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Abundance, Egg Production, and Age-Sex-Size Composition of the Chinook Salmon Escapement in the Chena River, 1990

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ABSTRACT

In 1990, 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 314 chinook salmon in early August. Captured chinook salmon were marked with jaw tags, fin-clipped, and released. In mid-August, 812 chinook salmon carcasses were collected. Fifty-two of these carcasses had been marked. The estimate of abundance was 5,603 (standard error = 1,164) chinook salmon. The estimates of the number of females and males were 2,633 (standard error = 564) and 2,970 (standard error = 846), respectively. During aerial surveys, the highest count of live and dead chinook salmon was 1,436, about 26 percent of the mark-recapture point estimate. Estimated egg production for the 1990 escapement was 24.69 million eggs (standard error = 1.44 million).

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

INTRODUCTION

Exploitation of stocks of Yukon River chinook salmon *Oncorhynchus tschawytscha* is complex and requires 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 sub-districts of the Yukon River commercial fishery. Chinook salmon returning to the Chena River contribute to these down river commercial, subsistence, and personal use fisheries. Popular sport fisheries also exist in several Tanana River tributaries (Table 1) including the lower 72 km of the Chena River.

To perpetuate the fisheries and stocks of chinook salmon, fishery managers set commercial, subsistence, and personal use 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 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 fisheries in the Chena and Salcha rivers are managed based on a guideline harvest range. In the Chena River this guideline harvest range is 300 to 600 chinook salmon, while in the Salcha River it is 300 to 700 chinook salmon.

One method a fishery manager has of evaluating the effect of the harvest on the stocks of chinook salmon is to estimate the number of fish that reach their spawning grounds. When the number of chinook salmon is less than a desired level then the harvest is considered too high. This information can be used to directly manage the recreational fishery in the Chena River, and insure that the recreational harvest does not significantly impact the escapement.

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 mature chinook salmon in the Chena River during aerial surveys has ranged from less than 500 to more than 2,500 (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. Barton (1987a and 1988), Barton and Conrad (1989), and Skaugstad (1990a) found that the numbers of mature chinook salmon counted during aerial surveys of the Chena River in 1986, 1987, 1988, and 1989 were about 22, 20, 59, and 44%, respectively, of the estimated abundance from mark-recapture experiments. Skaugstad (1988, 1989, and 1990b) 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.

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

Table 1. Harvests of anadromous chinook salmon by sport, commercial, subsistence, and personal use fisheries, Tanana drainage, 1978 through 1989.

	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[eg]	7,090
1989	685	123	375	231	231	39	87	963	2,181[d]	2,297[eg]	5,001
1990	N.A.[f]	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	2,989[dg]	N.A.	N.A.

[a] Creel census estimates from Clark and Ridder (1987), Baker (1988, 1989), and Merritt et al. (1990).
[b] Sport fishery harvest estimates from Mills (1979-1990).
[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, and 833 fish in 1990).
[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.

The specific objectives in 1990 were to estimate:

1. the abundance of spawning chinook salmon in the Chena River, and compare this estimate of abundance with aerial survey counts of abundance;

2. the age-sex-length compositions of chinook salmon in the Chena River;

3. potential egg production for the escapement of chinook salmon in the Chena River.

MATERIALS AND METHODS

Capture and Marking

Adult chinook salmon were captured from 26 July through 2 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 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 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 (26, 27, and 28 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 (1 ,2, and 3 August), one pass was made in all three sections.

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 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. One pass was made through each section in a drifting riverboat starting at the upstream end of each section. 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 of the first 620 carcasses for age analysis.

Abundance Estimator

A Darroch estimator stratified by geographical location was selected as the appropriate estimator (described in Appendix A1). The Darroch estimator (Darroch 1961, cited in Seber 1982) used is summarized below:

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.

