51	119
Recovery Rate	0.03	0.13	0.14	0.10
Females:				
Marked	6	19	9	34
Unmarked	62	60	62	184
Total Collected	68	79	71	218
Recovery Rate	0.09	0.24	0.13	0.16

The chi-square statistic could not be used to evaluate the amount of mixing of either marked male or marked female chinook salmon that occurred between river sections. More than half of the expected values in the contingency table were less than five; 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). Casual examination of these data indicated that there was only partial mixing of marked males or females between river sections (Table 8).

Abundance Estimate

Based on the results of the previous tests, abundance was estimated for males and females separately. The abundance of males was estimated using the Petersen method for males smaller than 900 mm (1,479, SE = 430) and for males larger than 900 mm (148, SE = 49). There were too few males in the above 900 mm and below 900 mm categories to perform a reliable Darroch estimate. The abundance of females was estimated using Darroch's method to adjust for unequal recapture rates and partial mixing of marked chinook salmon among the three river sections (1,039, SE = 194). The combined estimated abundance of male and female chinook salmon was approximately 2,666 (SE = 249).
For comparison, the estimated abundance using the Darroch estimator and pooled by length and sex was 2,730 (SE = 501).

The desired sample sizes for the number of fish marked and examined during the experiment were not obtained because the actual population size was less than expected. The small population size is supported by the observation of fewer chinook salmon during marking and carcass collection events compared to previous years. Although fewer chinook salmon were present, the desired accuracy of the estimated abundance was achieved (based on a pooled Petersen estimator).

Tag Loss

Of the 311 chinook salmon that were marked with fin clips and jaw tags, 46 were recovered during the carcass survey. All 46 carcasses were fin clipped but only 41 still had jaw tags; five jaw tags were lost during the mark-recapture experiment this year. The estimated proportion of jaw tags lost was 0.11 (SE = 0.05). Tag loss did not bias abundance estimates because fish were double marked.

Age, Sex, and Size Composition

Age, sex, and length data were obtained from all chinook salmon during the carcass survey. These fish spent one to five years in the ocean and nearly all fish spent just one year in freshwater (Table 9). The dominant age class for females was 1.4 (brood year 1983) and for males was 1.3 (brood year 1984). About 81% of the females were age 1.4 or older and about 50% of the males were age 1.3.

Based on separate estimates of abundance the ratio of females to males was about 2:3. Females comprised about 39% of the population and males comprised about 61% of the population.

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

Females:

River Section Where Marks Were Released	River Section Where Marks Were Recaptured				Number Marked	Number Not Recaptured
	Upper	Middle	Lower	Total		
Upper	6	1	0	7	35	28
Middle	0	18	2	20	60	40
Lower	0	0	7	7	46	39
Total	6	19	9	34	141	107
Unmarked Carcasses	62	60	62	184		
Total Carcasses	68	79	71	218		

Males:

River Section Where Marks Were Released	River Section Where Marks Were Recaptured				Number Marked	Number Not Recaptured
	Upper	Middle	Lower	Total		
Upper	1	0	0	1	44	43
Middle	0	4	5	9	81	72
Lower	0	0	2	2	45	43
Total	1	4	7	12	170	158
Unmarked Carcasses	37	26	44	107		
Total Carcasses	38	30	51	119		

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

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	0				
1.2	1	<0.01	<0.01	6	6
1.3	35	0.19	0.03	194	47
1.4	122	0.65	0.04	678	131
1.5	29	0.16	0.03	161	40
Totals	187	1.0		1,039	145
Males:					
1.1	1	0.01	0.01	16	16
1.2	11	0.11	0.03	177	53
1.3	50	0.50	0.05	806	112
2.2	2	0.02	0.01	32	23
1.4	35	0.35	0.05	564	94
2.3	1	0.01	0.01	16	16
1.5	1	0.01	0.01	16	16
Totals	101	1.0		1,627	160
Females and Males:					
1.1				16	16
1.2				184	52
1.3				999	102
2.2				32	23
1.4				1,242	116
2.3				16	16
1.5				177	38
Totals				2,666	

