Estimated Abundance of Adult Fall Chum Salmon in the Middle Yukon River, Alaska, 1998-1999

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by

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Abstract

Mark and recapture data were collected to estimate the seasonal and weekly abundance of fall chum salmon *Oncorhynchus keta* during 1998 and 1999 in the middle Yukon River. Fish were captured using two fish wheels for marking and two fish wheels for recovery. Marking and recovery sites were separated by a distance of 52 km. For the two years, spaghetti tags were applied at the marking sites to 8,527 and 12,350 fish, respectively. Concurrent to marking, 15,581 and 18,648 fish were examined for marks at the recovery site. Excluding multiple recaptures, 759 fish, respectively, were recaptured in 1998 and 825 fish were recaptured in 1999. Using a Darroch estimator, seasonal estimates were 194,963 and 189,724 fish, respectively. Weekly estimates were also generated. Statistical diagnostics indicated a potential of limited selective sampling by sex and/or length in 1999, but seasonal estimates of abundance calculated using data stratified by those factors were similar to non-stratified estimates; bias was then limited. In the four years of study, nonrandom mixing based on bank orientation was detected for the first time during 1999. Plots of weekly estimates based on the nine potential combinations of mark and recovery fish wheels suggest that the estimate is robust to this violation to the assumption of random mixing in regard to the bank of first capture. As in previous years, non-stratified seasonal estimates continued to be within 15% of the sum of upriver escapement estimates from projects upstream combined with harvest. Data collected during 1998 and 1999 comprise the third and fourth year of the study. We have not found reason to think that the methodology used is anything but useful and reliable.

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Introduction

In 1996 the U.S. Fish and Wildlife Service began an effort to estimate the migrating population of fall chum salmon *Oncorhynchus keta* in the Yukon River above the confluence with the Tanana River, Alaska. Results from the first two years of the study established that the estimator developed by Darroch (1961) could be applied successfully to the conditions found on the Yukon River. In addition, the estimates were judged acceptable for the proposed purpose of partitioning the estimate by drainage and/or stock using telemetry and, potentially, genetic analysis (Gordon et al. 1998; Underwood et al. 2000). The analysis from the first two years of investigation indicated that the apparent violations of the assumption of equal probability of recapture detected by statistical diagnostics did not cause bias; modeling reported by Gordon et al. (1998) suggested that differential movement was the likely cause of the significant diagnostics test. The hypothesis regarding differential movement was further supported in 1997 when stratification was possible due to improvements in data collection protocols. Estimates stratified by sex and length were not significantly different from unstratified estimates of the same populations; bias was negligible (Underwood et al. 2000).

Thus, the perceived reliability of the estimate continues to improve. In that regard, this paper reports the population estimates for 1998, 1999, and associated statistical diagnostics.

Study Area

The Yukon River is the fifth largest drainage in North America, an area of approximately 855,000 km^2 (Bergstrom et al. 1998). Three of the tributaries of the Yukon River are major rivers themselves, each approximately 1,000 km in length. They are the Koyukuk, Tanana, and Porcupine rivers and join the Yukon River at river kilometer 800, 1,100 and 1,600, respectively.

The middle Yukon River, upstream from the Tanana River, is almost 2 km at its widest point and flows at 6 to 12 km per hour. Due to the glacial origins of some of its tributaries, the Yukon River is very silty during the summer but clears during winter. The region experiences a continental climate with long, cold winters and brief, warm summers. Air temperatures below freezing are common during September. The river generally freezes by late October or November and the ice remains until May of the following year.

Two study sites were maintained on the mainstem Yukon River upstream from the Tanana River confluence (Figure 1). The location was selected to minimize capture of fall chum salmon returning to the Tanana River drainage, which constitutes the only major area of fall chum salmon spawning downstream from the study area. The marking site was located at an area known locally as “The Rapids,” a narrow canyon 1,176 km from the mouth of the Yukon River. At the marking site, one fish wheel was located on each bank. The recapture site was 52 km upstream from the marking site near the village of Rampart, Alaska. Similarly, one fish wheel was located on each bank at the recapture site.

Methods

Assumptions of the Estimator

The study was designed as a two-event, temporally stratified mark-recapture experiment. We used the model of Darroch (1961) to generate weekly and total estimates of fall chum salmon abundance in the middle Yukon River. Assumptions regarding the application of Darroch's model in this study were discussed by Gordon et al. (1998) and Underwood et al. (2000).

Sampling Procedures

Fish were captured using two fish wheels for marking and two fish wheels for recovery; the two capture locations were separated by 52 km. Sampling procedures at the marking and recapture fish wheels (Figure 2) were the same as described in detail by Underwood et al. (2000). Briefly, fish were captured with fish wheels and either processed immediately or stored in a live box until processed. Processing at the marking wheels included recording fish length (mid-eye to fork in cm), sex, color, fishing effort, release time and date, and the application of a sequentially numbered spaghetti tag. At the recapture fish wheels, data included recorded tallies of the total number of tagged and untagged fish captured per day, fishing effort, release time and date, and tag numbers of recaptured fish. In addition, a sub-sample (n = 150) of fish length and the sex were recorded each week at the recapture site. Dates in which data were collected varied slightly between years (Tables 1 and 2).