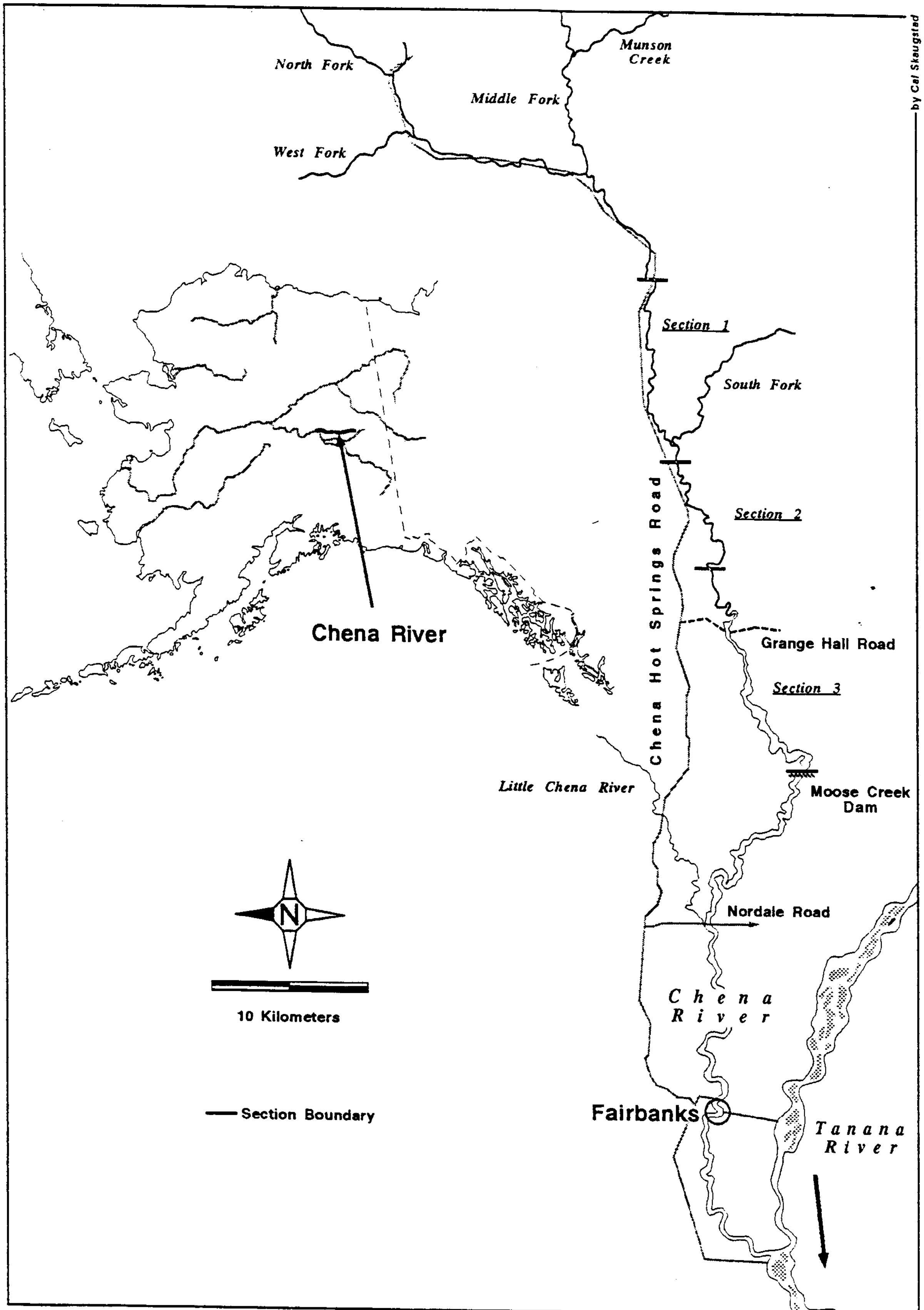

Figure 1. Chena River study area.

$$\underline{\hat{N}} = DuM^{-1}\underline{a} \qquad (1)$$

where:

$\underline{\hat{N}}$ = a vector of the estimated abundance of unmarked chinook salmon in each recovery stratum j;

Du = a diagonal matrix of the number of unmarked chinook salmon carcasses examined for tags in recovery stratum j.

M = a matrix of n_{ij} the number of tagged fish in each recovery stratumj, which were released in tagging stratum i; and,

$\underline{a}$ = a vector of the number of chinook salmon marked and released in tagging stratum i.

The total abundance was then estimated as $\hat{N}$ + the number of marked chinook salmon.

The variance-covariance matrix of $\hat{N}$ was estimated as follows:

$$E[(\hat{N}-N)(\hat{N}-N)']=D_N B^{-1} D_u D^{-1}{}_a B'^{-1} D_N + D_N(D_q - I) \qquad \text{(Seber 1982)} \qquad (2)$$

where,

D_N = diagonal matrix of estimated abundance in each stratum;

D_q = diagonal matrix of reciprocals of p_i, which is the estimated probability of an animal surviving and being caught;

B = matrix of B_{ij}, the probability that a member of a_i is in stratum j at sampling and that it is alive; and,

B = $D^{-1}{}_a M D_q$.

Bootstrap procedures (Efron and Gong 1983) were used to investigate any statistical bias in the estimate of abundance. Five hundred bootstrap samples were drawn randomly from the mark-recapture histories of all 1,074 fish in the experiment. Each bootstrap sample was built by randomly drawing 1,074 samples with replacement from the body of mark-recapture histories. An estimate of abundance was calculated for each bootstrap sample with Equation 1 giving 500 estimates of abundance. A measure of the statistical bias was the difference between the point estimate from the original sample and the average of the bootstrap estimates.

