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Abundance, Egg Production, and Age-Sex-Length Composition of the Chinook Salmon Escapement in the Salcha River, 1991

by

Cal Skaugstad

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ABSTRACT

In 1991, the abundance of chinook salmon *Oncorhynchus tshawytscha* that returned to spawn in the Salcha River near Fairbanks, Alaska, was estimated using a mark-recapture experiment. A riverboat equipped with electrofishing gear was used to capture 475 chinook salmon in late July. Captured chinook salmon were marked with jaw tags, fin clipped, and released. In early August, 706 chinook salmon carcasses were collected of which 59 were marked. The estimate of abundance was 5,608 (standard error = 664). The proportions of males and females were 0.55 and 0.45, respectively. Males spent 1 to 6 years in the ocean while females spent 3 to 6 years. The estimate of potential egg production for the 1991 escapement was 23 million eggs (standard error = 1.7 million). A count of chinook salmon during an aerial survey on 20 July was 2,212, about 39% of the abundance estimate from the mark-recapture experiment.

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

INTRODUCTION

Management of stocks of Yukon River chinook salmon *Oncorhynchus tshawytscha* is complex and 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 pass through six different commercial fishing districts in the Yukon and Tanana rivers. Subsistence and personal use fishing also occur in each district. At the mouth of the Salcha River there is a popular sport fishery in which annual harvests have approached 1,000 chinook salmon in some years (Table 1).

To perpetuate the stocks of chinook salmon, fishery managers set harvest levels for the various fisheries 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 numbers of chinook salmon that enter the Yukon River along with results from prior years (numbers of chinook salmon that were harvested and numbers of chinook salmon that reached spawning grounds). An important factor when evaluating stock status of chinook salmon is the number of spawners that successfully reach their spawning grounds (escapement). When the number of spawners is less than desired, then the overall harvest level was probably too high. This information can be used in the future to better estimate harvest levels that allow optimal numbers of chinook salmon to reach spawning grounds.

The Salcha River is a 250 km long, clear stream flowing into the Tanana River about 60 km east of Fairbanks (Figure 1). From 1972 to 1990, the number of mature chinook salmon counted in the Salcha River during aerial surveys has ranged from 391 to 6,757 (Barton 1984, Skaugstad 1990a, Burkholder 1991). These counts imply that the Salcha River supports one of the largest populations of spawning chinook salmon in the entire Yukon River drainage. Aerial surveys, however, can only give an index of abundance because only a portion of the entire spawning population is usually present during a single aerial survey. Also, there are other factors such as weather, water level, water clarity, and overhanging vegetation that affect the surveyor's ability to count chinook salmon. Skaugstad (1988, 1989, 1990a) and Burkholder (1991) found that the number of chinook salmon counted during surveys of the Salcha River in 1987, 1988, 1989, and 1990 was about 40%, 61%, 71%, and 35% 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 less than 20% of the fish counted through a weir in Clear Creek (near Nenana).

Mark-recapture experiments are more expensive to conduct than aerial surveys but they are able to provide estimates of abundance. By conducting aerial surveys and mark-recapture experiments at the same time, a relationship might be established to expand counts from an aerial survey into estimates of abundance.

The objectives of the chinook salmon project for the Salcha River in 1991 were to:

Table 1. Harvests of anadromous chinook salmon by sport, commercial, subsistence, and personal use fisheries, Tanana drainage, 1978 - 1991.

	On-Site Sport Harvest Estimates[a]		Statewide Survey Estimates of Sport Harvest[b]						Estimated Harvest by User Group		
Year	Chena River	Salcha River	Chena River	Salcha River	Chatanika River	Nenana River	Other Streams	All Waters	Commercial Harvests[c]	Subsistence and Personal Use Harvests[c]	Total Known Harvest
1978	none	none	23	105	35	none	0	163	635	1,231	2,029
1979	none	none	10	476	29	none	0	515	772	1,333	2,620
1980	none	none	0	904	37	none	0	941	1,947	1,826	4,714
1981	none	none	39	719	5	none	0	763	987	2,085	3,835
1982	none	none	31	817	136	none	0	984	981	2,443	4,408
1983	none	none	31	808	147	none	10	1,048	911	2,706	4,665
1984	none	none	0	260	78	none	0	338	867	3,599	4,804
1985	none	none	37	871	373	none	75	1,356	1,142	7,375	9,873
1986	none	526	212	525	0	none	44	781	950	3,701	5,432
1987	none	111	195	244	21	7	7	474	1,202	4,096	5,772
1988	567	19	73	236	345	36	54	744	786[d]	5,584[e,g]	7,090
1989	685	123	375	231	231	39	87	963	2,181[d]	2,297[e,g]	5,001
1990	24	200	64	291	37	0	0	439	2,989[d]	3,759[e,g]	7,140
1991	none	308[f]	N.A.[h]	N.A.	N.A.	N.A.	N.A.	N.A.	1,163[d,g]	N.A.	N.A.

[a] Creel census estimates from Clark and Ridder (1987), Baker (1988, 1989), Merritt et al. (1990), Hallberg and Bingham (1991).

[b] Sport fishery harvest estimates from Mills (1979-1991).

[c] Commercial, subsistence, and personal use estimates from ADFG (1990) and ADFG (in press).

[d] Includes chinook salmon sold from ADFG test fisheries occurring near Nenana and Manley (24 fish in 1988, 440 fish in 1989, 833 fish in 1990, and 91 fish in 1991).

[e] The personal use designation was implemented in 1988 to account for non-rural fishermen participating in this fishery. Harvest by personal use fishermen was 395 fish in 1988 and 495 fish in 1989.

[f] Data from Hallberg and Bingham (*In press*).

[g] Preliminary data and subject to change.

[h] N.A. means data not available at this time.