Efforts to reduce holding time at the capture fish wheels were made by minimizing the time fished at the marking site. Marking wheels were also modified using padding, plastic mesh, and nylon mesh netting to reduce impact injuries.

Analysis of Tagging and Recovery Wheel Data

Migration times.— We calculated migration times for all fish released at the marking wheels and subsequently caught 52 km upstream in the recapture wheels. Because we did not know the exact time of day that fish were caught in the recapture wheels, the midpoint was used to calculate the migration end time:

$$Migration\ Time = \frac{(r + g)}{2} - d \qquad \textbf{(1)}$$

where

r = date and time variable, to nearest minute, of a marked fish's release at the recapture wheels,

g = date and time variable, to nearest minute, of the beginning of a sampling period at the recapture wheels, and

d = migration start time, date and time variable, to nearest minute, of a marked fish's release at the marking wheels.

Equal probability of capture and movement to recapture strata.— Statistical tests could not be developed for two estimator assumptions (Gordon et al. 1998; Underwood et al. 2000): (1) all fish had an equal probability of recapture, or (2) all fish had the same probability distribution of movement between marking and recapture wheels. Instead, we tested the hypothesis that the recapture probabilities, the product of the probability of capture and the probability of movement to the recapture strata, were the same for all marked fish within a release stratum.

Multinomial logistic regression using generalized logits (Agresti 1990) was used to model the probability of recapture as a function of sex coded as an indicator variable and fish length. In choosing a model, a likelihood-ratio test compared the fitted model with a simpler one and then removed parameters one by one until it was determined that the fitted model added significant explanatory value over the simpler one. The process was started by comparing the full model, i.e., one containing the effects of sex, length, and their interaction with an intercept-only model. The model selection process continued only if the full model was chosen over the intercept-only model, i.e., if the likelihood-ratio test statistic, G^2 (full | intercept-only) was significant (*P* # 0.05). Next, a comparison was made between the full model and the main-effects model, i.e., one containing terms for sex and size only. If the test statistic was significant, the main-effects model was compared to the best-fitting single-effect model, i.e., one containing sex or size.

Data collected at the marking and recapture sites were temporally stratified into statistical weeks (Tables 1 and 2). At the marking site, statistical weeks began on Monday and ended on Sunday. At the recapture site, statistical weeks began on Tuesday and ended on Monday; the one-day lag allows for migration time from the marking site. Separate analyses were performed for each marking week.

Random mixing.— A log-linear model was used to test the global hypothesis that the bank of marking was statistically independent of the bank of recapture during the season but conditioned on the week of marking (Agresti 1990, section 7.4.1). If the test was significant ($P > 0.05$), unconditional tests were separately conducted on data from individual strata to discover time periods in which dependence might have occurred.

Abundance estimate.— Following Darroch (1961), we estimated weekly and seasonal abundance at the marking site as done in previous years (Gordon et al. 1998; Underwood et al. 2000). Similarly, we had to apportion some recaptured fish to a week of marking because some marked fish escaped without having their tags read. Consequently, we estimated the number of fish tagged in stratum i and recaptured in recovery stratum j using:

$$\hat{c}_{ij} = c'_{ij} + u_j \frac{c'_{ij}}{\sum_{k=1}^{n} c'_{kj}} \quad \textbf{(2)}$$

where

c'_{ij} = the known number of fish tagged in stratum *i* and recaptured in recovery stratum *j*, and

u_j = the number of fish recaptured in recovery stratum *j* with unknown tag numbers.

Second, based on the distribution of travel times, we assumed that some of the untagged fish captured in recovery wheels during the first week of the study passed the tagging site before the start of the experiment. This violates the assumption of closure which, if true and left uncorrected, would bias our estimates upward. Thus, we used migration rate data from the second and third weeks of the study and the methods used by Cappiello and Bruden (1997) to approximate the number of unmarked fish (1) that passed the marking site after the study began and (2) that were captured in the recovery wheels upstream during the first week (Underwood et al. 2000). Similarly, we had to adjust downward the number of fish marked and released during the last week of the study because some of them did not pass the recovery site until after the study was completed. The implicit assumption was that marked and unmarked fish travel between marking and recapture sites at the same rate.

Because of the results of the analysis of random mixing for 1999, we generated seasonal and weekly estimates using data from the various combinations of fish wheels so that the distribution and variation of the abundance estimates could be examined. There were nine possible combinations. Two arbitrary examples of the nine were: first, data from the north marking wheel and north recapture wheel and second, data from both marking wheels and only the south recapture wheel.

