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Abundance, Egg Production, and Age-Sex-Length Composition of the Chinook Salmon Escapement in the Chena River, 1992

by

Matthew J. Evenson

March 1993

Alaska Department of Fish and Game

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ABSTRACT

In 1992, the number of adult chinook salmon *Oncorhynchus tshawytscha* 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 799 chinook salmon in late July and early August. Captured chinook salmon were marked with jaw tags, fin-clipped, and released. In early August, 581 chinook salmon carcasses were collected. Eighty-eight of these carcasses had been marked. The estimate of abundance was 5,230 (SE = 478) chinook salmon. The estimated number of females and males were 1,607 (SE = 162) and 3,623 chinook salmon (SE = 338), respectively. Estimated potential egg production was 14.9 million eggs (standard error = 1.1). Mean length-at-age statistics and age class composition estimates are presented. During aerial surveys, the highest count of live and dead chinook salmon was 825, or 16 percent of the mark-recapture point estimate.

KEY WORDS: chinook salmon, *Oncorhynchus tshawytscha*, Chena River, abundance, age-sex-size composition, aerial survey, egg production.

INTRODUCTION

Management of stocks of Yukon River chinook salmon *Oncorhynchus tshawytscha* is complex and requires accurate estimates of escapement for 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 sub-districts of the Yukon River commercial fishery. Chinook salmon returning to the Chena River contribute to these down-river commercial fisheries as well as to several subsistence, personal use, and sport fisheries (Table 1). A sport fishery takes place in the lower 72 km of the Chena River (Figure 1).

To perpetuate the fisheries and stocks of chinook salmon, fishery managers set commercial, subsistence, personal use, and sport harvest limits with the objective of achieving the escapement goal (1,400 spawners). This goal is based on an average of aerial survey counts. Harvest levels for the current year are set 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. The sport fishery in the Chena River is managed based on a guideline harvest range of 300 to 600 chinook salmon.

The Chena River has one of the largest chinook salmon escapements in the Yukon River drainage. Estimates of abundance and age-sex-size compositions using mark-recapture techniques have been obtained since 1986 in the Chena River (Barton 1987a, 1988; Barton and Conrad 1989; Skaugstad 1990a; and Evenson 1991, 1992). The "in-season" escapements for various spawning stocks have historically been determined by aerial counts of chinook salmon on or near the spawning grounds. From 1974 to 1990 the highest annual count of chinook salmon in the Chena River during aerial surveys has ranged from less than 500 to more than 2,500 fish (Barton pers. comm.[1]). 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. Numbers of mature chinook salmon counted during aerial surveys of the Chena River from 1986 through 1991 were 22, 20, 59, 44, 26, and 42% respectively, of the estimated abundance from mark-recapture experiments. In addition to underestimating abundance, aerial surveys do not provide estimates of age-sex-size compositions or potential egg production, which are needed to better assess the quality of the spawning escapement.

The specific objectives in 1992 were to estimate:

1. the abundance of adult chinook salmon in the Chena River; and,

2. the age, sex, and length compositions of chinook salmon in the Chena River.

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[1] Barton, Louis. 1990. Personal Communication. ADF&G, 1300 College Rd., Fairbanks, AK 99701.

Table 1. Harvests of anadromous chinook salmon by sport, commercial, subsistence, and personal use fisheries, Tanana River drainage, 1978 through 1992.

Year	On-Site Sport Harvest Estimates[a]		Statewide Survey Estimates of Sport Harvest[b]						Estimated Harvest by User Group		Total Known Harvest
	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]	
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]	5,441[eg]	7,090
1989	685	123	375	231	231	39	87	963	2,181[d]	3,046[eg]	5,001
1990	24	200	64	291	37	0	0	439	2,989[d]	3,759[eg]	7,140[g]
1991	none	362	110	373	82	11	54	630	1,163[dg]	2,687[eg]	4,480[g]
1992	none	4[h]	N.A.[f]	N.A.	N.A.	N.A.	N.A.	N.A.	712[dg]	N.A.	N.A.

[a] Creel census estimates from Clark and Ridder (1987), Baker (1988, 1989), Merritt et al. (1990), and Hallberg and Bingham (1991 and 1992).

[b] Sport fishery harvest estimates from Mills (1979-1992).

[c] Commercial, subsistence, and personal use estimates (Schultz, Keith. 1991. Personal Communication. Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701.

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

[g] Preliminary data and subject to change.

[h] Data from Hallberg and Bingham *In press*.