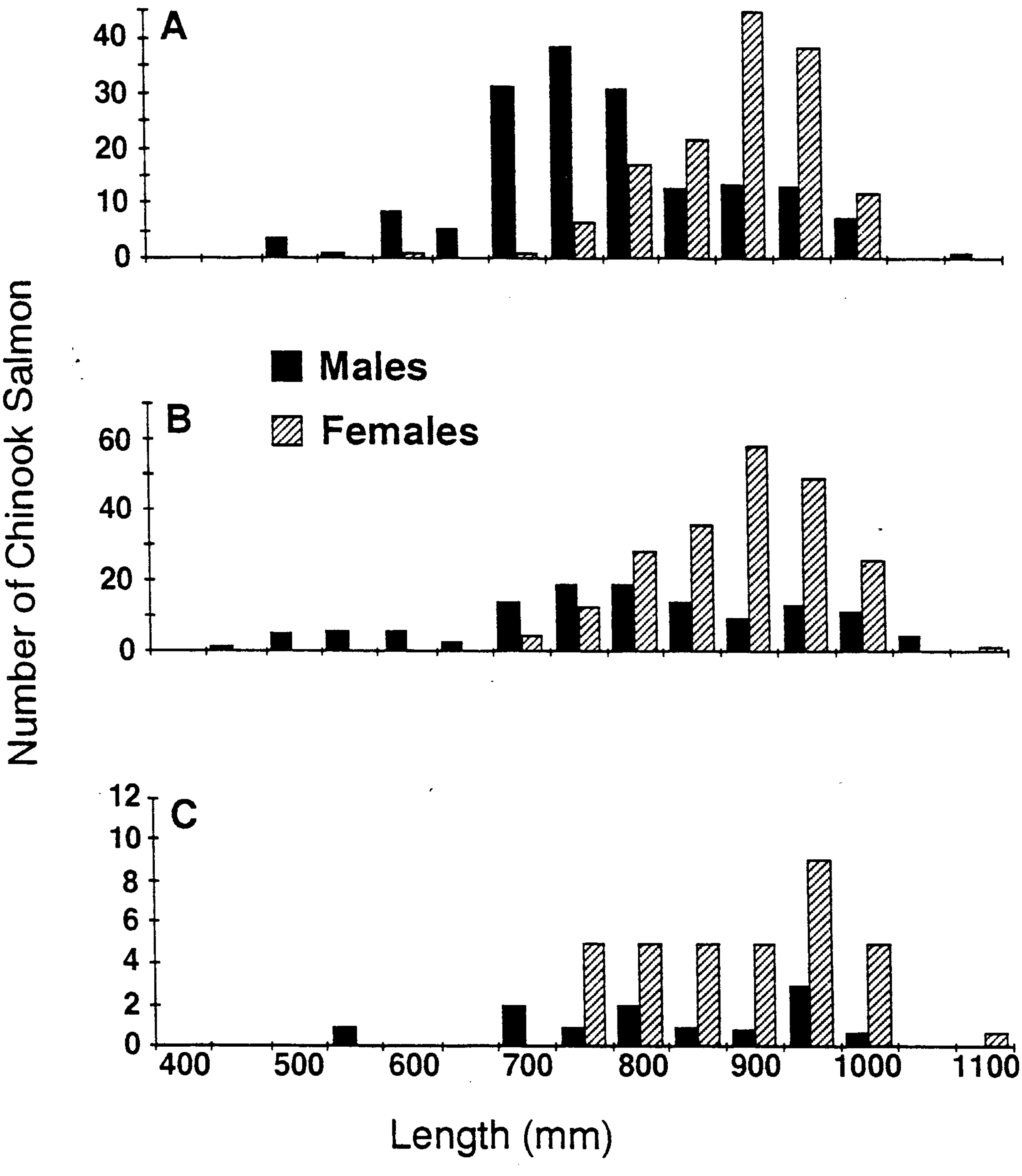

Figure 2. Distributions of the lengths of chinook salmon captured during A) both marking events, B) the carcass survey, and C) marked chinook salmon recovered during the carcass survey.