Results

Summary of Tagging and Recovery Wheel Data

During 1998, late run timing and low fall chum salmon abundance delayed the start of the tagging project until August 3. Tagging continued through September 19 and 8,527 fall chum salmon were tagged. Lengths of tagged fish ranged from 47 to 71 cm. Males made up 46% and females 54% of the tagged fish. Holding time mean, median, and mode were 2.9, 2.4, and 2.1 h, respectively, and ranged from 0.5 to 7.7 h. From August 4 to September 23, a total of 15,581 fall chum salmon were examined for marks at the recapture site. Excluding multiple recaptures, 759 marked fish were recaptured. The seasonal recapture rate was 4.6%, which was calculated by combining the daily catch of both recapture wheels and excluding multiple recaptures.

During 1999, low fall chum salmon runs delayed the start of tagging until August 4. Tagging continued through September 22 and 12,350 fall chum salmon were tagged. Lengths of tagged fish ranged from 44 to 70 cm. Male fish made up 47% of the tagged fish and females made up 53%. Holding times mean, median, and mode were 1.7, 1.5, and 1.4 h, respectively, and ranged from 0.1 to 8.2 h. From August 4 to September 25, a total of 18,648 fall chum salmon were examined for marks at the recapture site. Excluding multiple recapture, 1,198 marked fish were recaptured. The seasonal recapture rate was 6.4%.

Migration times.— During 1998 the seasonal mode to swim the 52 km between the marking and recapture sites was 1.2 d. Estimated mean travel times in a statistical week ranged from 1.2 d in week 1 and week 7 to 4.9 d in week 2 (Figure 3). The mean and variability of travel times generally decreased from statistical week 2 to week 7. Approximately 90% of tagged fish released during week 2 took 10.6 d or less to reach the recapture site. In week 7 approximately 90% of the tagged fish released took 1.5 d or less to reach the recapture site.

During 1999 the seasonal mode for a fish to swim from the marking site to the recapture site was 1.4 d. The mean and variability of travel times generally decreased throughout the study. Estimated mean travel times in a statistical week ranged from 3.6 d in week 2 to 1.3 d in week 8 (Figure 4). Mode travel time ranged from 1.4 d in week 1 to 1.0 d in week 8. Approximately 90% of the fish took 6.2 d or less in week 1 and 1.5 d in week 8.

Equal probability of capture and movement to recapture strata.— During 1998, selective sampling based on length and sex appeared to have little effect on the estimate; no bias was detected. Likelihood ratio tests of the full model and intercept logistic regression models (Table 3) indicated that the main effects of length and sex and the interaction term had no significant contribution to the fit of the model. Thus, no simplified models needed to be tested. A second technique, comparing a stratified estimate to the unstratified estimate, verified the results of the logistic regression (see Abundance Estimates below).

In 1999, likelihood ratio tests indicated significant differences between the full and intercept logistic regression models in weeks 4 and 7 (Table 4). Analysis of the full model and the main-effects-only model (no interaction term) indicated significant interaction in week 7 indicating stratification by length and sex was needed. In week 4, the interaction term was not significant, so further evaluation of the individual effects of sex and length was needed. Comparisons of week 4 main-effects model with each single-effects model showed a significant effect due to the sex of the fish, thus, stratification by sex was appropriate in 1999.

Random mixing.— During 1998, marked fish randomly mixed between release at the marking site's north and south banks and the recapture site's north and south banks (Table 5). No interaction between banks and weeks was detected (G^2 = 4.70, P = 0.32). In addition, once the interaction term was dropped, no main effects were significant (G^2 = 3.08, P = 0.37). These results are interpreted as an indication of random mixing and indicated that no stratification of the data by bank was required.

In contrast during 1999, bank fidelity was detected by a significant interaction among marking wheels, wheels of recapture, and statistical weeks (G^2 = 12.89, P=0.02, Table 6). Chi square tests of independence for each of the 2-by-2 contingency tables for wheel of release versus wheel of recapture by week indicated that the sixth statistical week, August 6-12, was the only week for which the hypothesis of independence was rejected (X^2 = 7.6, P = 0.006) . Running the original analysis without data from statistical week 6 indicated no statistical dependence.

Abundance estimates.— Mark and recapture data from 1998 (Table 7) were used to generate seasonal and weekly estimates of abundance (Table 8). Coefficients of variation ranged from 0.33 to 0.57 the first three statistical weeks and were 0.15 or less thereafter. Sample sizes were lower in the first three weeks than later (Table 7). Estimates for males and females were computed separately, and their sum differed from the seasonal estimate by less than 2% (Table 9). Similarly, the sum of length-stratified estimates (fish # 57 and >57) was less than 2% different from the seasonal abundance estimate (Table 9). Thus, biases based on length and sex were negligible.

The 1999 mark and recapture data (Table 10) also provide seasonal and weekly abundance estimates (Table 11). Coefficients of variation of the weekly abundance estimate were less than 0.13, except in the first and last weeks (0.20 and 0.32 respectively) when sample sizes as well as probability of capture were low. Seasonal estimates stratified by male and female when combined were 2% higher than the non-stratified estimate (Table 12). The combined seasonal estimate stratified by length (fish #56, 57-59, and $60cm) was 195,858 or 3% greater than the non-stratified estimate (Table 12).