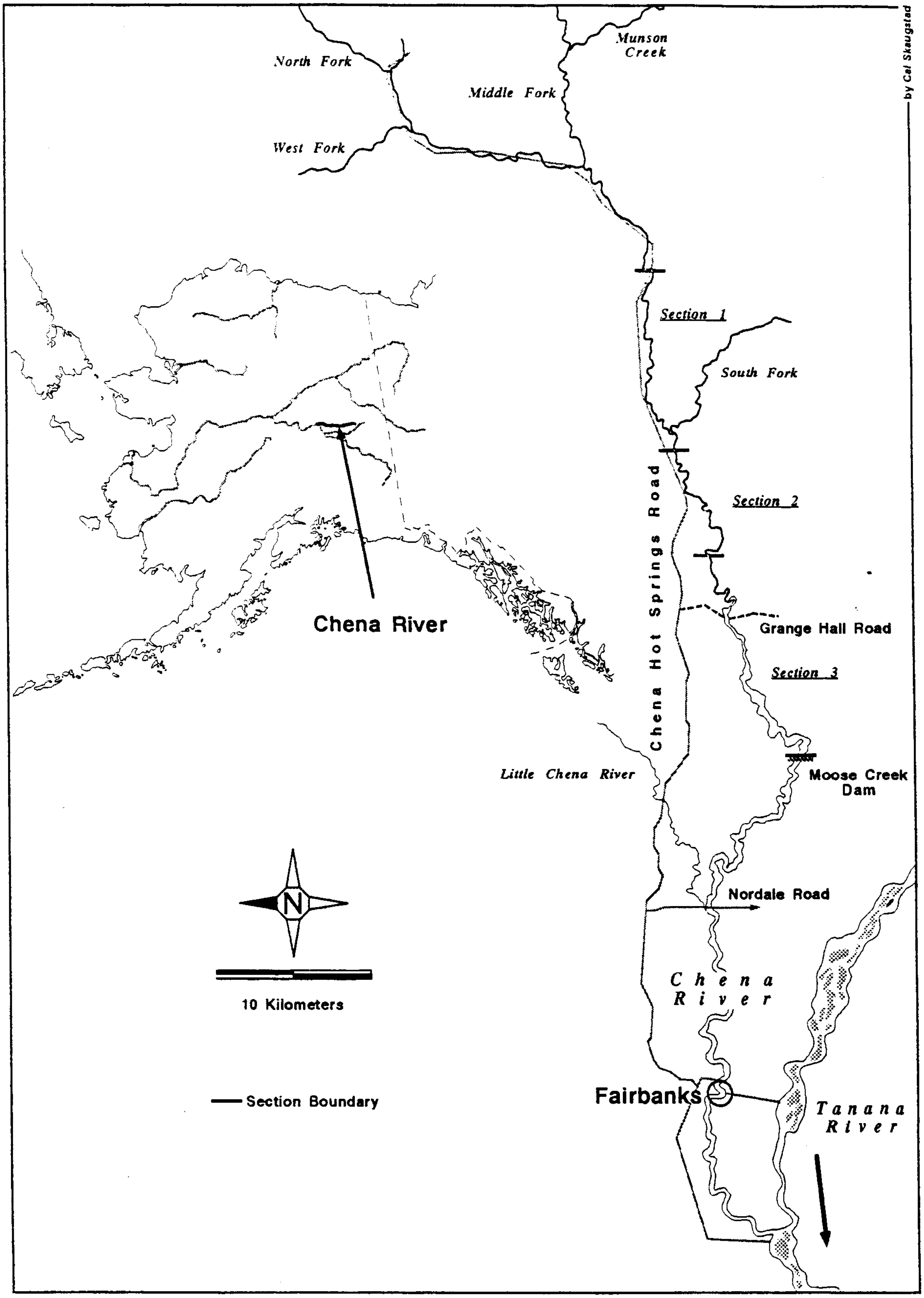

Figure 1. Chena River study area.

Potential egg production resulting from the 1992 escapement was estimated. Escapement counts obtained by Division of Commercial Fisheries staff through aerial surveys are presented and compared with mark-recapture estimates. Also included in this report are age, sex, and length compositions of chinook salmon sampled during 1992 from the Goodpaster River. These data are not related to research conducted on the Chena River, but are included in this report as a convenient means of archiving chinook salmon escapement information in a Tanana River tributary.

MATERIALS AND METHODS

Capture and Marking

Adult chinook salmon were captured between 29 July and 5 August using a riverboat equipped with electrofishing gear (Clark 1985; Table 2). 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 river kilometer 72 to river kilometer 145 (measured from the mouth) was sampled in this manner. Past aerial surveys of the Chena River have shown that almost all chinook salmon spawn in this area (Skaugstad 1990a). The sample area was divided into three approximately equal sections (Figure 1). During the first marking event (29, 30, and 31 July), one pass was made through each section. Each pass through a section started at the upstream end of the section and progressed downstream. Similarly, during the second marking event (3, 4, and 5 August), one pass was made through all three sections (Table 3).

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, and pelvic fin clips were used to monitor tag loss and to identify the location and period of capture of those fish loosing tags. 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, and from the presence of stripped eggs or milt.

Recovery

Tags were recovered from chinook salmon carcasses from the same three river sections in which electrofishing occurred. Three passes were made through each section in a drifting riverboat starting at the upstream end of each section (Table 3). Long handled spears were used to collect carcasses. The carcasses were measured and examined for fin clips and jaw tags. The sex was determined from observation of body morphology. Three scales were removed from each carcass and placed onto gum cards for age analysis. These gum cards were used to make impressions of the scales on triacetate film (using a Carver laboratory press model 2518: 2 min at 15,000 lbs at a temperature of 250°F). Ages were determined by counting annuli on these impressions with the aid of a microfiche reader. Scales were taken from the left side approximately two rows above the lateral line and along a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Clutter and Whitesel 1956).

Table 2. Description of equipment and control settings used 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.

Table 3. Catches of chinook salmon by day and by sampling area for electrofishing and carcass surveys conducted during 1992.

River Section	Marking Event (Electrofishing)			Recapture Event (Carcass Survey)			
	Pass 1	Pass 2	Total	Pass 1	Pass 2	Pass 3	Total
<u>Upper</u>							
Date	Jul 29	Aug 3		Aug 6	Aug 11-12	Aug 17	
Males	132	103	235	41	46	26	113
Females	41	37	78	24	22	14	60
Total	173	140	313	65	68	40	173
<u>Middle</u>							
Date	Jul 30	Aug 4		Aug 7	Aug 12-13	Aug 18-19	
Males	121	144	265	76	90	34	200
Females	57	54	111	54	48	23	125
Total	178	198	376	130	138	57	325
<u>Lower</u>							
Date	Jul 31	Aug 5		Aug 5	Aug 14	Aug 20	
Males	43	33	76	13	38	5	56
Females	18	16	34	8	12	7	27
Total	61	49	110	21	50	12	83
<u>All Sections</u>							
Date	Jul 29-31	Aug 3-5		Aug 5-7	Aug 11-14	Aug 17-20	
Males	296	280	576	130	174	65	369
Females	116	107	223	86	82	44	212
Total	412	387	799	216	256	109	581

Abundance Estimator

Abundance was estimated with the Chapman (1951) modified Petersen model (Seber 1982). Tests of the assumptions of this estimator (Appendix A1) indicated that the data required stratification into length classes to reduce bias in the abundance estimate caused by different capture rates among the length classes. Abundance and its associated variance were estimated by (Seber 1982):

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

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

where:

$\hat{N}$ = estimated abundance of chinook salmon;
n_1 = number of chinook salmon marked and released during Event 1;
n_2 = number of chinook salmon captured during Event 2; and,
m_2 = number of chinook salmon with marks in Event 2.

The stratified estimate of abundance was calculated by estimating abundance of each length class and then summing stratum estimates. Because the estimates were assumed independent, the variance of total abundance was also estimated by summing stratum estimates of variance. A z-test was used to determine if the two estimates were different (Seber 1982, page 121).

Tag Loss

The proportion of tags lost during the study and the associated variance were estimated using:

$$\hat{p}_t = n_u/n_r; \text{ and,} \qquad (3)$$

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

where:

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

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

n_r = the total number of fish recaptured.

Age, Length, and Sex Compositions

Age composition was calculated from chinook salmon sampled during the carcass survey. Length and sex compositions were calculated from all chinook salmon sampled during both events. All estimates of proportions and associated variance were calculated similarly using the general formulae:

$$\hat{p}_z = n_z/n; \text{ and,} \tag{5}$$

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

where:

$\hat{p}_z$ = the estimated proportion (by sex, age, or length) of chinook salmon in category z;

n_z = the number of chinook salmon in category z; and,

n = the total number of chinook salmon in the sample.