Lengths of females ranged from 660 to 1,100 mm while males ranged from 420 to 1,090 mm (Figure 2). Chinook salmon less than 700 mm were predominantly males. The mean lengths of females were usually greater than the mean lengths of males by age (Table 10).

Population Egg Production

The estimate of egg production based on length (ME-FT) was 9.80 million eggs (SE = 0.19 million; Table 11). The estimate of egg production based on ocean age was 9.80 million eggs (SE = 4.03 million; Table 12). These estimates were based on the relation between length and fecundity and age and fecundity determined by McCracken and Skaugstad (In press) for chinook salmon captured in the Tanana River. Age class 1.4 females accounted for about 63% of the population egg production.

Effects of Electrofishing

Of the 337 chinook salmon carcasses examined, no unspawned females (marked or unmarked) were found. A female was considered to have been injured by electrofishing during spawning if the volume of eggs remaining in a carcass was more than 1/4 of the estimated capacity. Based on these data, the null hypothesis (electrofishing did not affect the spawning success of females) could not be rejected.

Aerial Survey

Counts of live and dead chinook salmon during aerial surveys on 12, 18, 22, and 30 July were 134, 968, 652, and 1,180 (Table 13). Survey conditions were rated "fair," "good," "fair," and "fair," respectively, on a scale of "poor, fair, good, and excellent." The maximum count on 30 July was about 44% of the point estimate from the mark-recapture experiment.

DISCUSSION

Examination of the data from the mark-recapture experiment indicated that there was only partial mixing of marked chinook salmon between river sections. Marked fish were recovered either in the section where they were marked or in sections downstream from where they were marked. No marked fish was recovered in a section upstream from where it was marked. 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 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. Partial mixing of marked fish also occurred for chinook salmon in the Salcha River in 1987 and 1988 (Skaugstad 1988, 1989). Partial mixing, however, is not a problem when marked and unmarked fish behave in a similar manner (the probability of movement is the same for marked and unmarked fish).

A potential problem with using electricty to stun fish is the possibility of injury that may effect the probability of recapture. If chinook salmon suffer

Table 10. Estimated length-at-age of chinook salmon.

Ocean Age	Sample Size	Length (mm) Mean	SE	Range
Females:				
1	2	810	60	750 - 870
2	2	790	80	710 - 870
3	50	814	12	660 - 1,100
4	109	870	6	700 - 1,100
5	33	929	10	810 - 1,000
Total	196			
Males:				
1	6	640	37	520 - 730
2	14	573	40	420 - 960
3	55	772	11	570 - 970
4	24	886	22	610 - 1,090
5	16	771	22	620 - 930
Total	115			
Females and Males:				
1	8	683	43	520 - 870
2	16	600	45	420 - 960
3	105	792	11	570 - 1,100
4	133	873	9	610 - 1,100
5	49	877	14	620 - 930
Total	311			

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

Length (mm)	Number of Fish	Fecundity (millions)	SE (millions)
660	5	0.02	0.02
670	5	0.03	0.03
680	0	0	0
690	5	0.03	0.03
700	10	0.06	0.04
710	19	0.12	0.07
720	0	0	0
730	19	0.13	0.07
740	19	0.13	0.07
750	5	0.03	0.03
760	29	0.21	0.10
770	24	0.18	0.09
780	29	0.22	0.10
790	24	0.19	0.09
800	29	0.23	0.10
810	33	0.27	0.12
820	43	0.36	0.14
830	33	0.29	0.12
840	29	0.25	0.11
850	33	0.30	0.12
860	29	0.26	0.12
870	38	0.36	0.14
880	81	0.78	0.23
890	67	0.66	0.21
900	62	0.62	0.20
910	33	0.34	0.14
920	67	0.70	0.22
930	48	0.51	0.19
940	38	0.41	0.16
950	48	0.53	0.19
960	71	0.80	0.26
970	33	0.38	0.16
980	19	0.22	0.12
990	0	0	0
1,000	5	0.06	0.06
1,100	13	0.13	0.10
	1,039	9.81	0.78[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 Chena River chinook salmon, 1989.