As a result of the fidelity to the bank of tagging, nonrandom mixing was apparent in 1999. Thus, seasonal abundance estimates were generated for the nine possible combinations of tagging site, recapture site, and north and south fish wheels at each site (Table 13). Estimates generated from selected wheel locations varied from 151,144 to 204,751 fish. Standard errors of the estimates were greatly influenced by sample sizes. In most weeks, the 95% confidence intervals for abundance estimates overlapped (Figure 5) with the exceptions of weeks 2 and 6.

Discussion

Seasonal estimates for 1998 and 1999 extended a trend of decreasing annual runs of fall chum salmon above the Tanana River observed since a recent peak in 1996. Runs were in excess of 650,000 in 1996, 270,000 in 1997, and 194,000 in 1998 for a comparable time period of August and September (Gordon et al. 1998; Underwood et al. 2000). In 1999, the estimate was comparable to 1998, and the downward trend experienced from 1996 to 1998 essentially stopped. Reasons for the declines to below 200,000 fish are unknown. Competing hypotheses include poor egg-fry survival, changing ocean temperature regimes, and effects of bycatch in Bering Sea ground fisheries, and intercept fisheries (Kruse 1998).

Variation and trends regarding travel times between marking and recovery sites were similar to those of past years given that Gordon et al. (1998) rounded days up to the nearest day while Underwood et al. (2000, this paper) rounded down and calculated days to the nearest tenth of a day. Most commonly, travel times remained between one and two days. A comparison of travel time among years, if found similar, may eliminate the need to know individual tag numbers.

Diagnostic statistics examining for sex and length selectivity gave no indication of selectivity in any week during 1998, relieving the necessity to stratify the data. In 1999, one statistical week showed significant interactions between main effects and another week showed significant main effects. However, as in past years, we stratified by sex and length and demonstrated that any detected bias did not affect the outcome of the estimate. In comparison, in 1996 and 1997, two to three weeks had indications of significant main effects or significant interaction between sex and length effects. In 1996, no stratified estimate was possible because length data at the recovery site appeared biased. In response, Gordon et al. (1998) modeled the effects of changing movement and probability of capture and found that bias was likely to be negligible. During 1997, similar statistical indications of potential bias were examined by stratifying the estimate and comparing the stratified and unstratified estimates. Again, this indicated that bias from sex and length characteristics was minimal. Thus, the estimator and methodology appear to be robust.

In 1999 for the first time in four years of data collection, nonrandom mixing based on wheel of capture was detected statistically. Our method, logistic regression, combines data of the various weeks and negates the possibility of directly determining if the departures from randomness are widespread or found in only one week. A possible indication was gained using a two-factor test of best fit which suggests that only statistical week 6 departed from randomness. Christensen (1990) described possible erroneous conclusions from this procedure. Hence, we further examined the data by generating estimates from data stratified by all the possible combinations of fish wheels, nine in all (Table 13). The estimates had a range of 53,607 fish, approximately twice the range of the bound of the estimate of 27,868 fish. Finally, the comparison of nine possible estimates for each week demonstrated that, in general, estimates were distributed within the bound of each other for a given week, indicating the robust nature of the estimator. Despite the exceptions, weeks 2 and 6, the best estimates are probably those with higher sample sizes and recapture rates. Most likely, the best estimate is that which uses data from all four wheels.

Population estimates at the Rampart-Rapids during 1996-1999 have fallen below and above estimates based on the sum of four escapement projects and the estimated harvest (Table 14). Estimates have been within 15% of these numbers each year. We conclude that the techniques employed produce a useful estimate that tends to correspond with other sources of information.

Several other factors should be mentioned regarding variation of the abundance estimates and comparison with upriver escapement projects. First, it is currently not possible to tell by gross examination when the fall chum salmon run begins. Summer chum are likely included at the beginning of tagging in some years, and some fall chum are missed because of the tagging start and stop dates. Genetic data collected during the sampling from 1998 on may shed some light on the nature of the mixed stocks eventually. Second, upriver escapement projects are also subject to unquantified variation. Factors like high water shut down side-scan sonar occasionally each year. Despite these factors, correlation between the up-river projects and this study is high indicating they respond to the population and environmental factors similarly. We conclude then that the upriver escapement project assess the abundance of the primary stocks that exist.

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Table 1.— Statistical week sampling dates of fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, August 3 to September 21, 1998. At the marking site weeks were started on Monday and concluded on Saturday. At the recapture site, weeks were started on Tuesday and concluded on Monday to allow for migration.

Statistical week	Date
Marking site	
1	Aug 3 through Aug 9
2	Aug 10 through Aug 16
3	Aug 17 through Aug 23
4	Aug 24 through Aug 30
5	Aug 31 through Sep 6
6	Sep 7 through Sep 13
7	Sep 14 through Sep 19
Recapture site	
1	Aug 4 through Aug 10
2	Aug 11 through Aug 18
3	Aug 18 through Aug 24
4	Aug 25 through Aug 31
5	Sep 1 through Sep 7
6	Sep 8 through Sep 14
7	Sep 15 through Sep 21

Table 2.— Statistical week sampling dates of fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, August 3 to September 25, 1999. At the marking site, weeks were started on Monday and concluded on Saturday. At the recapture site, weeks were started on Tuesday and concluded on Monday to allow for migration.