The abundance of each sex-age group was estimated using:

$$\hat{N}_{sa} = (\hat{p}_a)(\hat{p}_s)(\hat{N}) \tag{7}$$

The variance was estimated using (Goodman 1960):

$$V(\hat{N}_{sa}) = \hat{N}^2\hat{p}_s^2V(\hat{p}_a) + \hat{N}^2\hat{p}_a^2V(\hat{p}_s) + \hat{p}_s^2\hat{p}_a^2V(\hat{N}) - \hat{N}^2V(\hat{p}_s)V(\hat{p}_a) - \hat{p}_s^2V(\hat{N})V(\hat{p}_a) - \hat{p}_a^2V(\hat{N})V(\hat{p}_s) + V(\hat{N})V(\hat{p}_s)V(\hat{p}_a) \tag{8}$$

where:

$\hat{N}$ = the estimated abundance for all chinook salmon

$V(\hat{N})$ = the variance of abundance

$\hat{p}_s$ = the estimated proportion of chinook salmon of sex s;

$V(\hat{p}_s)$ = the variance of the estimated proportion of chinook salmon of sex s;

$\hat{p}_a$ = the estimated proportion of chinook salmon of age a;

$V(\hat{p}_a)$ = the variance of the estimated proportion of chinook salmon of age a;

Estimates of mean length-at-age were generated with standard normal procedures. Simple averages and squared deviations from the mean were used to calculate means and variances of the means.

Potential Egg Production

Fecundity for chinook salmon of a given length was predicted using a regression model of fecundity against length (Skaugstad and McCracken 1991) developed from a sample of 49 female chinook salmon collected from the Tanana River during 1989. The variables and parameters from this study are designated with subscript "o" below. The model was used to estimate fecundity and associated variance for the smallest possible female in each 10 mm length interval:

$$\hat{F}_k = a_o + b_o \underline{L}_k\text{; and,} \qquad (9)$$

$$\hat{V}(\hat{F}_k) = MSE_o \left\{ 1 + \frac{1}{n_o} + \frac{(\underline{L}_k - \bar{L}_o)^2}{\sum L_{oi}^2 - (\sum L_{oi})^2/n_o} \right\} \qquad (10)$$

where:

$\hat{F}_k$ = fecundity of the smallest possible fish in 10 mm length interval k;
$\underline{L}_k$ = lower limit of 10 mm length interval k;
$\bar{L}_o$ = mean length of fish from sample o (902 mm);
L_{oi} = length of fish i in sample o;
n_o = size of sample o (49);
a_o = y intercept of sample o (-7,937.5);
b_o = slope of sample o (19.97);
MSE_o = mean square error from the regression of F on L from sample o (2,656,900); and,
$\hat{V}(\hat{F}_k)$ = variance of $\hat{F}_k$.

Potential egg production and associated variance was estimated by multiplying the estimated abundance of all females in a 10 mm length interval by the estimated fecundity of the smallest possible fish in that length interval:

$$\hat{E} = \sum \hat{N}_k \hat{F}_k\text{; and,} \qquad (11)$$

$$\hat{V}(\hat{E}) = \sum \hat{N}_k^2 \hat{V}(\hat{F}_k) + \hat{F}_k^2 \hat{V}(\hat{N}_k) - \hat{V}(\hat{N}_k)\hat{V}(\hat{F}_k) \qquad (12)$$

where:

$\hat{E}$ = the estimated potential egg production of spawning chinook salmon population;

$\hat{V}(\hat{E})$ = the variance of $\hat{E}$

$\hat{N}_k$ = the estimated number of females of length interval k (Equation 7);

$V(\hat{N}_k)$ = the variance of $\hat{N}_k$ (Equation 8).

$\hat{F}_k$ = the estimated fecundity of the smallest possible fish in length interval k (Equation 9); and,

$V(\hat{F}_k)$ = the variance of $\hat{F}_k$ (Equation 10).

Aerial Survey

Personnel from the Division of Commercial Fisheries of the Alaska Department of Fish and Game counted the total number of spawning chinook salmon in the Chena River on seven different occasions between 17 July and 11 August. Counts were made from low flying, fixed-wing aircraft. Barton (1987b) describes the methods used by the Division of Commercial Fisheries for aerial surveys.

Goodpaster River: Age, Length, and Sex Compositions

Chinook salmon carcasses were collected from the Goodpaster River on 4 August. Age and sex compositions, as well as proportions of male and female chinook salmon in 50 mm length categories were estimated using the procedures described above (Equations 5 and 6).

Hypothesis Tests and Computer Softwares

The hypothesis tests conducted in this experiment included Chi-square analysis and Kolmogorov-Smirnov two sample tests. In both cases, a test was considered significant when the probability of committing a type I error (α) was less than or equal to 0.05. Two statistical software packages were used for these tests. Chi-square analyses were performed using SAS (SAS Institute Inc., Cary, North Carolina), while Kolmogorov-Smirnov tests were performed using Statgraphics (Version 5.0; STSC Inc., Rockville, Maryland).

RESULTS

A total of 799 chinook salmon were captured, tagged, and released during the marking event. During the recapture event, 581 carcasses were collected and examined for tags and fin clips. Eighty-eight of these fish were marked. Three marked fish had lost jaw tags.

Tests of Equal Probability of Capture Assumptions for a Petersen Estimator

The following results were based on data from the mark-recapture experiment to test the hypotheses (described in Appendix A1) of equal probability of capture by sex, length, river area and time during at least one sampling event.

Equal Probability of Capture by Sex:

Recapture rates for males and females differed significantly (males = 0.09; females = 0.17; χ^2 = 11.46, df = 1, P = 0.001; Table 4). However, the probabilities of capture during the first event (marked to unmarked ratio during the carcass survey) were similar (χ^2 = 2.01, df = 1, P = 0.16) for males and females (Table 5). Thus, there was no sex selectivity during the first event.

Equal Probability of Capture by Length:

There were significant differences between the length distribution of all marked releases and the length distribution of all recaptures obtained during the carcass sample (D = 0.17; P = 0.022), and between the length distribution of all marked fish and the length distribution of all fish captured during the carcass survey (D = 0.17; $P > 0.016$; Figure 2). This indicated there was size selectivity during the carcass survey, while the selectivity of the marking event is unknown.

To minimize bias of unequal capture rates due to size, a stratified estimate of abundance was calculated. Based on the length frequency distribution, the data was initially divided into three length strata. Because there was no significant difference (χ^2 = 0.40, df = 1, P = 0.53) in capture rate between fish 630-760 mm and those >760 mm, these groups were pooled. This left two length strata, fish 350-629 mm and those ≥630 mm, which had different (χ^2 = 6.34, df = 1, P = 0.01) capture rates (Table 6).