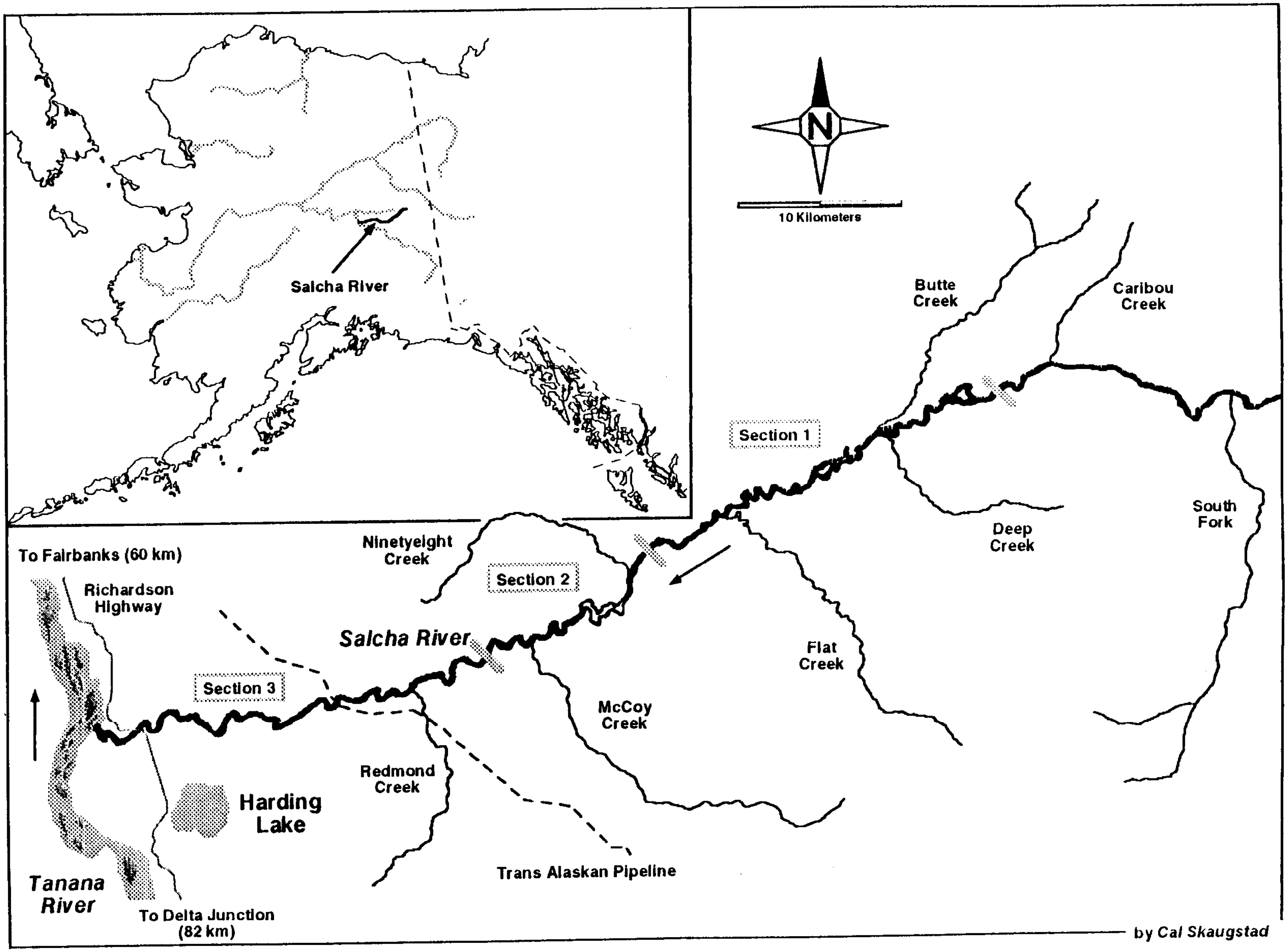

Figure 1. Salcha River study area.

1. estimate the abundance of spawning chinook salmon in the Salcha River; and,

2. estimate the age-sex-length compositions of chinook salmon in the Salcha River.

In addition, the population abundance estimate was compared to counts of spawning salmon from aerial surveys; and, potential egg production of the escapement was estimated.

METHODS

The number of chinook salmon that reached their spawning grounds in the Salcha River were estimated using a Petersen mark-recapture experiment. This type of experiment required two events. During the first event, a sample of the population was captured, marked, and released back into the population. During the second event, after allowing time for the marked and unmarked to mix, another sample was collected and examined for marks. Terms used in mark-recapture experiments to describe capture of animals during the first and second events usually apply to live animals. This report uses "collect" to refer to the capture of chinook salmon carcasses in the second event.

Event 1 - Capture and Marking

Adult chinook salmon were captured using a riverboat equipped with electrofishing gear (Clark 1985, Table 2). Chinook salmon were stunned using pulsating direct current electricity, dipped from the river with long handled dip nets and placed in a holding tank. River water was continuously pumped through the holding tank. 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. The sample area was divided arbitrarily into three sections (Figure 1). One pass was made through sections 1, 2, and 3 on 26, 27, and 28 July, respectively. A second pass was made through sections 1, 2, and 3 on 29, 30, and 31 July. Each pass through a section started at the upstream end. Any chinook salmon carcasses found during the first event were also collected.

All captured chinook salmon were tagged, fin clipped, measured, and released. A uniquely numbered metal tag was attached to the lower jaw of each fish. A combination of adipose, pectoral, anal, 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.

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

Table 2. Description of equipment, control settings, and water conductivity while electrofishing the Salcha River in 1991.

Generator characteristics:	4 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 wire rope.
Water conductivity:	90 - 130 microsiemens/cm^3.
Water temperature	10 - 12°C

Event 2 - Collection and Mark Recovery

Chinook salmon carcasses were collected from the same three river sections in which electrofishing was performed. One pass was made through sections 1, 2, and 3 on 5, 6, 7, and 8 August. Carcasses were collected with long handled spears from a drifting riverboat. Each carcass was measured to the nearest 5 mm and examined for a jaw tag and fin clip. Sex was determined from observation of body morphology. Three scales were removed from each carcass for age analysis. Scales were taken from the left side approximately two rows above the lateral line on a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Clutter and Whitesel 1956). When scales were not present in this area, they were removed from the right side or as close as possible to the area.

Test of Assumptions for Abundance Estimator

To prevent a biased estimate, this type of Petersen mark-recapture experiment required that certain assumptions were satisfied (Seber 1982).

The assumptions of a Petersen estimator are:

1. marking does not affect the catchability of fish;

2. marked fish do not lose their marks between sampling events;

3. recruitment and death of fish do not occur between sampling events; and,

4. every fish has an equal probability of being marked and released alive during the first sampling event; *or* every fish has an equal probability of being captured during the second sampling event; *or* marked fish mix completely with unmarked fish between sampling events (Seber 1982).

The following tests were used to determine if some of these assumptions were not satisfied.

Gear Bias:

To evaluate gear bias by sex, a contingency table was constructed using numbers of marked fish recovered and not recovered during the second event. The chi-square statistic was then used to test the null hypothesis of no significant difference between the rates of recovery by sex.