Statistical week	Date
Marking site	
1	Aug 4 through Aug 8
2	Aug 9 through Aug 15
3	Aug 16 through Aug 22
4	Aug 23 through Aug 29
5	Aug 30 through Sep 6
6	Sep 7 through Sep 12
7	Sep 13 through Sep 19
8	Sep 20 through Sep 22
Recapture site	
1	Aug 5 through Aug 9
2	Aug 10 through Aug 16
3	Aug 17 through Aug 23
4	Aug 24 through Aug 30
5	Sep 1 through Sep 6
6	Sep 7 through Sep 13
7	Sep 14 through Sep 20
8	Sep 21 through Sep 25

Table 3.— Results of logistic regressions of capture histories on length, mid-eye to fork length (cm), and sex of fall chum salmon migrating past the marking and recapture wheels on the Yukon River, Alaska, August 3 to September 21, 1998. Comparisons are between the intercept (no characteristics included) and full (size, sex, and the interaction) models, the full and main effects (size and sex) models, and between the main effects and best single-effect (size or sex) models. G^2 is the likelihood ratio test statistic used in the comparison of the models of the effect of these characteristics on the probability of recapture in recapture weeks k and $k + 1$.

Marking week, *k*	Logistic regression model -2 log likelihood		G^2	df	*P*
	Intercept	**Full**			
1	31.71	30.43	1.30	3	0.73
2	215.95	207.09	8.86	6	0.18
3	491.55	482.72	8.83	6	0.18
4	1061.87	1055.23	6.64	6	0.36
5	1401.98	1395.79	6.20	6	0.40
6	1282.74	1277.03	5.72	6	0.46
7	369.47	363.57	5.91	3	0.12

Table 4.— Results of logistic regressions of capture histories on length, mid-eye to fork length (cm), and sex of fall chum salmon migrating past the marking and recapture wheels on the Yukon River, Alaska, August 4 to September 25, 1999. Comparisons are between the intercept (no characteristics included) and full (size, sex, and the interaction) models, the full and main-effects (size and sex) models, and between the main-effects and best single-effect (size or sex) models. G^2 is the likelihood ratio test statistic used in the comparison of the models of the effect of these characteristics on the probability of recapture in recapture weeks k and $k + 1$.

Marking week, k	Logistic regression model -2 log likelihood			G^2	df	P
	Intercept	**Full**				
1	258.65	254.03		4.62	6	0.59
2	1591.09	1583.54		7.55	6	0.27
3	1682.08	1675.54		6.54	6	0.36
4	1788.15	1775.16		12.98	6	0.04
5	1247.95	1247.48		0.47	6	0.99
6	1243.80	1236.80		7.00	6	0.32
7	767.30	750.78		16.52	6	0.01
8	87.75	86.41		1.35	3	0.72
	Full	**Main effect**				
4	1775.16	1776.46		1.29	2	0.52
7	750.78	761.1		10.31	2	0.01
		Best single effect				
	Main effects	**sex**	**length**			
4	1776.46	1786.01		9.55	2	.049
4	1776.46		1776.51	0.05	2	1.0
		Intercept vs best single				
	Intercept	**Sex**				
4	1788.15	1786.01		2.13	2	0.34

Table 5.— Bank of tagging versus bank of recapture for tagged Yukon River fall chum salmon, July 1 to September 24, 1998.

		Recaptured fish (row %)	
Marking week	Marking bank	North bank	South bank
1	North	3 (100)	0 (0)
	South	0 (0)	0 (0)
2	North	18 (100)	0 (0)
	South	6 (86)	1 (14)
3	North	40 (87)	6 (13)
	South	12 (75)	4 (25)
4	North	59 (79)	16 (21)
	South	59 (88)	8 (12)
5	North	86 (84)	17 (16)
	South	91 (88)	12 (12)
6	North	66 (73)	25 (27)
	South	72 (76)	23 (24)
7	North	9 (56)	7 (44)
	South	26 (96)	1 (4)

Table 6.— Bank of tagging versus bank of recapture for tagged Yukon River fall chum salmon, August 4 to September 25, 1999.

		Recaptured fish (row %)	
Marking week	Marking bank	North bank	South bank
1	North	14 (67)	7 (33)
	South	7 (54)	6 (46)
2	North	69 (65)	37 (35)
	South	49 (52)	45 (48)
3	North	66 (60)	44 (40)
	South	64 (60)	42 (40)
4	North	76 (70)	33 (30)
	South	97 (71)	40 (29)
5	North	67 (71)	27 (29)
	South	60 (64)	36 (36)
6	North	50 (54)	42 (46)
	South	70 (74)	25 (26)
7	North	45 (71)	18 (29)
	South	37 (82)	8 (18)
8	North	4 (100)	0 (0)
	South	5 (83)	1 (17)

Table 7.— Adjusted weekly tagging and capture histories of tagged fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, August 3 to September 19, 1998.