Tag Loss

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

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

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

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, length and sex compositions were calculated from those chinook salmon sampled during the carcass survey for which scales were collected. The proportion of females and males by ocean age or length and associated variance were estimated using:

$$\hat{p}_k = a_k/n \quad (5)$$

$$\hat{V}(\hat{p}_k) = \hat{p}_k(1-\hat{p}_k)/(n-1) \quad (6)$$

where:

$\hat{p}_k$ = the estimated proportion of females (or males) of ocean age or length k in the sample;

a_k = the number of females (or males) of ocean age or length k in the sample;

n = the total number of females and males in the sample; and,

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

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

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

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

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

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.

Population Egg Production

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

$$\hat{F} = a + bL_j \tag{9}$$

$$\hat{V}(F_j) = MSE \left\{ 1 + \frac{1}{n} + \frac{(L_j - L)^2}{\sum L_j^2 - (\sum L_j)^2/n} \right\} \tag{10}$$

where:

F_j = fecundity of fish j;

L_j = length of fish j;

n = sample size (from Skaugstad and McCracken in press); and,

MSE = mean square error from the regression of F on L.

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

$$\hat{E} = \sum \hat{N}_k \hat{F}_k; \tag{11}$$

$$\hat{V}(E) = \sum V(\hat{N}_k \hat{F}_k); \text{ and} \tag{12}$$

$$V(\hat{N}_k \hat{F}_k) = \hat{N}_k^2 V(\hat{F}_k) + \hat{F}_k^2 V(\hat{N}_k) - V(\hat{N}_k) V(\hat{F}_k) \tag{13}$$

where:

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

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

$\hat{F}_k$ = the mean fecundity for females of length interval k as determined by Skaugstad and McCracken (In press) for chinook salmon in the Tanana River drainage;

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

$\hat{V}(F_k)$ = the variance of the mean fecundity for females of length k; and,

$\hat{V}(N_k)$ = the variance of the estimated number of females of length interval k.

Aerial Survey

Personnel from the Division of Commercial Fisheries of the Alaska Department of Fish and Game counted the total number of adult chinook salmon in the Chena River on four different occasions (16 July, 18 July, 21 July, and 27 July). Counts were made from low flying, fixed-wing aircraft. Barton (1987b) describes the methods used by the Division of Commercial Fisheries for aerial surveys.

RESULTS

A total of 314 chinook salmon were captured, tagged, and released from 25 July to 2 August. During the recapture event 812 carcasses were collected and examined for tags and fin clips from 6 August to 9 August; 52 of these fish were marked.

Tests of Assumptions for a Petersen Estimator

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

Selectivity in the Carcass Survey:

No selectivity in the carcass survey was indicated. Males were recovered with similar rates as were females (males = 0.17; females = 0.25ε $\chi^2 = 1.69$, df = 1, $0.25 < p < 0.1$; Table 3). Nor were large chinook salmon captured at different rates than were smaller salmon (Kolmogorov-Smirnov two sample test on lengths of marked vs. lengths of recapture fish, P = 0.083; Figure 2). Since the length distributions of marked fish were different than the length distribution of all fish captured during the carcass survey (Kolmogorov-Smirnov two sample test on lengths of fish captured electrofishing vs. lengths of fish captured in the carcass survey $P < 0.001$; Figure 3), and since no size selectivity was observed in the carcass survey, electrofishing gear used in the first sampling event was size-selective. Therefore, the estimate of abundance was not stratified by length or sex categories, but only those chinook salmon collected during the carcass survey (second event) were used for estimating the proportions of length, sex, and age compositions (discussed below).

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

Fate of Fish Marked During the Electrofishing Event	Males	Females	Total
Recovered	29	23	52
Not Recovered	171	91	262
Total (Recovered and Not Recovered)	200	114	314
Recovery Rate	0.15	0.20	0.17