Three tests were used to evaluate gear bias by size (length of the fish). Length distributions were compared for: 1) chinook salmon captured in the first event and marked chinook salmon carcasses recovered in the second event; and, 2) chinook salmon captured in the first event and chinook salmon carcasses collected in the second event. The Kolmogorov-Smirnov statistic was used to test the null hypothesis of no difference between length frequency distributions. 3) Rates of recovery were compared using a contingency table constructed of numbers of marked chinook salmon that were recovered and not recovered by size (small and large) during the second event. The division between small and large was determined through examination of length frequency histograms of carcasses collected in the second event. The chi-square statistic was used to test the null hypothesis of no difference between rates of recovery for small and large fish.

Timing:

Rates of recovery of chinook salmon marked during the first pass (early) and second pass (late) in Event 1 were used to evaluate timing bias. A contingency table was constructed using numbers of marked chinook salmon recovered and not recovered in Event 2 by time (early and late). The chi-square statistic was used to test the null hypothesis of no significant difference between rates of recovery of chinook salmon marked during the early pass and late pass in Event 1.

Location:

To evaluate rates of capture by river section, a contingency table was constructed using numbers of marked and unmarked chinook salmon carcasses collected by section in Event 2. A chi-square statistic was used to test the null hypothesis of no difference between rates of capture.

To evaluate mixing of marked fish between river sections, a contingency table was constructed using numbers of marked chinook salmon carcasses that were and were not recovered during Event 2. A chi-square statistic was used to test the null hypothesis that section of capture in Event 2 was independent of section of release in Event 1.

<u>Abundance Estimator</u>

Based on the results of these tests, abundance was estimated using an unstratified 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:

$\hat{N}$ = estimated abundance of chinook salmon;
n_1 = number of chinook salmon marked in Event 1;
n_2 = number of chinook salmon carcasses collected in Event 2; and,
m_2 = number of chinook salmon carcasses with marks in Event 2.
$V(\hat{N})$ = variance of $\hat{N}$

The sampling bias of the abundance estimate was investigated with bootstrap procedures (Efron and Gong 1983). One thousand bootstrap samples were drawn randomly from the capture histories of all 1,022 fish in the experiment. Each bootstrap sample was built by randomly drawing 1,022 fish with replacement from the body of the capture histories. An estimate of abundance was calculated for each bootstrap sample with Equation 1 giving 1,000 estimates of abundance. The measure of the statistical bias was the difference between the point estimate from the original sample and the average of the 1,000 estimates from the bootstrap procedure.

Tag Loss

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

$$\hat{p}_t = n_u/n_r \quad \text{and,} \tag{3}$$

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

where:

$\hat{p}_t$ = proportion of tags lost;
n_u = number of recovered fish without jaw tags;
n_r = total number of marked fish recovered; and,
$\hat{V}(\hat{p}_t)$ = variance of $\hat{p}_t$.

Age, Sex, and Length Compositions

Proportions of females and males by ocean age or length interval were estimated using:

$$\hat{p}_i = a_i/n \quad \text{and,} \tag{5}$$

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

where:

$\hat{p}_i$ = estimated proportion of females (or males) of ocean age i or length interval i;
a_i = number of females (or males) of ocean age i or length interval i in Event 2;
n = total number of females and males in Event 2; and,
$\hat{V}(\hat{p}_i)$ = variance of $\hat{p}_i$.

Abundance of females (or males) of ocean age i or length interval i in the population was estimated using:

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

Variance of the product N_i was estimated using an exact variance of products (Goodman 1960):

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

<u>Egg Production From Escapement</u>

Predictions of fecundity for a given length were estimated as follows (Skaugstad and McCracken 1991):

$$\hat{F} = a_o + b_o L_j \quad (9)$$

$$\hat{V}(F_j) = MSE_o \left\{ 1 + \frac{1}{n_o} + \frac{(L_j - \bar{L}_o)^2}{\sum L_{oi}^2 - (\sum L_{oi})^2/n_o} \right\} \quad (10)$$

where:

- $\hat{F}_j$ = fecundity of fish j captured in 1991;
- L_j = length of fish j captured in 1991;
- L_{oi} = length of fish i (from Skaugstad and McCracken 1991);
- n_o = sample size (49, from Skaugstad and McCracken 1991);
- a_o = y-intercept (-7,940, from Skaugstad and McCracken 1991);
- b_o = slope (20, from Skaugstad and McCracken 1991)
- MSE_o = mean square error (2,365,812, from Skaugstad and McCracken 1991); and,
- $\hat{V}(F_j)$ = variance of $\hat{F}_j$.

Egg production of the spawning chinook salmon was estimated using:

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

$$\hat{V}(E) = \sum \hat{V}(\hat{N}_i\hat{F}_i); \text{ and,} \quad (12)$$

$$V(\hat{N}_i\hat{F}_i) = \hat{N}_i^2\hat{V}(F_i)+\hat{F}_i^2\hat{V}(N_i)-\hat{V}(N_i)\hat{V}(F_i) \quad (13)$$

where:

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

$\hat{N}_i$ = estimated number of females of length interval i;

$\hat{F}_i$ = mean fecundity for females of length interval i (Skaugstad and McCracken 1991) for chinook salmon in the Tanana River drainage;

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

$V(\hat{F}_i)$ = variance of the mean fecundity for females of length interval i; and,

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

Aerial Survey

Personnel from the Fairbanks office of the Division of Commercial Fisheries of the Alaska Department of Fish and Game counted live and dead adult chinook salmon in the Salcha River on 20 July. Counts were made from low flying, fixed-wing aircraft. Barton (1987c) described the methods used for these aerial surveys.

RESULTS

In the first event, 475 chinook salmon were captured, marked, and released. During the second event, 706 chinook salmon carcass were collected and examined for marks. Of these fish, 59 were marked.

Tests of Assumptions for Abundance Estimator

Results from these tests were used to select an appropriate abundance estimator and methods for estimating age, sex, and length compositions.

Gear Bias:

Rates of recovery of males and females were 0.12 and 0.14, respectively. Rates of recovery were not significantly different ($P = 0.53$, Table 3).

Length distributions of live chinook salmon captured in Event 1 and marked chinook salmon carcasses collected in Event 2 were not different ($P = 0.31$; Figure 2). Length distributions of live chinook salmon captured in Event 1 and all chinook salmon carcasses recovered in Event 2 were different ($P = 0.0035$; Figure 2). These tests indicated that there was no size selectivity during Event 2 but there was during Event 1. Only chinook salmon collected during Event 2 were used to estimate sex and age compositions. Length distributions of chinook salmon captured in the Salcha River were bi-modal (Figures 3a, 3b, 3c). Rates of recovery of small fish (0.10) and large fish (0.13) were not significantly different ($P = 0.56$, Table 4).