Marking week, i	Marked fish released, a_i	Recapture week, j 1	2	3	4	5	6	7	Fish not recaptured
		Recaptured the first time							
1	220	3	0	0	0	0	0	0	217
2	372	0	9	13	2	0	1	0	347
3	680	0	0	40	20	1	1	0	618
4	1,600	0	0	0	120	23	0	0	1,457
5	2,260	0	0	0	0	201	5	0	2,054
6	2,173	0	0	0	0	0	185	1	1,987
7	1,131	0	0	0	0	0	0	42	1,089
Estimated unmarked fish, b_j		110	187	703	2,499	4,009	5,294	1650	

Table 8.— Seasonal and weekly estimates, standard error (SE), coefficient of variations (*V)*, probability of capture (*P*), and SE of *P* of the 1998 run of fall chum salmon at the marking site.

Date of estimate	Estimate	SE of estimate	Coefficient of variation *V*	Probability of capture *P*	SE of *P*	*V* of SE
Seasonal estimate						
Seasonal	194,963	9,397	0.05			
Weekly estimates						
Aug 3 - Aug 9	8,507	4,847	0.57	0.026	0.015	0.58
Aug 10 - Aug 16	9,093	2,968	0.33	0.041	0.013	0.32
Aug 17 - Aug 23	6,796	2,468	0.36	0.100	0.036	0.36
Aug 24 - Aug 30	31,496	2,897	0.09	0.051	0.005	0.10
Aug 31 - Sep 6	42,504	3,055	0.07	0.053	0.004	0.08
Sep 7- Sep 13	58,635	4,252	0.07	0.037	0.003	0.08
Sep 14 - Sep 19	37,931	5,740	0.15	0.029	0.004	0.14

Table 9.— Estimates stratified by sex and length, standard error (SE), and high and low 95% confidence interval bounds of the 1998 run of fall chum salmon at the marking site. The bound is calculated as the estimate ± 2*SE.

Strata	Estimat e or total	SE of estimate	High bound	Lower bound
Stratification by sex				
Female	105,445	6,397	118,239	92,651
Male	87,159	6,696	100,551	73,767
Total	192,604			
Stratification by length				
Length # 57	67,703	5,685	79,073	56,333
Length > 59	124,680	6,680	138,040	111,320
Total	192,383			

Table 10.— Adjusted weekly tagging and capture histories of tagged fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, August 4 to September 25, 1999.

Marking week, *i*	Marked fish released, a_i	Recapture week, *j* 1	2	3	4	5	6	7	8	Fish not recaptured
		Recaptured the first time								
1	332	25	8	0	1	0	0	0	0	298
2	2,262	0	143	48	4	5	0	0	0	2,062
3	2,477	0	0	173	37	6	0	0	0	2,261
4	2,205	0	0	0	197	46	3	0	0	1,959
5	1,725	0	0	0	0	182	6	1	0	1,536
6	1,899	0	0	0	0	0	185	2	0	1,712
7	1,145	0	0	0	0	0	0	101	7	1,037
8	301	0	0	0	0	0	0	0	10	291
Estimated unmarked fish, b_j		587	3,487	2,781	2,815	1,894	2,235	1,640	599	

Table 11.— Seasonal and weekly estimates, standard error (SE), coefficients of variation (*V*), probability of capture (*P*), and SE of *P* of the 1999 run of fall chum salmon at the marking site.

Date of estimate	Estimate	SE of estimate	*V* of the estimate	Probability of capture *P*	SE of *P*	V SE of *P*
Seasonal estimate						
Seasonal	189,742	6,967	0.04			
Weekly estimates						
Aug 4 to Aug 8	8,127	1,592	0.20	0.041	0.008	0.20
Aug 9 to Aug 15	54,449	4,625	0.08	0.041	0.004	0.10
Aug 16 to Aug 22	26,439	3,332	0.13	0.094	0.012	0.13
Aug 23 to Aug 29	28,411	2,211	0.08	0.078	0.006	0.08
Aug 30 to Sep 6	12,851	1,383	0.11	0.134	0.014	0.10
Sep 7 to Sep 12	25,104	1,797	0.07	0.076	0.005	0.07
Sep 13 to Sep 19	19,386	1,884	0.10	0.059	0.006	0.10
Sep 20 to Sep 22	14,974	4,879	0.32	0.020	0.006	0.30

Table 12.— Estimates stratified by sex and length, standard error (SE), and high and low 95% confidence interval bounds of the 1999 run of fall chum salmon at the marking site. The bound is calculated as the estimate ± 2*SE

Strata	Estimate or total	SE of estimate	High bound	Lower bound
Stratification by sex				
Female	84,518	3,797	92,112	76,924
Male	109,284	7,375	124,034	94,534
Total	193,802			
Stratification by length				
Length # 56	52,693	4,003	60,702	44,687
57 < length #59	72,124	4,287	80,698	63,550
length $ 60	71,041	6,316	83,673	58,409
Total	195,858			

Table 13.— Seasonal estimates of fall chum salmon run size generated using the nine possible combinations of two marking and two recovery fish wheels.