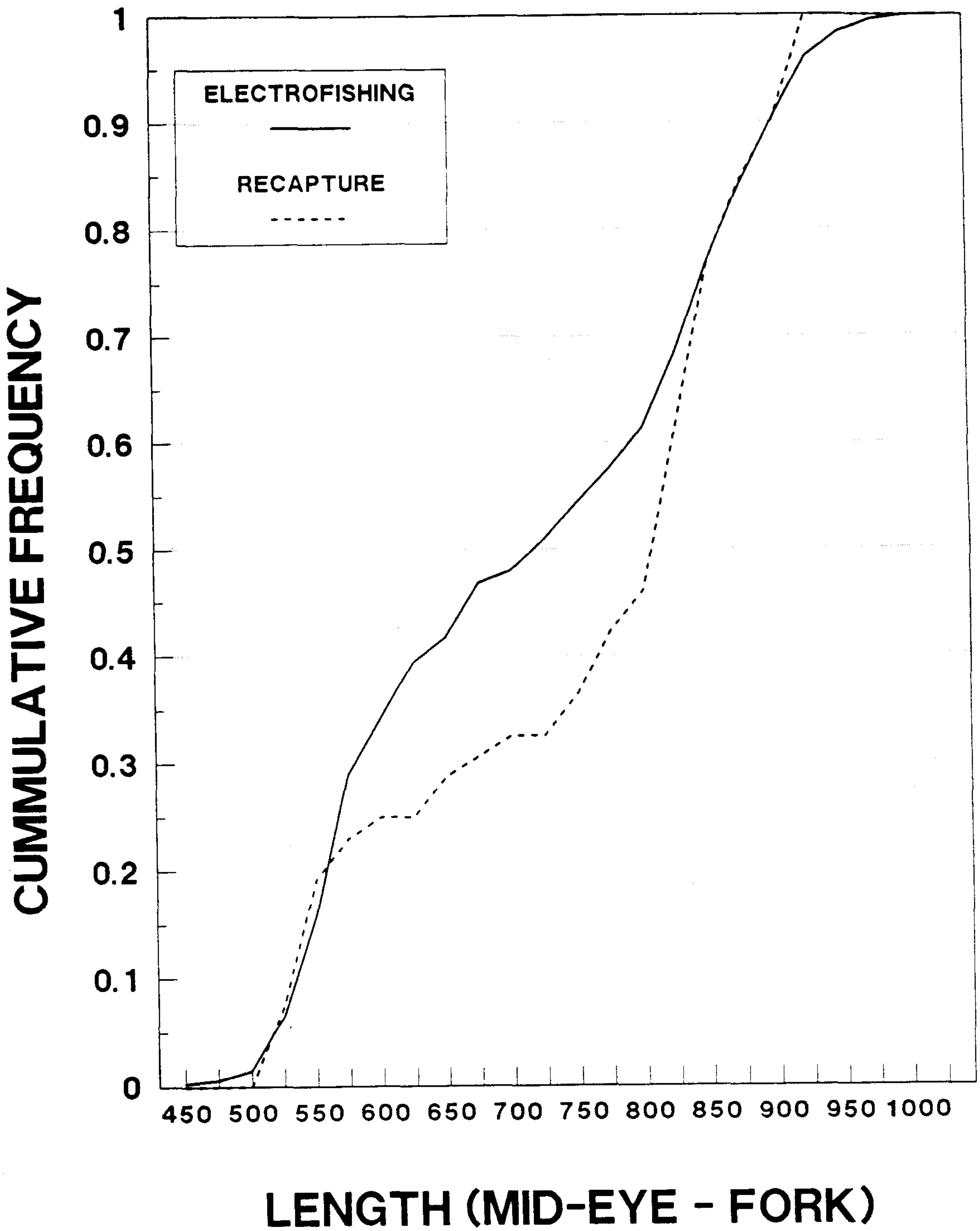

Figure 2. Length frequency distributions of all chinook salmon captured using electrofishing, and in the carcass survey.