Table 3. Number of marked male and female chinook salmon carcasses collected in Event 2.

	Males	Females	Total
Recovered	36	23	59
Not recovered	275	141	416
Total released	311	164	475
Recovery rate	0.12	0.14	0.12

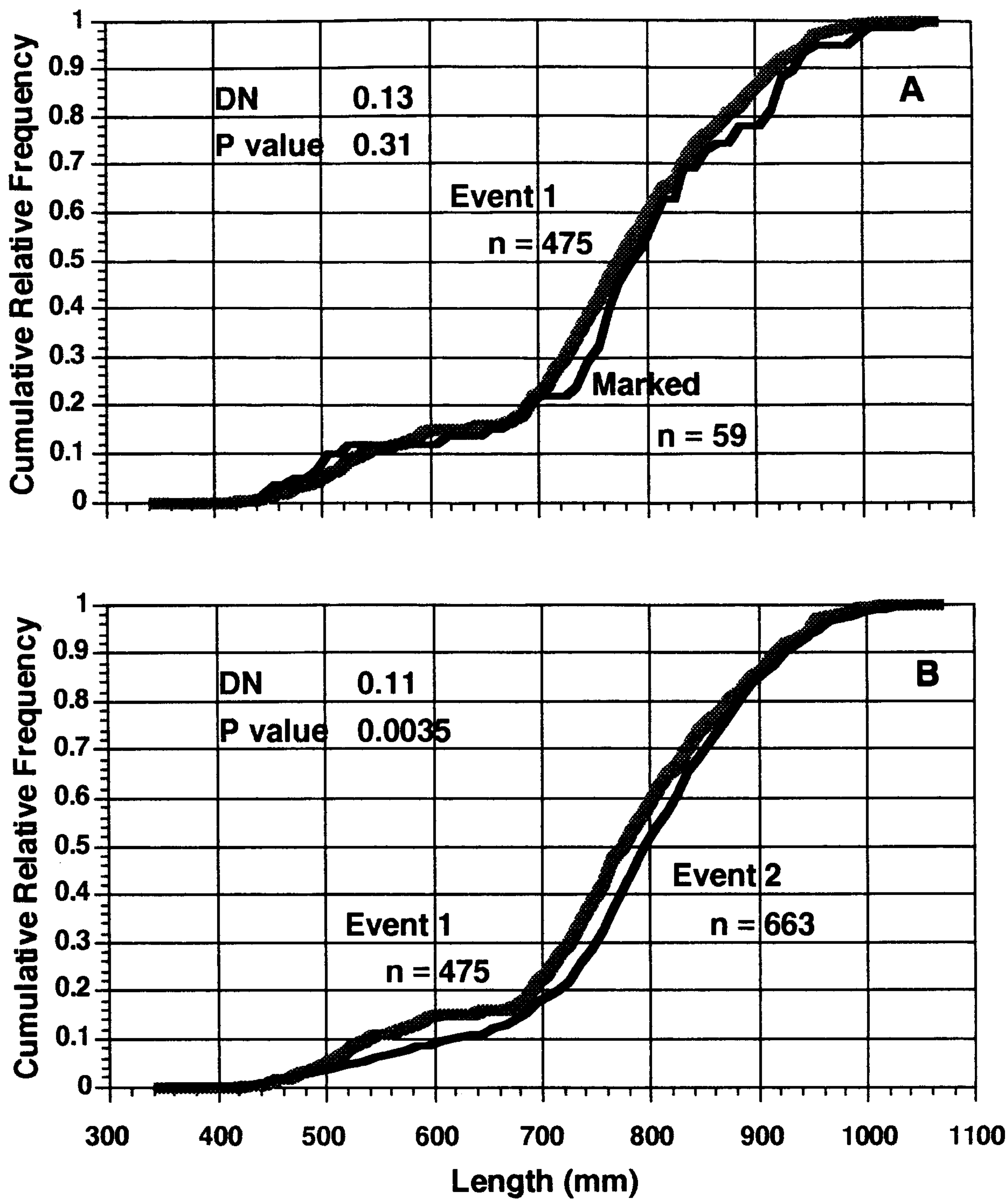

Figure 2. Cumulative relative frequency of chinook salmon captured in Event 1 and marked chinook salmon recovered in Event 2 (A); and all chinook salmon captured in Event 1 and collected in Event 2 (B).

Timing:

Rates of recovery of marked chinook salmon were 0.11 (early) and 0.14 (late) (Table 5). Rates of recovery were not significantly different (P = 0.37).

Location:

Rates of capture in Sections 1, 2, and 3 were 0.08, 0.09, and 0.08 (Table 6). Rates of capture were not significantly different (P = 0.88).

The chi-square statistic could not be used to evaluate the level of mixing of marked salmon between sections because one-third of the expected values were less than five. In chi-square analysis 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, examination of the capture history showed there was only partial mixing of marked fish between sections and movement from one section to another was usually downstream (Table 7).

<u>Abundance Estimate</u>

The estimated abundance of spawning chinook salmon in the Salcha River was 5,608 (SE = 664). The estimated sampling bias of the abundance estimate was 100 (Figure 4).

<u>Tag Loss</u>

Of the 59 marked fish recovered during the second event, 46 had jaw tags and 13 were identified by fin clips because jaw tags were lost. The estimated proportion of tags lost was 0.22 (SE = 0.054).

<u>Age, Sex, and Length Compositions</u>

Of the 706 chinook salmon carcasses collected during the second event, ages were obtained for 513 fish. These fish spent 1 to 6 years in the ocean and all fish spent one year in freshwater (Table 8). The dominant age class for males was 1.3 (brood year 1986) and for females was 1.4 (brood year 1985).

Proportions of males and females were about 0.55 and 0.45. Based on these proportions, estimates of abundance for males was 3,086 (SE = 380) and for females was 2,522 (SE = 317).

Lengths of males ranged from 355 to 1,055 mm and females ranged from 690 to 1,045 mm (Table 9). The distribution of lengths of females had one mode while the distribution of lengths of males had two modes (Figures 3a, 3b, 3c). Mean lengths of females was greater than mean lengths of males for ages 1.3, 1.4 and 1.6 (Table 9). Age of males less than 660 mm ranged from 1.1 to 1.3 (Table 9).