Fish wheels used to generate estimate			
Marking wheels	Recovery wheels	Estimate	SE of estimate
north and south	north and south	189,742	6,967
north and south	north only	200,393	8,520
north and south	south only	179,988	28,559
north only	north only	204,751	14,193
north only	south only	151,144	11,476
north only	north and south	196,068	14,066
south only	north only	189,587	11,743
south only	south only	159,853	15,266
south only	north and south	173,473	7,882

Table 14.— Comparison of the annual Darroch estimate with measured components of the run upstream including escapement projects of the four major spawning stocks and harvest numbers upstream of the tagging site.

Description	1996	1997	1998	1999
		Escapement projects		
Chandalar River.	208,170	199,874	75,811	88,662a
Sheenjek River	247,965	80,423	32,894	14,229[a]
Fishing Branch River	77,278	26,959	13,248	12,904[a]
Mainstem border passage	143,758	94,725	48,047	65,896[a]
		Harvest above the study area		
Rampart	896	645	100	4,324 b
Steven's Village	991	1,585	1,076	20 b
Beaver	9	243	409	16 b
Fort Yukon	8,144	6,119	3,035	9,702 b
Circle	5,308	3,707	37	2,722 b
Central	132	0	0	0 b
Eagle	14,916	14,488	543	11,292 b
Chalkytsik	505	421	50	442 b
Other	1,230	936	433	746 b
Sum of harvest	32,131	28,144	5,683	29,264 [b]
Sum of escapement and harvest	709,302	430,125	175,683	210,955b
		Variance of Rampart-Rapids estimate from other totals		
Darroch estimate (this project)	654,296	369,547	194,963	189,743
Percent difference	-7.8	-14.1	11.0	-11.0

[a] Preliminary estimates at the time of printing (JTC 1999).

[b] This number should be considered a preliminary estimate of harvest pending completion of final project reports (Borba 2000).