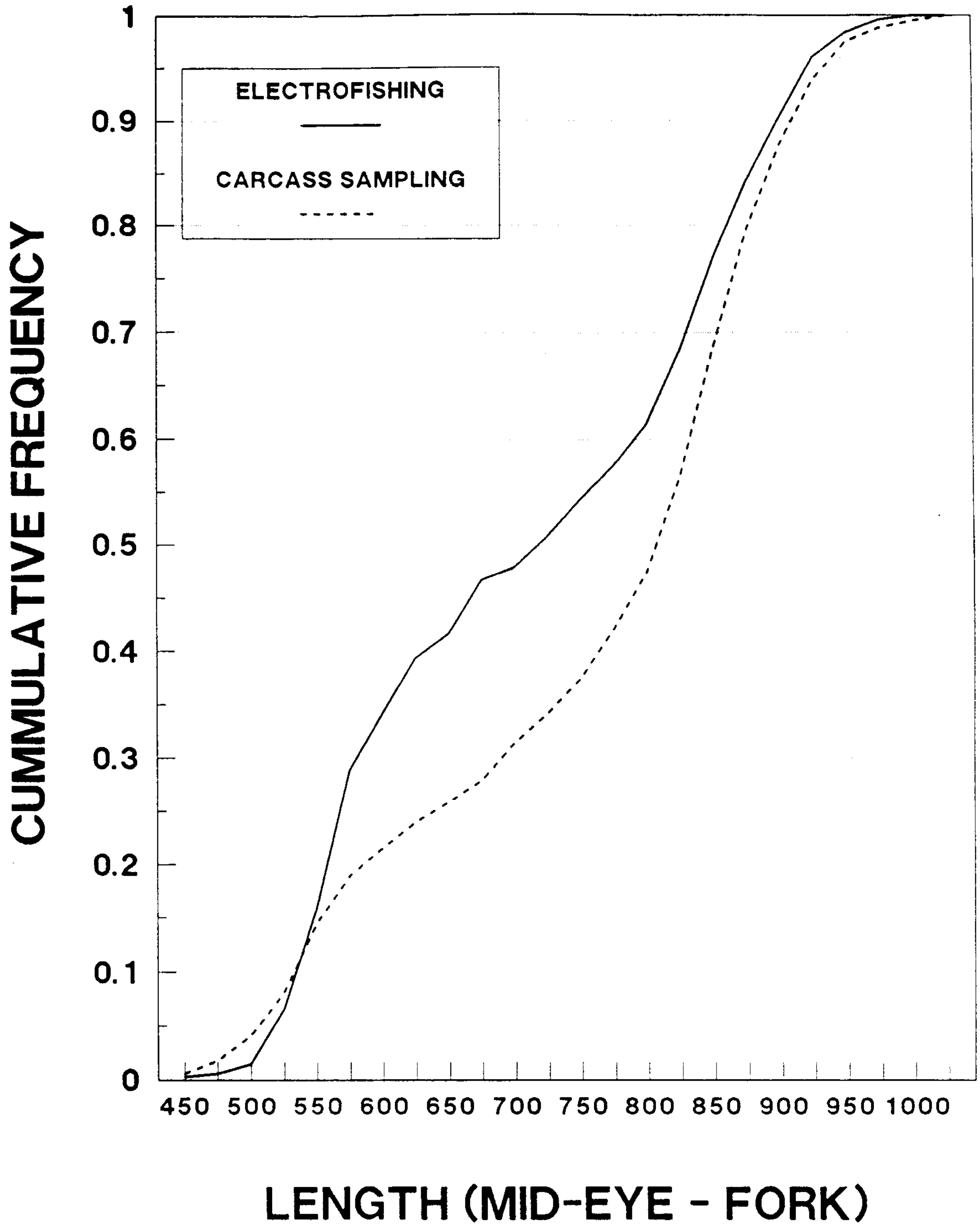

Figure 3. Length frequency distributions of all chinook salmon captured using electrofishing, and marked chinook salmon in the carcass survey.

Closed Population:

The marked-to-unmarked ratio of chinook salmon was significantly different at all sites during the carcass sampling event ($\chi^2 = 10.45$, df = 2, $0.005 > p > 0.01$; Table 4). Therefore, all fish did not have an equal probability of capture during either sampling event, and marked fish did not mix completely with unmarked fish between the two sampling events. Mixing was not complete, but did occur to some extent (Table 5).

Abundance Estimate

Based on the results of the previous tests, both sexes and all lengths were combined and Darroch's method (Darroch 1961) was used to obtain a single estimate of abundance. This method requires that the study area be stratified into at least two geographic areas in order to compensate for the unequal probabilities of capture throughout the study area. The estimate was first attempted using three geographic river sections (described in methods section; Table 6). However, because no fish which were marked in the lower river section were recaptured in any river section, Darroch's methods could not be used for this stratification scheme. Data for the lower and middle river sections were then combined and the estimate was obtained using two geographic strata (Table 7). The combined estimate of abundance of male and female chinook salmon was 5,603 (SE = 1,164). The second estimate using the resampling techniques (described above) and the same river area designations was 6,321 (SE = 1,626). The sampling bias was therefore 718 fish (Figure 4).

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. Fifty-two marked chinook salmon carcasses were recovered; 51 had tags, and only 1 had a distinguishable fin clip and no tag attached. The estimated proportion of tags lost during the mark-recapture experiment was 0.02 (SE = < 0.01).

Age, Length, and Sex Compositions

Age, sex and length data were obtained from 549 of the 812 chinook salmon collected during the carcass survey. These fish spent two to five years in the ocean and nearly all fish spent just one year in freshwater (Table 8). The dominant age class for females was 1.4 (brood year 1984) and for males was 1.2 (brood year 1986). Fifty-three percent of these fish were males, while 47% were females. Based on these proportions, estimates of abundance were 2,970 (SE = 846) for males and 2,633 (SE = 564) for females.

Lengths of females ranged from 831 to 1,010 mm while males ranged from 458 to 1,030 mm. Chinook salmon less than 750 mm were predominantly males. The mean lengths of females were usually greater than the mean lengths of males for a given age (Table 9).

Table 4. Number of marked and unmarked chinook salmon collected during carcass sampling by river section.

	River Section			
	Upper	Middle	Lower	Total
Marked	13	36	3	52
Unmarked	297	353	110	760
Total Collected	310	389	113	812
Recovery Rate	0.04	0.09	0.03	0.06

Table 5. Number of chinook salmon that were marked during the electrofishing event and recaptured during carcass sampling.

River Section of Release	River Section of Recapture		
	Lower	Middle	Upper
Lower	0	0	0
Middle	3	32	4
Upper	0	4	9

Table 6. Capture and recapture history of marked chinook salmon by river section.

River Section Where Marks Were Released	River Section Where Marks Were Recaptured				Number Marked	Number Not Recaptured
	Upper	Middle	Lower	Total		
Upper	9	4	0	13	133	120
Middle	4	32	3	39	161	122
Lower	0	0	0	0	20	20
Total	13	36	3	52	314	262
Unmarked Carcasses	297	353	110	760		
Total Carcasses	310	389	113	812		

Table 7. Capture and recapture history of marked chinook salmon by river section[a] (lower and middle sections combined).