Equal Probability of Capture by River Area:

The marked-to-unmarked ratios of chinook salmon were similar among the three river areas during the carcass sampling event (χ^2 = 5.574, df = 2, P = 0.062). Because this test was not significant, there was no need to test for mixing of fish among locations. However, examination of recapture rates by river area indicated that some mixing did occur (Table 7).

Equal Probability of Capture by Time During the Carcass Survey:

The marked to unmarked ratios differed among each of the three passes during the carcass survey (χ^2 = 16.558, df = 2, $P < 0.001$; Table 8). This indicated that either handling during the marking event facilitated a premature death, or that fish entered the river after the final marking pass and were not available for capture during the marking event.

Abundance Estimate

The unstratified estimate of abundance of all chinook salmon was 5,230 (SE = 478). The stratified estimates of abundance were 3,236 (SE = 544) for small chinook salmon (<630 mm) and 2,344 (SE = 247) for large chinook salmon (≥630 mm) giving a total abundance of 5,580 (SE = 597). The size selective bias associated with the unstratified estimate was not severe as there was no

Table 4. Number of male and female chinook salmon marked while electrofishing that were recovered and not recovered during carcass sampling.

	Males	Females	Total
Recovered	50	38	88
Not Recovered	526	185	711
Total Released	576	223	799
Recovery Rate	0.09	0.17	0.11

Table 5. Number of marked and unmarked male and female chinook salmon that were collected during carcass sampling.

	Males	Females	Total
Marked (m_2)	50	38	88
Unmarked	319	174	493
Total Caught (n_2)	369	212	581
m_2/n_2	0.14	0.18	0.15

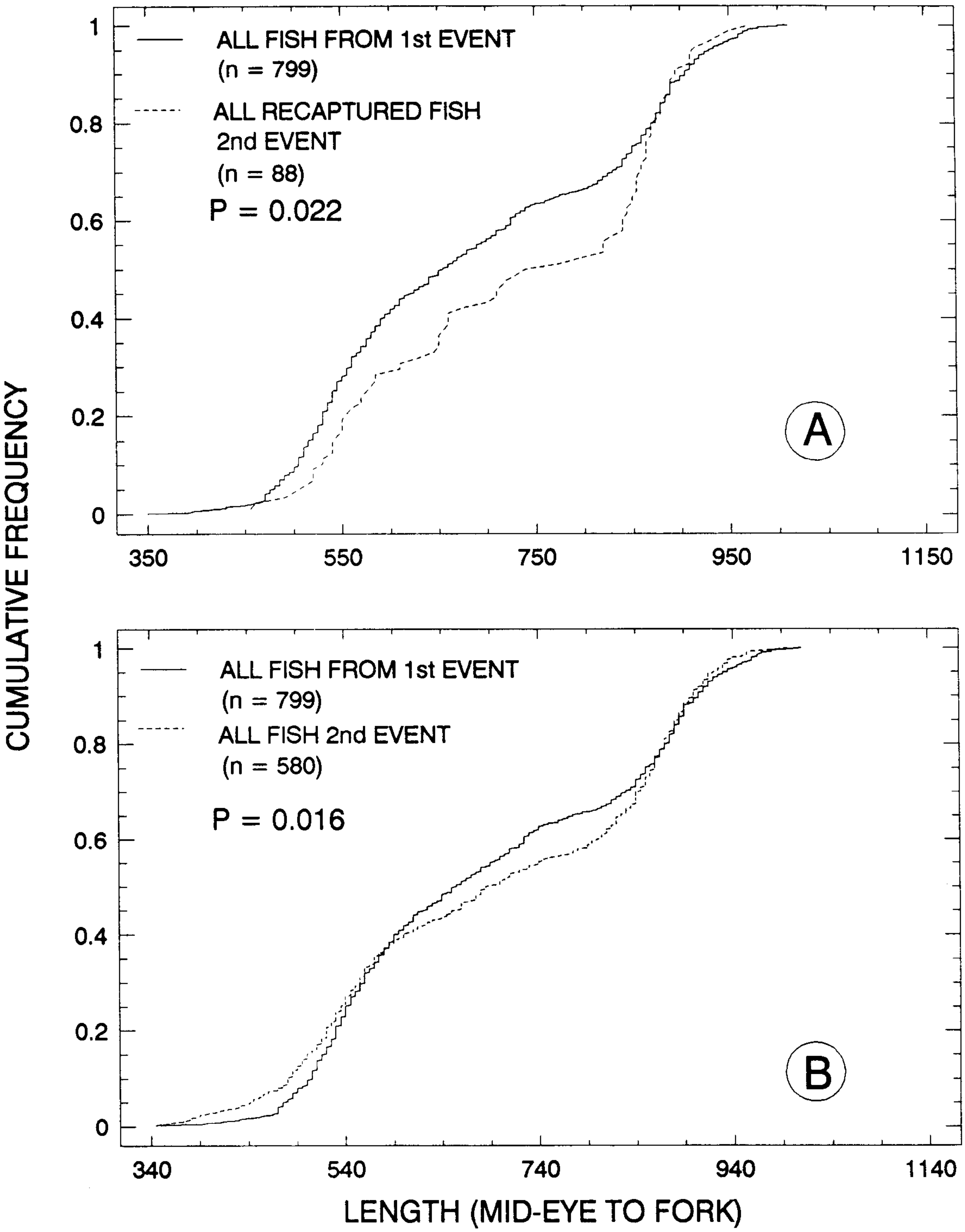

Figure 2. Cumulative length frequency distributions comparing lengths of all chinook salmon captured during the marking event to: A) lengths of all recaptured chinook salmon; and, B) lengths of all chinook salmon captured during the recapture event.

Table 6. Results of contingency table analyses of the recapture rates, by length, for chinook salmon in the Chena River in 1992.

Test	350	630	760	1000	Significance Tests[b] χ^2	df	p
		Test Breaks[a] (mm ME-FK)					
1	<————	><————	><————	>	6.818	2	0.033
2		<————	><————	>	0.395	1	0.529
3	<————	><————	————	>	6.343	1	0.012

[a] Each group of lines corresponds to a battery of tests. The symbols "><" correspond to boundaries between adjacent categories in a test.

[b] Tests are RxC contingency tables and χ^2 statistics for H_o: $p_i = p$ where p_i = probability of catching a chinook salmon in the ith length group. The numbers of marked fish caught and not caught were used in the contingency table.