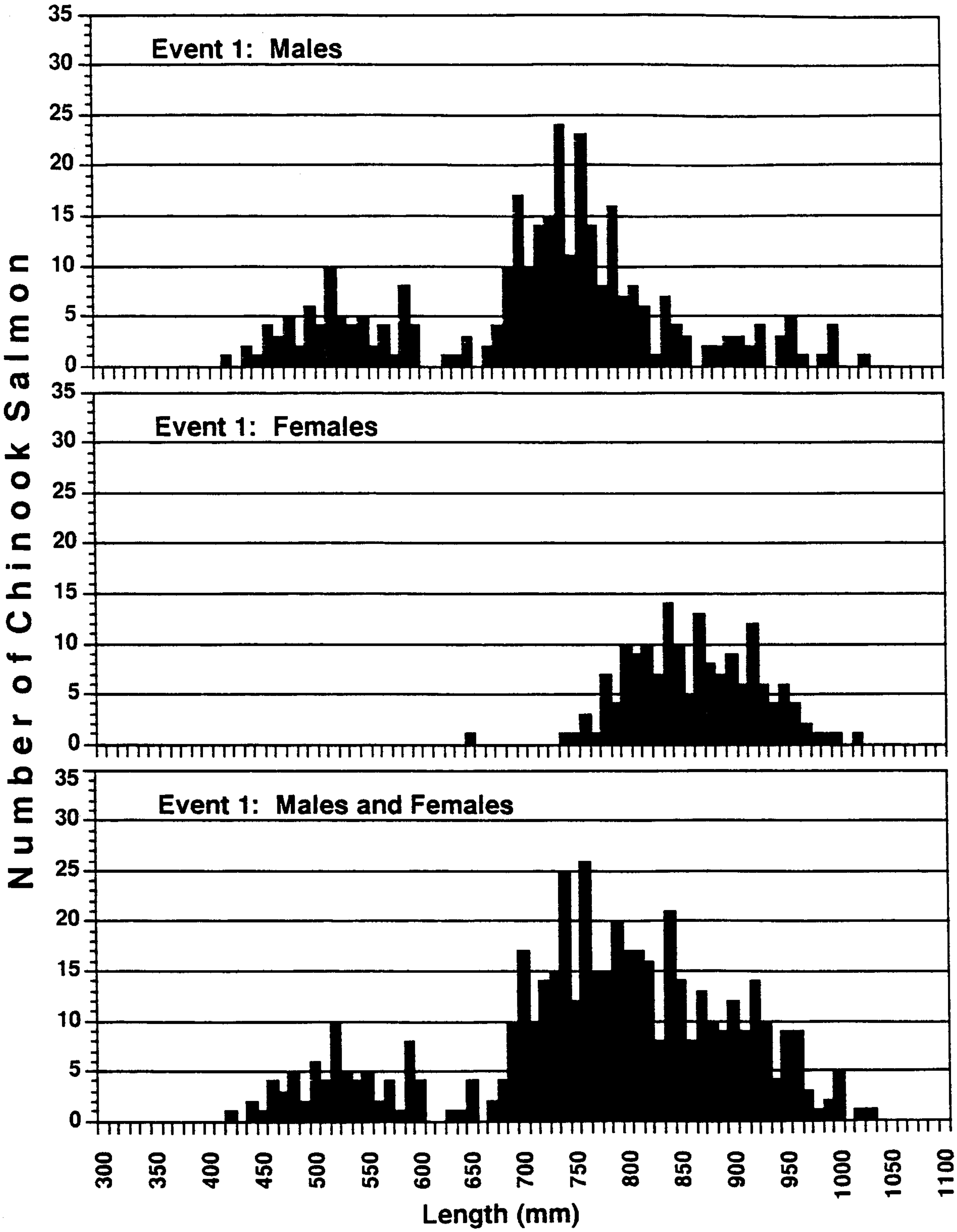

Figure 3a. Histogram of lengths of chinook salmon captured in Event 1.

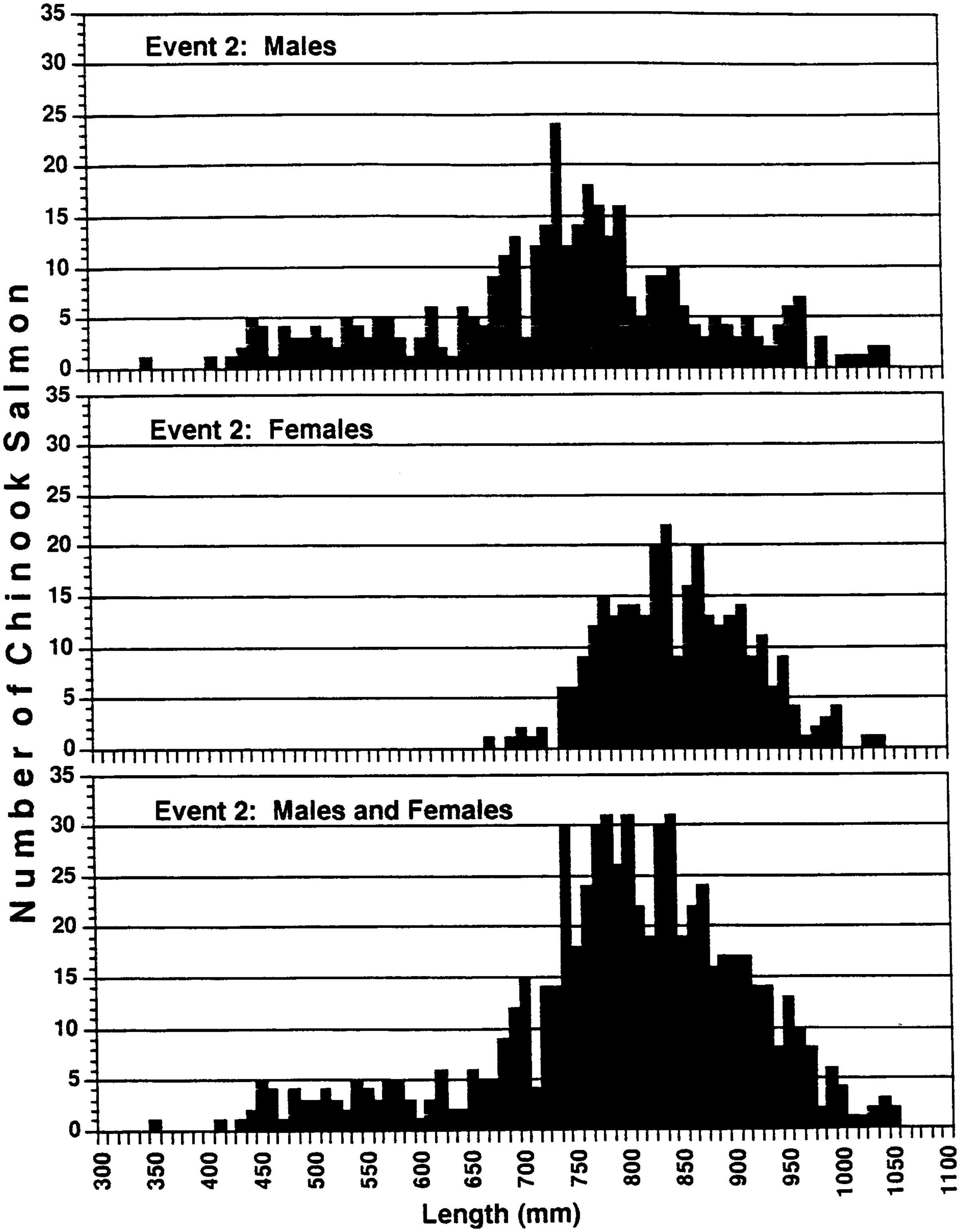

Figure 3b. Histogram of lengths of chinook salmon captured in Event 2.