River Section Where Marks Were Released	River Section Where Marks Were Recaptured			Number Marked	Number Not Recaptured
	Upper	Middle/Lower	Total		
Upper	9	4	13	133	120
Middle/Lower	4	35	39	181	142
Total	13	36 3	52	314	262
Unmarked Carcasses	297	463	760		
Total Carcasses	297	502	760		

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

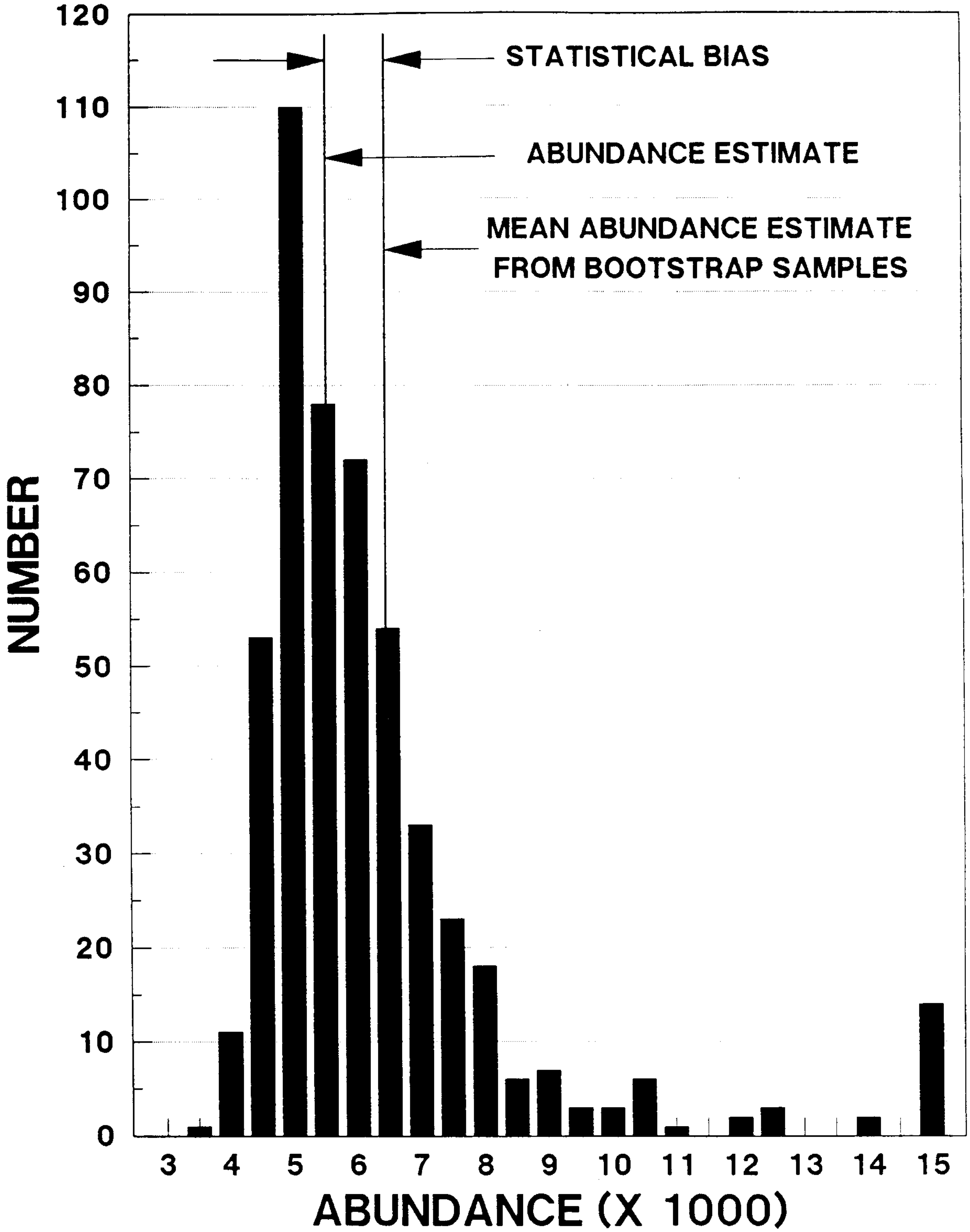

Figure 4. Histogram of 500 abundance estimates used to determine the statistical bias of the point estimate.