Table 7. Capture and recapture history of all chinook salmon captured during the mark-recapture experiment.

River Section Where Marks Were Released	River Section Where Marks Were Recaptured				Number Marked	Number Not Recaptured
	Upper	Middle	Lower	Total		
Upper	33	13	0	46	313	267
Middle	0	34	1	35	376	341
Lower	0	2	5	7	110	103
Total	33	49	6	88	799	711
Unmarked Carcasses	140	276	77	493	Total Number of Unique Fish Examined	
Total Carcasses	173	325	83	581	1,292	

Table 8. Number of marked and unmarked chinook salmon carcasses that were collected during each of three passes of the recapture event.

	Pass During Recapture Event			
	1	2	3	Total
Unmarked	167	225	101	493
Marked	49	31	8	88
Total	216	256	109	581
Recapture Rate	0.227	0.121	0.073	0.151

significant difference between these two estimates (z = 0.47, P = 0.64). Because the unstratified estimate had a much lower variance, it was selected as the appropriate estimator.

Tag Loss

Because all marked fish received both a metal jaw tag and a fin clip, the proportion of tags lost during the mark recapture experiment could be estimated. Eighty-eight marked chinook salmon carcasses were recovered; 85 had metal jaw tags, and three had a distinguishable fin clip and no jaw tag attached. The estimated proportion of jaw tags lost during the mark-recapture experiment was 0.03 (SE = 0.02).

Age, Length, and Sex Compositions

Age data were obtained from 467 of the 581 chinook salmon collected 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 of females was 1.4 (brood year 1986) and of males was 1.2 (brood year 1988).

Chinook salmon from both sampling events were used to estimate the proportions of males and females in the population. Females comprised 31% (SE = 1) of the population, while males comprised 69% (SE = 1). The estimates of abundance were 1,607 female chinook salmon (SE = 162) and 3,623 male chinook salmon (SE = 338; Table 9).

Lengths of females ranged from 720 to 995 mm, while males ranged from 345 to 955 mm. Mean length of males (593 mm; SE = 8) was substantially smaller than mean length of females (862 mm; SE = 3; Table 10). Male chinook salmon were predominantly smaller than 750 mm (87%; SE = 1.1), while females were predominantly larger than 750 mm (98%; SE = 0.6; Figure 3).

Potential Egg Production

Lengths of female chinook salmon from both events were combined to estimate proportions and abundance for 10 mm length increments. Based on these estimates, total potential egg production was estimated to be 14,877,810 eggs (SE = 1,057,332; Table 11).

Aerial Survey

Aerial survey counts ranged from a low of 48 on 17 July to a peak count of 825 live and dead chinook salmon on 11 August. Survey conditions on 11 August ranged from "fair" to "poor" on a scale of "poor, fair, and good". This peak count represented 16% of the estimate of abundance from the mark-recaptureexperiment, and was the lowest observed proportion from aerial counts conducted since 1986 (Table 12).

Goodpaster River: Age, Length, and Sex Compositions

One hundred seven chinook salmon carcasses were collected from the Goodpaster River. Sex and length were determined for all of these fish, while ages were

Table 9. Estimates of proportions and abundance of female and male chinook salmon by age class collected during carcass sampling.

	Brood Year and Age Group							
	1989	1988	1987		1986		1985	
	1.1	1.2	1.3	2.2	1.4	2.3	1.5	Total
Females								
Sample Size	0	0	50	0	124	1	1	176
Proportion of Females in Sample								0.31
Standard Error								0.01
Proportion of Females at age in sample	0	0	0.28	0	0.70	0.01	0.01	
Standard Error								
Abundance	0	0	457	0	1,132	9	9	1,607
Standard Error	0	0	71	0	126	9	9	162
Males								
Sample Size	9	197	59	1	22	1	0	289
Proportion of Males in Sample								0.69
Standard Error								0.01
Proportion of Males at age in sample	0.03	0.68	0.20	<0.01	0.08	<0.01	0	
Standard Error	0.01	0.03	0.02	<0.01	0.02	<0.01	0	
Abundance	113	2,470	740	13	276	13	0	3,623
Standard Error	38	251	110	13	62	13	0	338
Total								
Sample Size	9	197	110	1	147	2	1	467[a]
Proportion at age in Sample	0.02	0.42	0.23	<0.01	0.31	<0.01	<0.01	1.00
Standard Error	0.01	0.02	0.02	<0.01	0.02	<0.01	<0.01	0.00
Abundance	113	2,470	1,196	13	1,408	22	9	5,203
Standard Error	35	235	152	11	188	16	11	478

[a] Total sample contained two fish for which sex was not identified.

Table 10. Estimated length-at-age of Chena River chinook salmon, 1992.

Ocean Age	Sample Size	Length (mm) Mean	SE	Range
Females:				
3	51	821	6	720 - 895
4	125	877	3	775 - 970
5	1	995	-	995
Total	177	862	3	720 - 995
Males:				
1	9	378	10	345 - 440
2	197	535	4	380 - 855
3	61	707	7	590 - 850
4	22	889	10	750 - 955
Total	289	593	8	345 - 955
Females and Males:				
1	9	378	10	345 - 440
2	197	535	4	380 - 855
3	112	759	7	590 - 895
4	147	879	3	750 - 970
5	1	995	-	995
Total	466	772	8	345 - 995