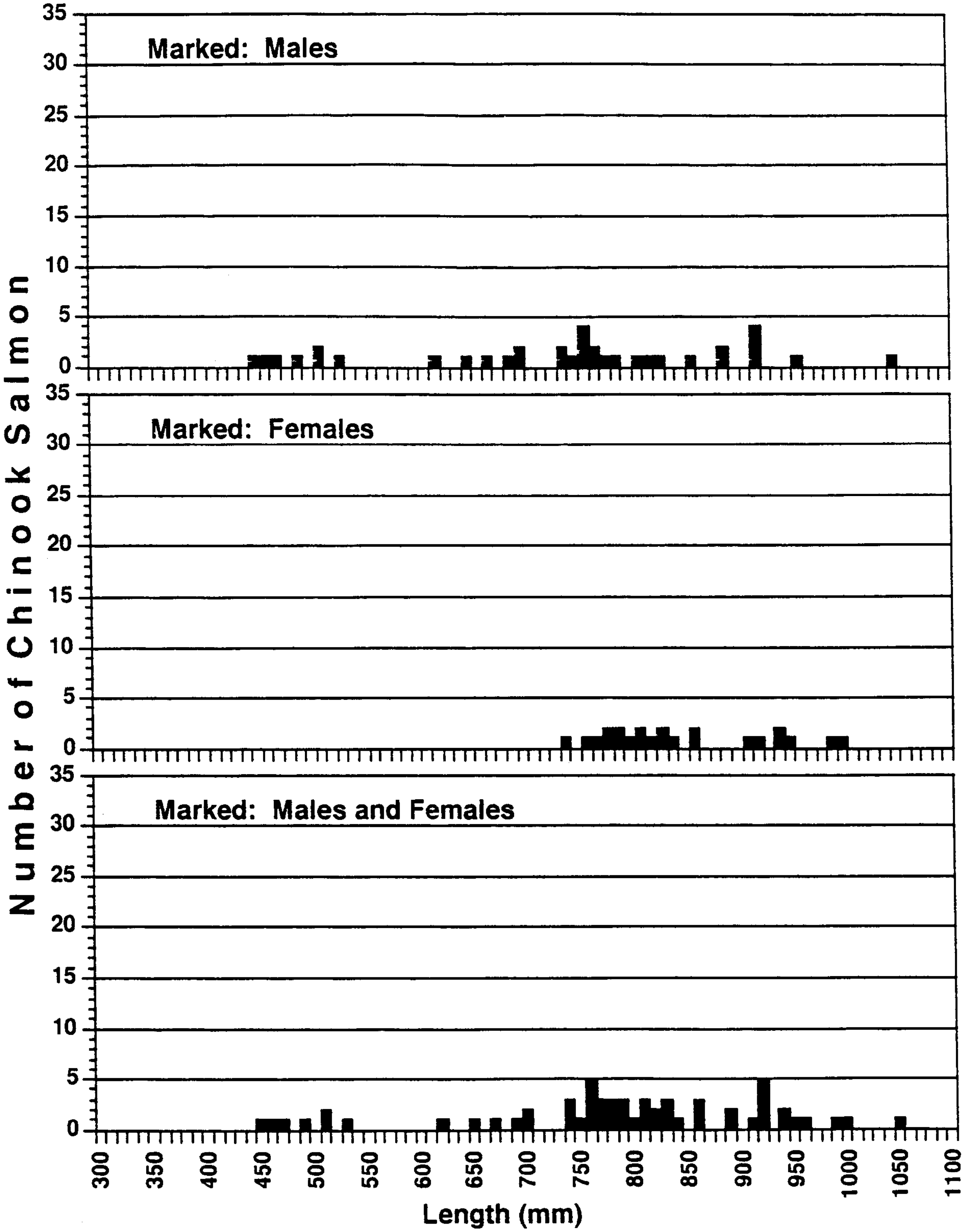

Figure 3c. Histogram of lengths of marked chinook salmon captured in Event 2.

Table 4. Number of small and large chinook salmon carcasses collected in Event 2.

	Small	Large	Total
Recovered	8	51	59
Not recovered	69	347	416
Total released	77	398	475
Recovery rate	0.10	0.13	0.12

Table 5. Number of chinook salmon carcasses recovered in Event 2 that were marked in the first pass (early) and second pass (late) in Event 1.

	Early	Late	Total
Recovered	22	37	59
Not recovered	181	235	416
Total released	203	272	475
Recovery rate	0.11	0.14	0.12

Table 6. Number of marked and unmarked chinook salmon carcasses collected in Event 2 by river section.

	River Section			
	1(Upper)	2(Middle)	3(Lower)	Total
Marked	25	20	14	59
Unmarked	280	202	165	647
Total collected	305	222	179	706
Recovery rate	0.08	0.09	0.08	0.08

Table 7. Capture and recovery history of chinook salmon by river section.