Table 8. 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:						
	1.2	2	<0.01	<0.01	22	15
	1.3	50	0.09	0.01	510	131
	1.4	189	0.34	0.02	1,927	415
	1.5	17	0.03	<0.01	174	65
Totals		258	0.47	0.02	2,633	564
Males:						
	1.2	123	0.22	0.02	1,255	277
	1.3	90	0.16	0.02	919	206
	2.2	1	<0.01	<0.01	10	10
	1.4	74	0.14	0.02	756	175
	1.5	3	0.01	<0.01	34	19
Totals		291	0.53	0.02	2,970	846
Females and Males:						
	1.2	125	0.23	0.02	1,277	282
	1.3	140	0.26	0.02	1,428	312
	2.2	1	<0.01	<0.01	11	11
	1.4	263	0.48	0.02	2,684	571
	1.5	20	0.04	0.01	202	69
Totals		549	1.00		5,603	1,164

Table 9. Estimated length-at-age of Chena River chinook salmon, 1990.

Ocean Age	Sample Size	Length (mm) Mean	SE	Range
Females:				
2	2	852	21	831 - 873
3	50	827	11	653 - 994
4	189	863	3	747 - 1,020
5	17	901	12	814 - 1,010
Total	258	862	4	653 - 1,020
Males:				
2	124	564	4	458 - 735
3	90	724	10	502 - 973
4	74	861	11	530 - 1,030
5	3	876	43	826 - 962
Total	291	693	9	458 - 1,030
Females and Males:				
2	126	569	5	458 - 873
3	140	761	9	502 - 994
4	263	865	4	530 - 1,030
5	20	897	12	814 - 1,010
Total	549	772	6	458 - 1,030

Population Egg Production

The estimate of total egg production based on length was 24.69 million eggs (SE = 1.44 million; Table 10).

Aerial Survey

Survey conditions ranged from "poor" to "fair to poor", on a scale of "poor, fair, and good" (Table 11). The maximum count was 1,436 total live and dead chinook salmon on 27 July and coincided with the first marking event. This count was about 26% of the point estimate from the mark-recapture experiment, and was proportionally lower than in 1988 and 1989, but was proportionally higher than in 1986 and 1987 (Table 12).

DISCUSSION

The success of this annual mark-recapture experiment is dependant on timing of the sampling events. 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 probabilities of capture during both sampling events is more likely. During the first electrofishing event most fish captured had already spawned, and only a few had not. Very few carcasses were noticed along the course of the study area. During the second electrofishing event catches were much lower than during the first event. Nearly all fish captured had spawned, and more carcasses were noticed. During the carcass survey only a few carcasses had decomposed to the extent that sex and length could not be determined, indicating that most fish were not dead for more than a few days. Some live fish were still in the river during the carcass sampling, but all appeared to be in post-spawning condition. This information indicates that the first electrofishing event and the carcass survey were conducted during the appropriate time frames, but the second electrofishing event was probably conducted too late.

An unbiased abundance estimator requires the gear to capture all chinook salmon in the population with equal probability. In this experiment the electrofishing gear was selective by size and by sex, whereas the carcass sampling was neither size nor sex selective. With electrofishing gear it is next to impossible to capture every chinook salmon that is encountered. In fact, the smaller chinook are easier to capture as they are not as strong swimmers as are larger chinook salmon. Also, they do not swim out of the electric field as readily. Smaller chinook salmon are also easier to land with a net than are larger chinook salmon. As the smaller chinook salmon tend more to be males, electrofishing tends to be more selective for small males. Hypothesis testing of data from this experiment supports these assertions.

During carcass sampling, however, nearly every chinook salmon that was encountered was sampled. Thus, much larger sample sizes were attained, and the chance of being either size or sex selective appears to be less than with

Table 10. Estimated egg production of chinook salmon in the Chena River, 1990.

Length Class (mm)	Number of Females	Estimated Egg Production (eggs)	SE (eggs)
580-650	14	70,000	36,000
660	14	73,000	35,000
670	7	38,000	18,000
680	7	39,000	17,000
690	14	81,000	35,000
700	0	0	0
710	7	43,000	17,200
720	21	134,000	51,000
730	7	46,000	17,000
740	7	48,000	17,000
750	14	98,000	34,000
760	21	151,000	50,000
770	28	207,000	67,000
780	57	433,000	136,000
790	28	218,000	66,000
800	85	680,000	201,000
810	43	353,000	101,000
820	135	1,134,000	318,000
830	118	1,015,000	277,000
840	163	1,434,000	382,000
850	120	1,080,000	281,000
860	261	2,401,000	610,000
870	169	1,589,000	394,000
880	233	2,237,000	543,000
890	148	1,450,000	345,000
900	212	2,120,000	494,000
910	156	1,591,000	363,000
920	113	1,175,000	263,000
930	128	1,357,000	299,000
940	78	842,000	182,000
950	78	858,000	182,000
960	49	549,000	115,000
970	49	559,000	115,000
980	7	81,000	16,000
990	14	165,000	33,000
1,000	14	168,000	33,000
1,010	14	171,000	33,000
TOTALS	2,633	24,690,000[a]	1,437,000[ab]

[a] Total does not equal sum of individual categories due to rounding errors.
[b] The standard error was calculated as the square root of the sum of the variances of the estimated fecundities for each length.