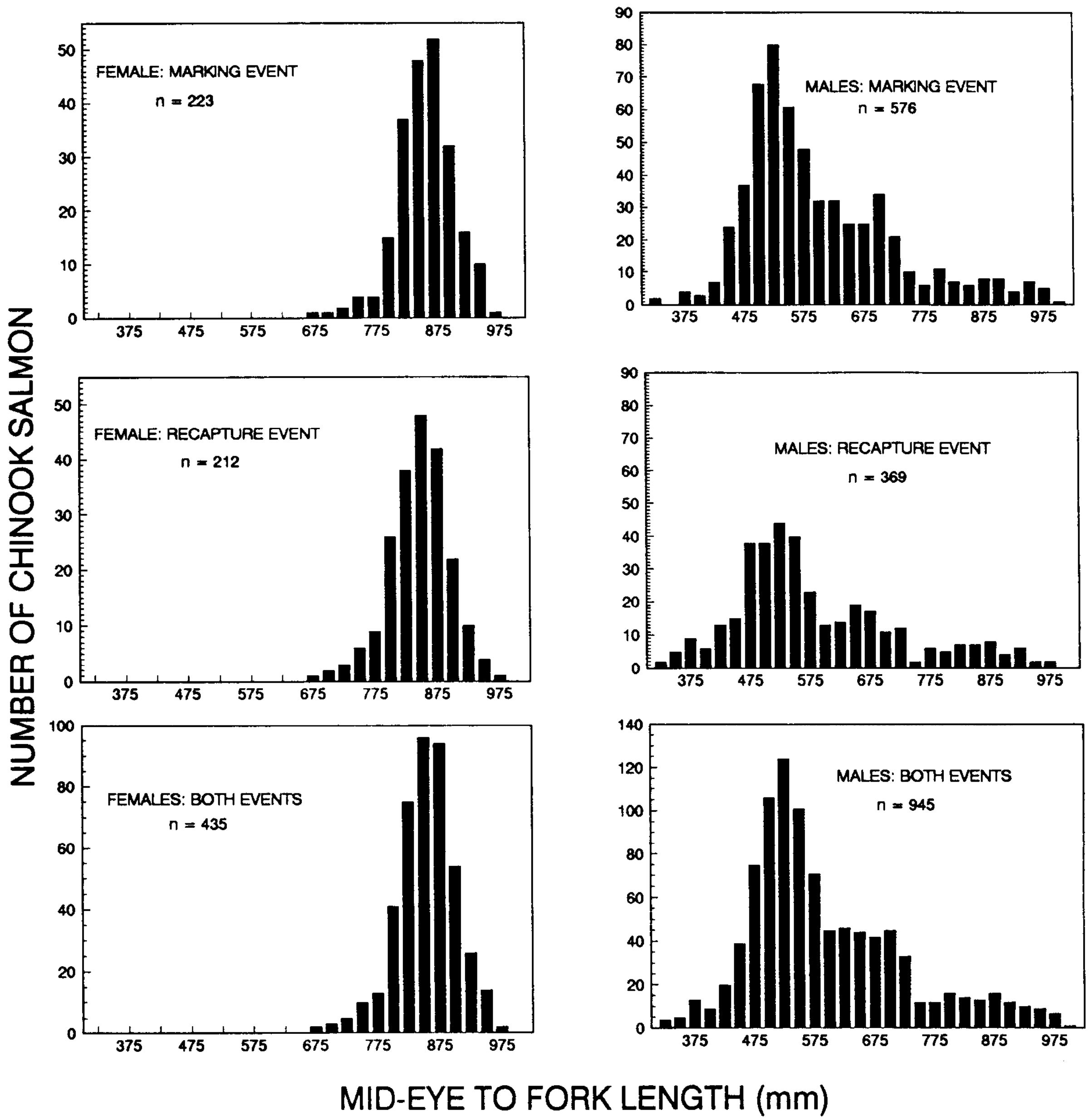

Figure 3. Length frequency distributions of female and male chinook salmon captured during the mark-recapture experiment.

Table 11. Estimated potential egg production of Chena River chinook salmon by length category, 1992.

Length Class (mm)	No. of Females in Sample	Estimated No. of Females in Population	Standard Error	Estimated Egg Production (eggs)	Standard Error
690	1	4	4	23,646	23,646
700	0	0	0	0	0
710	2	8	6	50,525	37,206
720	1	4	4	26,071	26,071
730	2	8	6	53,759	39,398
740	2	8	6	55,375	40,499
750	2	8	6	56,992	41,603
760	2	8	6	58,609	42,711
770	7	28	11	210,790	92,669
780	3	12	7	92,764	56,467
790	7	28	11	222,107	96,391
800	13	53	15	422,993	148,707
810	18	73	18	600,232	190,886
820	16	65	17	546,474	177,727
830	31	125	25	1,083,852	296,929
840	28	113	24	1,001,597	277,280
850	30	121	24	1,097,390	296,039
860	33	134	26	1,233,805	322,682
870	46	186	32	1,757,034	426,079
880	44	178	31	1,716,209	415,074
890	20	81	19	796,262	230,273
900	23	93	21	934,294	258,044
910	21	85	20	870,026	245,004
920	11	45	14	464,620	161,140
930	12	49	15	516,558	172,982
940	7	28	11	306,984	126,233
950	8	32	12	357,306	138,893
960	5	20	9	227,358	107,436
970	1	4	4	46,280	46,280
980	0	0	0	0	0
990	1	4	4	47,897	47,897
Totals	397	1,607		14,877,810	1,057,232[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 abundance, potential egg production, maximum aerial counts, and survey conditions for chinook salmon in the Chena River, 1986-1992.

Year		Abundance		Potential Egg Production	Aerial Survey	
	Total	Males	Females		Count	Condition
1986	9,065	6,746	2,301	NA[a]	2,031	Fair
SE =	1,080	923	538			
1987	6,404	2,903	3,501	NA[a]	1,312	Fair
SE =	557	379	416			
1988	3,346[b]	NA[a]	NA[a]	NA[a]	1,966	Fair-Poor[c]
SE =	556					
1989	2,666	1,627	1,039	9.81×10^6	1,180	Fair-Good[c]
SE =	249	160	145	0.78×10^6		
1990	5,603	2,970	2,633	24.69×10^6	1,436	Fair-Poor[c]
SE =	1,164	846	564	1.44×10^6		
1991	3,025	2,071	954	8.50×10^6	1,276	Poor
SE =	282	198	99	0.60×10^6		
1992	5,230	3,623	1,607	14.88×10^6	825	Fair-Poor[c]
SE =	478	338	162	1.06×10^6		

[a] Data is not available.
[b] Original estimate was 3,045 (SE = 561) for a portion of the river. The estimate was then expanded from distribution of spawners based upon aerial counts.
[c] During these surveys, conditions were judged to vary by area on a scale of "poor, fair, and good".

assigned to 93 samples. The proportions of females and males in this sample was 0.290 (SE = 0.044) and 0.710 (SE = 0.044), respectively. The dominant age class was 1.4 (22.6% of total sample; SE = 4.4) for females and 1.2 (35.5% of total sample; SE = 4.6) for males (Table 13). Nearly all females were 800 mm or larger, while most males were smaller than 750 mm (Table 14).

DISCUSSION

The success of this annual mark-recapture experiment is heavily dependant upon timing of the sampling events and characteristics of the run. Ideally, electrofishing should take place at a time when virtually all chinook salmon are in the river, have completed spawning, and have not yet died. Carcass sampling should take place immediately after all chinook salmon have died, but before they begin to decompose or become covered with silt on the river bottom. If sampling occurs under these conditions, then achieving equal probability of capture during at least one sampling event is most likely. In most years the run-timing is such that fish enter the system in a short period of time and are all available for capture during the marking event. Initiation of the marking event is based on timing and catch rates during prior years sampling (Appendix B1) and in part on a qualitative assessment of chinook salmon abundance and condition. This assessment is determined by a sampling crew conducting an annual mark-recapture experiment of Arctic grayling *Thymallus arcticus* in the same section of the Chena River. Also, aerial surveys conducted by the Division of Commercial Fisheries during this time give an indication of when abundance has peaked. Typically, a short hiatus (three or four days) designed to minimize loss of carcasses separates the marking and recapture events.