River Section Where Marked Fish Were Released	River Section Where Marked Fish Were Recovered				Number Marked	Number Not Recovered
	1(Upper)	2(Middle)	3(Lower)	Total		
1(Upper)	24	7	0	31	228	197
2(Middle)	0	12	4	16	164	148
3(Lower)	1	1	10	12	83	71
Total	25	20	14	59	475	416
Unmarked Carcasses	280	202	165	647		
Total Carcasses	305	222	179	706		

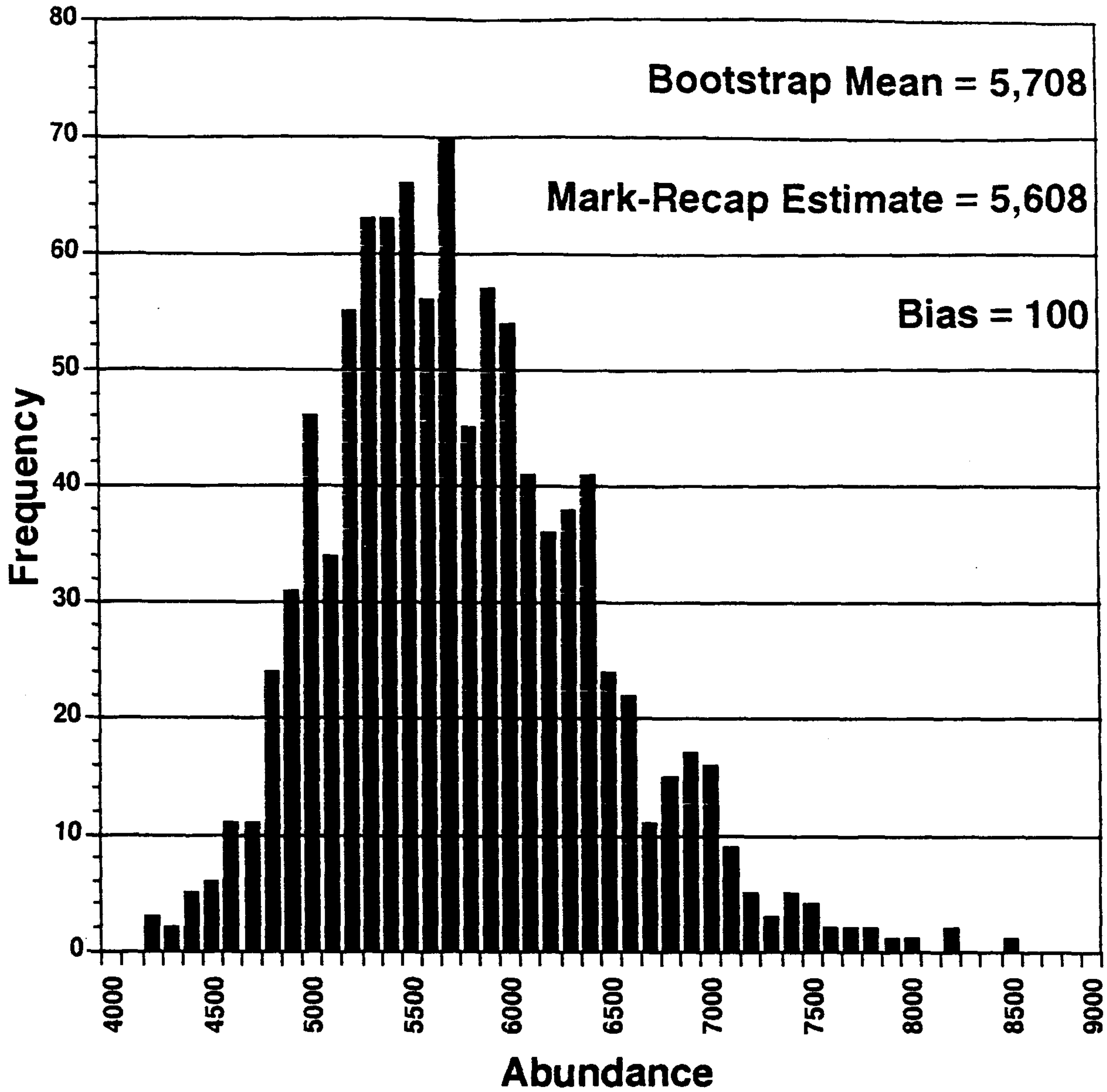

Figure 4. Frequency of 1,000 estimates of abundance using bootstrap procedures on the capture history from the mark-recapture experiment.

Table 8. Estimates of proportions and abundance of female and male chinook salmon by age class.[a]

Age Class	Sample Size	Proportion	Standard Error	Abundance	Standard Error
Females:					
1.1	0				
1.2	0				
1.3	32	0.062	0.011	350	73
1.4	164	0.320	0.021	1,793	241
1.5	44	0.086	0.012	481	87
1.6	1	0.002		11	11
Sub-totals	241	0.470	0.026	2,635	268
Males:					
1.1	1	0.002	0.002	11	11
1.2	39	0.076	0.012	426	82
1.3	133	0.259	0.019	1,454	203
1.4	84	0.164	0.016	918	142
1.5	14	0.027	0.007	153	44
1.6	1	0.002	0.002	11	11
Sub-totals	272	0.530	0.029	2,973	265
Sexes combined:					
1.1	1	0.002	0.002	11	11
1.2	39	0.076	0.012	426	82
1.3	165	0.322	0.021	1,804	243
1.4	248	0.483	0.022	2,711	344
1.5	58	0.113	0.014	634	108
1.6	2	0.004	0.003	22	16
Total	513	1.000	0.035	5,608	443

[a] For this analysis, only chinook salmon were used that were captured in Event 2 for which both age and length data were collected.

Table 9. Estimated length-at-age of chinook salmon.

Ocean Age	Sample Size	Length (mm) Mean	SE	Range
Females:				
1	0			
2	0			
3	31	771	6	690 - 840
4	162	851	4	740 - 980
5	43	911	9	785 - 1,045
6	1	995		
Males:				
1	1	355		
2	38	522	9	415 - 620
3	130	729	6	460 - 890
4	83	830	8	585 - 1,045
5	14	991	11	920 - 1,055
6	1	975		
Females and Males:				
1	1	355		
2	38	522	9	415 - 620
3	161	737	5	460 - 890
4	245	844	4	585 - 1,045
5	57	931	9	785 - 1,055
6	2	985	10	975 - 995

Population Egg Production

The estimated egg production of the spawning population was 23 million eggs (SE = 1.7 million; Table 10). Estimates of annual egg production since 1987 are summarized in Table 11.

Aerial Survey

During the aerial survey on 20 July, 2,212 chinook salmon were counted, about 39% of the estimated abundance of 5,608 (Table 12). The survey was rated "poor" because the biologist conducting the survey thought it occurred a few days before the greatest number of spawners were in the river (peak spawning). Since 1987, the proportion of the population observed during aerial surveys ranged from 0.35 to 0.71 and the proportion decreased as abundance increased (Table 12).

DISCUSSION

Examination of data from the mark-recapture experiment indicated that marked chinook salmon only partially mixed between river sections. The recapture history of marked chinook salmon for other mark-recapture experiments conducted with chinook salmon from the Salcha River (Skaugstad 1988, 1989, and 1990a; Burkholder 1991) and Chena River (Skaugstad 1990b and Evenson 1991) also showed partial mixing. Partial mixing is expected due to the experimental design and death of chinook salmon after spawning. When captured for marking (Event 1), 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 into areas with lower velocities and pools. Therefore, any mixing that occurred would be mainly downstream.