Table 11. Chinook salmon counted during aerial surveys of the Chena River, 1990.[a]

Date	Count	Survey Conditions[b]
16 July	501	Poor
18 July	637	Fair - Poor
21 July	684	Poor
27 July	1,436	Fair - Poor

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

[b] During these surveys, conditions were judged to vary by area on a scale of "poor, fair, and good".

Table 12. Estimated abundance, maximum aerial counts, and survey conditions for chinook salmon in the Chena River, 1986 through 1990.

Year	Estimated Abundance	S.E.	Aerial Survey Count	Aerial Survey Condition	Proportion Observed During Aerial Survey
1986	9,065	1,080	2,031	Fair	0.22
1987	6,404	563	1,312	Fair	0.20
1988	3,346[a]	---	1,966	Fair-Poor[b]	0.59
1989	2,666	249	1,180	Fair-Good[b]	0.44
1990	5,603	1,164	1,436	Fair-Poor[b]	0.26

[a] 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.

[b] During these surveys, conditions were judged to vary by area on a scale of "poor, fair, and good".

electrofishing. The results of this experiment indicated that the carcass sampling event was neither size nor sex selective. However, because of the sampling design used in this experiment (sampling dead fish during the recapture event), the hypothesis of an equal probability of capture for all chinook during the carcass survey could not be tested. Two of the three assumptions needed for an unbiased estimator were tested and not fulfilled (equal probability of capture during the electrofishing event and complete mixing of marked with unmarked fish within each sampling event). Because only one of the three assumptions need be fulfilled to have an unbiased estimate of abundance, the assumption of equal probability of capture during the carcass survey could be tested by comparing the estimates of abundance from Chapman's (1951) model and Darroch's (1961) model. These two estimates were different, but not significantly different (difference = 771; $P > 0.20$). This difference was enough, however, that Darroch's model was used as a more conservative estimate of abundance.

An unbiased abundance estimator also requires that marked fish mix completely with unmarked fish between sampling events. The data from this experiment indicated there was only partial mixing of marked chinook salmon between river sections. This problem is inherent with the present sampling design. Marked fish tend to be recaptured in the section they were tagged or in sections downstream. 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 and settle into areas with lower velocities as with pools. 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). Because the estimates of abundance from Chapman's model and Darroch's model were different, and because of the behavior of marked fish observed in this experiment, equal probability of movements between marked and unmarked fish was not likely.

Bias of the abundance estimate associated with tag losses in this investigation and similar studies (Skaugstad 1988, 1989, 1990a, and 1990b) 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 single tags that was lost in this experiment was easily identified by the presence of fin-clips.

The effects of electrofishing on the probability of recapturing marked chinook salmon are unknown. If electrofishing facilitates a premature death, then a carcass might decompose faster, could more likely be covered with silt or debris, could more likely be eaten by scavengers, or may be more likely to drift out of the study area. These events would result in a lower probability of recapture. This experiment was designed such that premature death would have little effect on the probability of recapture. Marking did not occur until after most fish had spawned. Because natural death occurs shortly after spawning, and because carcass sampling was initiated a short time after the marking events (two weeks after the first day of marking and four days after the last day of marking), any injury suffered during the marking event that may have caused premature death would have little effect on the probability of recapture of marked chinook salmon.

The estimate of abundance of all chinook salmon did not achieve the pre-experiment goal of a relative precision of ± 25% ($\alpha = 0.05$). The relative precision of total abundance in 1990 (41%) was substantially less than in 1989 (18%; Skaugstad 1990a) using similar techniques. This was a result of a low marked to unmarked ratio observed during the carcass sampling, and indicated that too few chinook salmon were marked during the electrofishing event. Catches during the second electrofishing event were much lower than during the first. If less time had elapsed between sampling events, higher catches may have occurred during the second event. Sampling bias, as determined from the bootstrap estimate of abundance, was 14% and was also indicative of a low marked to unmarked ratio. This was evident from the skewed distribution of the 500 bootstrap abundance estimates (Figure 4).

Age, sex, and mean length-at-age compositions were determined entirely from those fish collected during the carcass survey. Scales were taken from approximately 75% of the carcasses sampled. There was no significant difference in male to female ratios between carcasses sampled for scales and those carcasses that were not scale sampled ($\chi^2 = 0.48$, 1 df, $P < 0.5$). Scales were collected from the first 620 carcasses which included only fish from the upper and middle river sections. To avoid potential problems in the future, scales should be collected from all carcasses.

The Department of Fish and Game uses aerial surveys to assess population abundance because the cost is much less compared to mark-recapture experiments. 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. By comparing counts of chinook salmon from aerial surveys with estimates of abundance from mark-recapture techniques, it is hoped that a useable relationship can be developed to estimate population size from aerial surveys alone. Additional comparisons will be required to refine this relationship.

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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.

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.

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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.