The run-timing was later this year than during past years. Many (49%) of the female chinook salmon captured during the first marking pass were in prespawning condition, while fewer (33%) were noted in prespawning condition during the second marking pass. A negligible number of carcasses were noted during either marking pass. It is not known whether fish were still entering the system after the final marking event. During carcass surveys this year and in past years, some live chinook salmon were present. As long as these fish were present and available for capture during the marking event (i.e. the marked to unmarked ratio is the same as that of the carcasses), then the estimate will not be biased. During previous years, only one pass was made through each section during the carcass survey. Thus, there was no way to test the marked to unmarked ratio of the remaining live fish. During this experiment, three passes were made through each section. The marked to unmarked ratio declined with each successive pass (Table 8). This indicates that either marking and handling of fish facilitated premature death or, asdiscussed above, fish entered the system after the marking event was completed.

The scenario of premature death could bias the estimate of abundance either high or low. If all carcasses have the same probability of capture, then the estimate of abundance will be biased low, because the marked to unmarked ratio of dead fish will be higher than that of the live fish. If premature death causes a decline in the probability of capture of a carcass such as through

Table 13. Estimates of the proportions by age class, and mean length-at-age estimates for female and male chinook salmon sampled in the Goodpaster River, 1992.

	Age Class	Sample Size	Proportion of Sample	Standard Error	Mean Length	Standard Error
Females:						
	1.2	1	0.011	0.011	495	-
	1.3	4	0.043	0.021	850	13
	1.4	21	0.226	0.044	898	6
	2.3	1	0.011	0.011	710	-
Totals		27	0.291	0.047	867[a]	15
Males:						
	1.2	33	0.355	0.050	569	10
	1.3	25	0.269	0.046	722	14
	1.4	8	0.086	0.029	959	24
Totals		66	0.710	0.047	686[b]	18
Males and Females:						
	1.2	34	0.366	0.050	567	10
	1.3	29	0.312	0.048	739	15
	1.4	29	0.312	0.048	914	9
	1.5	1	0.011	0.011	710	-
Totals		93	1.000		739[c]	15

[a] Total sample size was 31 and included four female chinook salmon for which an age was not assigned.

[b] Total sample size was 76 and included ten male chinook salmon for which an age was not assigned.

[c] Total sample size was 107 and included 14 chinook salmon for which an age was not assigned.

Table 14. Length compositions of female and male chinook salmon carcasses sampled in the Goodpaster River, 1992.

Length Category	Sample Size	Proportion of Sample	Standard Error
Female:			
<500	1	0.009	0.009
500-549	0	0	0
550-599	0	0	0
600-649	0	0	0
650-699	0	0	0
700-749	1	0.009	0.009
750-799	0	0	0
800-849	6	0.056	0.022
850-899	14	0.131	0.033
900-949	7	0.065	0.024
950+	2	0.019	0.013
Totals:	31	0.290	0.044
Male:			
<500	5	0.047	0.011
500-549	8	0.075	0.011
550-599	17	0.159	0.024
600-649	6	0.056	0.015
650-699	13	0.121	0.026
700-749	9	0.084	0.036
750-799	0	0	0.039
800-849	4	0.037	0.026
850-899	4	0.037	0.024
900-949	4	0.037	0.015
950+	6	0.056	0.011
Totals:	76	0.710	0.044
Female and Male:			
<500	6	0.056	0.022
500-549	8	0.075	0.026
550-599	17	0.159	0.036
600-649	6	0.056	0.022
650-699	13	0.121	0.032
700-749	10	0.093	0.028
750-799	0	0	0
800-849	10	0.093	0.028
850-899	18	0.168	0.036
900-949	11	0.103	0.029
950+	8	0.075	0.026
Totals:	107[a]	1.000	0

carcasses decomposing, or washing out of the study area, then the abundance estimate would be biased high. The same result would occur if marking and handling facilitated stress to the point that fish left the study boundaries (i.e. drifted downstream). This phenomenon was noted in a mark-recapture experiment conducted on chinook salmon in the Kenai River, Alaska (Alexandersdottir and Marsh 1990). Both of these events violate the assumption that the population is closed, but are unlikely due to the short hiatus (three days) between the two capture events.

In the scenario of fish entering the system after the final marking pass, two possibilities exist. First, these fish did not die before the final carcass pass, and were never available for capture. In this case, the bias of the abundance estimate would be equal to the number of fish which entered the system after the final marking pass (some of the live fish may have been present and available for capture during the marking event). The second possibility is that some or all fish which entered the system after the final marking pass died and were available for capture during the carcass survey. This would dilute the marked to unmarked ratio of the carcasses and bias the estimate high. Based on the small number of live fish observed during the final pass of the carcass survey, it is believed that the bias associated with either scenario is small.

In this experiment there was no meaningful size or sex selectivity during either sampling event, and the ratios of marked to unmarked fish from the carcass survey were similar among river sections. Sufficient samples were collected to estimate age-sex-size compositions within the objective criteria for accuracy and precision (within five percentage points of the actual proportions 95% of the time). Accurate estimation of the proportions of female chinook salmon by length categories in turn provided an accurate estimate of population egg production (relative precision = 14%). The same methodology (mark by electrofishing, recapture by collecting carcasses) has been used to estimate abundance and age-sex-size compositions in the Salcha River since 1987 (Skaugstad 1988, 1989, 1990b, and 1992; Burkholder 1991) and in the Chena River since 1989 (Skaugstad 1990a: Evenson 1991, 1992). These studies have indicated that there is generally no sex selectivity within either sampling event. When there is size selectivity, it is typically during the electrofishing event.

The proportion of males to females comprising the spawning population sampled during four (1986, 1989, 1991 and 1992) of the last six (1986, 1987, 1989-1992) years for which sex and age composition have been estimated has ranged from 61 to 74%. Most of the smaller fish (ages 1.2 and 1.3) are males and most of the larger fish (age 1.4) are females. The abnormally high composition of small males in the Chena River escapement is similar to the composition noted in the Salcha River (Skaugstad pers. comm.[2]), another middle Yukon River tributary. It is dissimilar to the composition of the chinook salmon escapement in the Kenai River which is generally 43 to 50% male (Alexandersdottir and Marsh 1990, Hammarstrom 1992, *In press*).