Age Class	Estimated Number of Females	Average Fecundity[a]	Estimated Number of Eggs (millions)	SE
1.2 & 1.3	200	8,500	1.71	0.43
1.4	678	9,100	6.18	1.23
1.5	161	11,900	1.91	0.49
Totals	1,039		9.80	1.39

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

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

Date	Live	Dead	Total	Survey Conditions
12 July	134	0	134	Fair
18 July	967	1	968	Good
22 July	649	3	652	Fair
30 July	1,164	16	1,180	Fair

[a] Barton, Louis. Personal Communication. ADFG, Div. of Commercial Fisheries, 1300 College Rd., Fairbanks, AK 99712.

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 occurred after most chinook salmon in the river spawned but were still alive. Collection of carcass occurred after most of the chinook salmon 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 have caused premature death would have little, if any, effect on the probability of recapture of marked fish. Based on two years of sampling in the Chena River and three years of sampling in the Salcha River, it has been shown that electrofishing is an efficient method of capturing chinook salmon. Very few fish were killed and the potential harm to unspawned females was low because electrofishing was used after most of the females had spawned.

Because there was partial mixing of marked female chinook salmon, the abundance of female chinook salmon was estimated using the Darroch estimator which stratifies by geographic area (river section). However, stratification of the estimate of abundance may not be necessary when the probability of movement is equal for marked and unmarked fish. The mark-recapture history of marked chinook salmon showed some fish did not move while others moved downstream (Table 8). If the unmarked fish behaved in a similar manner, then stratifying the estimate of abundance was not necessary. A pooled Petersen estimator could be used in place of the Darroch estimator.

A significantly higher portion of marked females were recovered than males. This may be the result of different behavior when shocked. During the marking event, females were observed to remain near the bottom most of the time while males rose towards the surface and were easier to capture with a net.

The distribution and abundance of the different ages were comparable to that found in 1987 and 1988 (Barton 1988; Barton and Conrad 1989) for chinook salmon larger than 700 mm. Although fewer chinook salmon were captured in 1989, the ratio of females to males was similar to that found in 1987 and 1988 for fish larger than 700 mm. However, in 1988, males less than 700 mm comprised about one-half of the male population. In contrast, in 1989 males less than 700 mm comprised only about one-fifth of the male population. The distribution of lengths for females and males captured in the Chena River in 1989 were also similar to those found in the Salcha River in 1989.

The Department of Fish and Game uses aerial surveys to assess population abundance because the cost is much less compared to mark-recapture experiments that are used to estimate abundance. However, 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 Chena River in 1986, 1987, 1988, and 1989 the most chinook salmon counted during aerial surveys were about 22%, 21%, 59%, and 44% of the abundance estimated from mark-recapture experiments (Barton 1987b, 1988; Barton and Conrad 1989; and this study).

Although aerial surveys cost less than mark-recapture experiments, they provide fishery managers with only a minimum estimate or index of the population abundance. Estimates of abundance are more desirable but they cost more. By comparing counts of salmon from aerial surveys with estimates of abundance from mark-recapture experiments, a relationship can probably be developed to estimate population size from aerial surveys alone. This is the fourth year that an estimate of abundance from a mark-recapture experiment has been compared to counts from aerial surveys. There are too few data points to estimate a relationship between population abundance, aerial survey counts, and the effect of visibility. Additional comparisons are still required to refine the relationship between the proportion of the population observed during an aerial survey and the subjective evaluation of the aerial survey.

ACKNOWLEDGEMENTS

I wish to thank Betsy McCracken, Don Roach, Tim Balch, Tom Kerns, Rolland Holmes, and Susie Lozo for assisting with the collection of data in the field. This investigation was jointly financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-5, Job No. C-8-1 and through the United States - Canada Pacific Salmon Treaty, Yukon River, Cooperative Agreement Number NA90AA-H-FM010.

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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.