A potential problem with using electricity to stun fish is the possibility of injury that may affect the probability of recovery in Event 2. If chinook salmon suffered premature death from either electrofishing, handling during marking, or both, then probabilities of capture of marked and unmarked chinook salmon during Event 2 would be different. Different probabilities of recovery would cause the estimate of abundance to be less or more than the actual abundance. Marked chinook salmon that die early in the mark-recapture experiment are probably less likely to be collected depending on the time between events. As time increases between events, the ability to see carcasses probably decreases because carcasses are covered with silt, drift out of the study area, or decompose.

However, if marked and unmarked chinook salmon die within a short period after spawning, then the probabilities of collecting marked and unmarked fish should be equal. This experiment was designed so premature death of marked fish would have little effect on the probability of recovery. Event 1 occurred after most chinook salmon spawned but were still alive. Collection of carcasses occurred ten days after the start of Event 1 after most chinook salmon died. Therefore, due to the short period between events, any injury suffered during Event 1 that may have caused premature death should have

Table 10. Estimated potential egg production of chinook salmon from the Salcha River, 1991, based on relationship between length and fecundity. Relationship between length and fecundity estimated by Skaugstad and McCracken (1990).

Length (mm)	Number of Fish	SE (fish)	Egg Production (eggs)	SE (eggs)
680	8	8	48,000	48,000
690	8	8	49,000	49,000
700	17	12	102,000	75,000
710	0	0	0	0
720	17	12	109,000	80,000
730	8	8	56,000	56,000
740	17	12	115,000	85,000
750	42	19	297,000	150,000
760	67	25	489,000	209,000
770	101	31	753,000	283,000
780	127	35	967,000	339,000
790	118	34	926,000	327,000
800	135	37	1,085,000	367,000
810	93	30	764,000	285,000
820	143	38	1,210,000	395,000
830	110	33	947,000	331,000
840	219	49	1,938,000	561,000
850	84	28	762,000	286,000
860	93	30	857,000	310,000
870	152	39	1,433,000	444,000
880	160	41	1,544,000	468,000
890	110	33	1,079,000	364,000
900	127	35	1,270,000	408,000
910	76	27	777,000	296,000
920	84	28	880,000	321,000
930	118	34	1,256,000	407,000
940	59	23	640,000	266,000
950	67	25	745,000	293,000
960	42	19	474,000	226,000
970	25	15	289,000	173,000
980	8	8	98,000	98,000
990	8	8	100,000	100,000
1,000	42	19	508,000	241,000
1,010	17	12	206,000	148,000
1,020	0	0	0	0
1,030	8	8	107,000	107,000
1,040	0	0	0	0
1,050	8	8	110,000	110,000
Totals	2,522		22,989,000	1,674,000[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 11. Potential egg production of chinook salmon in the Salcha River, 1987-1991.

Year	Estimated Abundance				Estimated Production (millions)	
	Population	(SE)	Females	(SE)	Eggs	(SE)
1987	4,771	504	2,481	349	25.9	3.2
1988	4,562	556	1,525	197	16.2	2.8
1989	3,294	630	1,704	484	16.6	1.8
1990	10,728	1,405	5,322	735	52.0	2.7
1991	5,608	644	2,522	197	23.0	1.7

Table 12. Estimated abundance, peak aerial counts, aerial survey conditions, and proportions observed during peak aerial surveys for chinook salmon escapement in the Salcha River, 1987-1991.

Year	Estimated Abundance	SE	Aerial Survey Count	Aerial Survey Condition[a]	Proportion Observed During Peak Aerial Survey
1987	4,771	504	1,898	Fair	0.40
1988	4,562	556	2,761	Good	0.61
1989	3,294	630	2,333	Good	0.71
1990	10,728	1,404	3,744	Good	0.35
1991	5,608	664	2,212	Poor	0.39[b]

[a] During these surveys, conditions were judged on a scale of "poor, fair, good".
[b] Aerial survey was made a few days before spawning peaked.

caused little, if any, difference between the probabilities of collecting marked and unmarked carcasses. Five years of using electricity to stun chinook salmon has shown that electricity is an efficient method of capturing chinook salmon. The potential harm to unspawned chinook salmon is low because most fish have finished spawning. In Event 2, no unspawned female chinook salmon were collected which suggests either the timing of Event 1, the use of electricity, or both, did not impair successful spawning.

Effect of continuous direct current (cdc) and pulsating direct current (pdc) on egg viability and survival for chinook salmon has not been investigated under field conditions. Information for other species under laboratory and pseudo-field conditions is mixed. Fecundity of rainbow trout and survival of eggs were not affected by pdc (Maxfield et al. 1971). CDC caused higher mortality rates during early development of Atlantic salmon *Salmo salar* and brook trout *Salvelinus fontinalis* eggs that were placed in a concrete trough (Godfrey 1957). Mortality rates also increased with increased power. As egg development progressed, mortality rates decreased and increased power had little effect on increasing mortality rates. Mortality rates were less for eggs in gravel. These studies suggest egg survival in redds is probably dependent on development stage, electrical gradient, and duration of the electrical field. During Event 1 when electricity is used, most eggs were in redds from 0 to 7 days (based on observations of spawning during aerial surveys) and were exposed to the electrical field for no more than 10 seconds. The effect of electricity on chinook salmon eggs under these conditions is not known but is assumed to be negligible.

Attempts to estimate a relationship between the proportion of the population of chinook salmon observed during aerial surveys and estimates of abundance from mark-recapture experiments have shown that 1) there is an inverse relationship between the proportion of the population observed during an aerial survey and the size of the population; and, 2) the proportion of the population observed during an aerial survey is dependant on environmental factors and timing of the survey with peak spawning. Because of the effect of these factors, the number of paired aerial surveys and mark-recapture experiments since 1987 does not provide an adequate sample size for estimating a useful relationship.

The 95% confidence limits of the abundance estimate ($\pm$ 23% of the point estimate) were within the objective set in the operational plan (within 25% of the actual value 95% of the time). This indicates the numbers of chinook salmon captured in Events 1 and 2 were adequate to meet the objective. The small sampling bias of the abundance estimate (100) suggests the assumptions basic to the mark-recapture experiment were not significantly violated. When assumptions are violated, the sampling bias increases as the frequency distribution of the bootstrap estimates become more positively skewed.

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