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[2] Skaugstad, Cal. 1992. Personal Communication. ADF&G, 1300 College Rd., Fairbanks, AK 99701.

It is unclear why the escaping chinook salmon population in the Chena River is comprised of such high proportions of males during some years. One possible explanation could be a selection process in the downriver commercial and subsistence fisheries. Another explanation may include large returns of precociously maturing males.

Bias of the abundance estimate associated with tag losses in this investigation and similar studies (Skaugstad 1988, 1989, 1990a, 1990b, and 1992; Evenson 1991 and 1992; Burkholder 1991) was minimal or nonexistent. The jaw tags were securely attached around the lower jaw (dentary bone) and decomposition of the flesh did not facilitate tag loss. The capture history (location and date of tagging) of the three fish that lost tags in this experiment was easily identified by the presence of fin-clips. Tag loss is only of concern when it can not be identified.

Differences between the number of chinook salmon observed during aerial surveys and estimates of abundance from mark-recapture experiments indicate 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 relative to peak spawning. Because of the various effects of these factors, the number of paired aerial surveys and mark-recapture experiments since 1986 does not yet provide enough information to adequately describe the relationship. Alternative methods of assessing "in season" abundance should be considered.

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APPENDIX A

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

The following statistical tests will be 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 will be based on a contingency table of the number of males and females that were recaptured and were not recaptured. The chi-square statistic will be used to evaluate the bias.

If Test 1 indicates a significant bias, the following tests will be done for males and females, separately. If Test 1 does not indicate a significant bias, males and females will be combined and the following tests will be done.

2. Tests for significant gear bias by size will be based on: (A) Kolmogorov-Smirnov 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) Kolmogorov-Smirnov two sample test 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 is 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 is no size-selectivity during the second sampling event but there is size-selectivity during the first sampling event.

Case III:

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

There is size-selectivity during both sampling events.

Case IV:

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

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

-continued-

Depending on the outcome of the tests, the following procedures will be 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 the fish does not affect the probability of recapture; and,

2. Marked fish do not lose their mark.

Catching and handling the fish should not affect the probability of recapture because the experiment is designed to mark live fish and later recover carcasses. If the jaw tag is lost, the fin clip given each fish will identify the river section where it was marked.

Of the following assumptions, only one must be fulfilled:

1. Every fish has an equal probability of being marked and released during electrofishing;

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

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

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency table. The results will be used to determine the appropriate abundance estimator and if the estimate of abundance should be stratified by river section or period:

1. Null hypothesis is that marked-to-unmarked ratio is the same at all sites. Columns 1, 2, and 3 in the table will be the corresponding river section where the fish were recovered. Row 1 will be the number of marked fish collected during the carcass sampling event and row 2 will be the number of unmarked fish collected during the carcass sampling event. The column totals will be equal to the number of fish marked during the electrofishing event.

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If the test statistic is not significant, then either every fish had an equal probability of being marked (caught in the electrofishing gear) or marked fish mixed completely with unmarked fish between sampling events. In this case a Petersen estimate will be used to estimate abundance. If the test statistic is significant the following matrix will be created:

River Section of Release	River Section of Recapture		
	Lower	Middle	Upper
Lower			
Middle			
Upper			

If all the off-diagonal elements are zero, then a Petersen estimate will be calculated for each river section. The sum of the three estimates will be the overall abundance estimate. If the off-diagonal estimates are not zero, then Darroch's method will be used to estimate abundance. With these tests it is unknown whether the second assumption was fulfilled. Darroch's method will be used to insure an unbiased estimate.

APPENDIX B

Appendix B1. Historic catches of chinook salmon by day and by sampling area for mark-recapture experiments conducted in the Chena River during 1989-1992.

River Section	Electrofishing Marking Passes		Carcass Survey Recapture Passes
	1989		
Upper			
Date	Jul 27	Aug 2	Aug 8
Males	30	14	38
Females	14	21	68
Total	44	35	106
Middle			
Date	Jul 28	Aug 3	Aug 9
Males	59	22	30
Females	37	23	79
Total	102[a]	45	109
Lower			
Date	Jul 29	Aug 4	Aug 10
Males	26	19	51
Females	30	16	71
Total	57[a]	35	122
All Sections			
Date	Jul 27-29	Aug 2-4	Aug 8-10
Males	115	55	119
Females	81	60	218
Total	196[a]	115	337
	1990		
Upper			
Date	Jul 25	Jul 30-31	Aug 6-7
Males	69	21	155
Females	34	9	151
Total	103	30	306
Middle			
Date	Jul 26	Aug 1-2	Aug 7-8
Males	64	38	213
Females	33	26	175
Total	97	64	388
Lower			
Date	Jul 27	Aug 2	Aug 9
Males	7	1	53
Females	7	5	60
Total	14	6	113
All Sections			
Date	Jul 25-27	Jul 30-Aug 2	Aug 6-9
Males	140	60	421
Females	74	40	386
Total	214	100	807

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River Section	Electrofishing Marking Passes		Carcass Survey Recapture Passes		
			1990		
Upper					
Date	Jul 26	Jul 29	Aug 5		
Males	52	132	102		
Females	21	55	36		
Total	73	187	138		
Middle					
Date	Jul 27	Jul 30	Aug 6		
Males	96	100	125		
Females	34	49	55		
Total	130	149	180		
Lower					
Date	Jul 28	Jul 31	Aug 7		
Males	15	22	40		
Females	9	27	29		
Total	24	49	69		
All Sections					
Date	Jul 26-28	Jul 29-31	Aug 5-7		
Males	163	254	267		
Females	64	131	120		
Total	227	385	387		
			1992		
Upper					
Date	Jul 29	Aug 3	Aug 6	Aug 11-12	Aug 17
Males	132	103	41	46	26
Females	41	37	24	22	14
Total	173	140	65	68	40
Middle					
Date	Jul 30	Aug 4	Aug 7	Aug 12-13	Aug 18-19
Males	121	144	76	90	34
Females	57	54	54	48	23
Total	178	198	130	138	57
Lower					
Date	Jul 31	Aug 5	Aug 5	Aug 14	Aug 20
Males	43	33	13	38	5
Females	18	16	8	12	7
Total	61	49	21	50	12
All Sections					
Date	Jul 29-31	Aug 3-5	Aug 5-7	Aug 11-14	Aug 17-20
Males	296	280	130	174	65
Females	116	107	86	82	44
Total	412	387	216	256	109

[a] Totals include some fish for which sex was not determined.