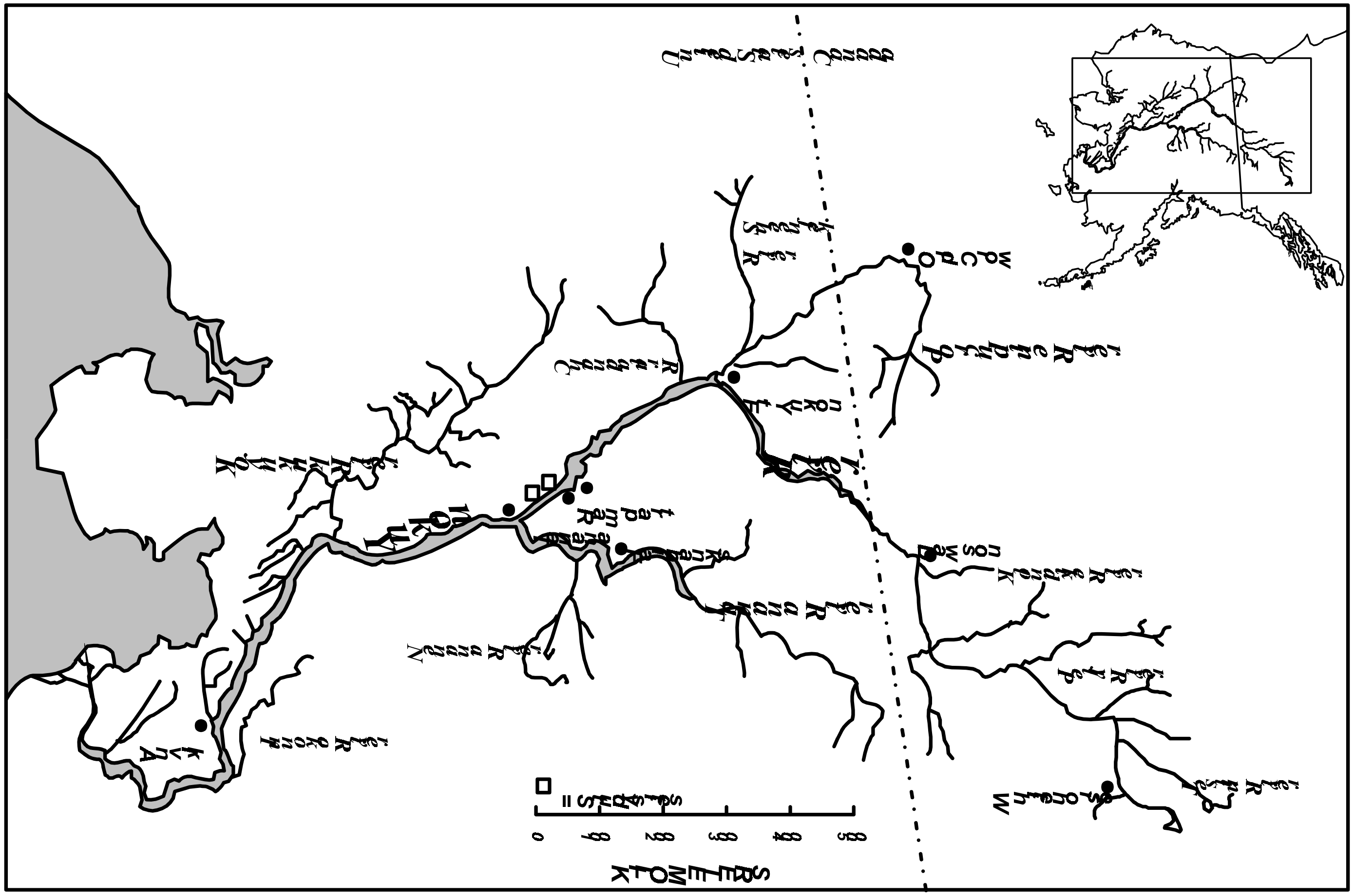

Figure 1.— Yukon River drainage showing project study sites. Open squares indicate study site locations.

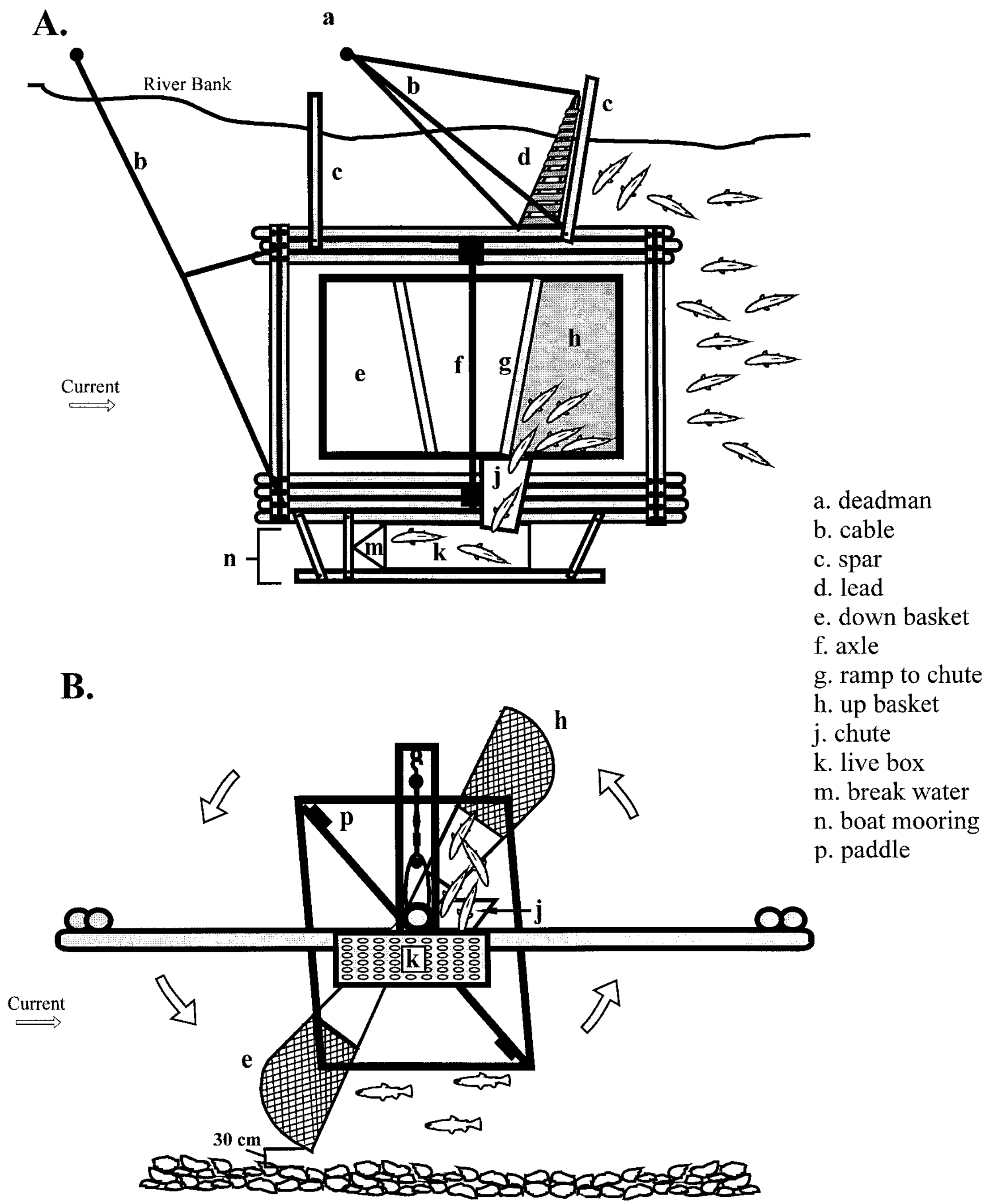

Figure 2.— Two-basket fish wheel equipped with padded chute and live holding box, used to collect fish during the marking and recapture events. A. Aerial view. B. Side view with arrows indicating the direction of wheel movement in response to the current.

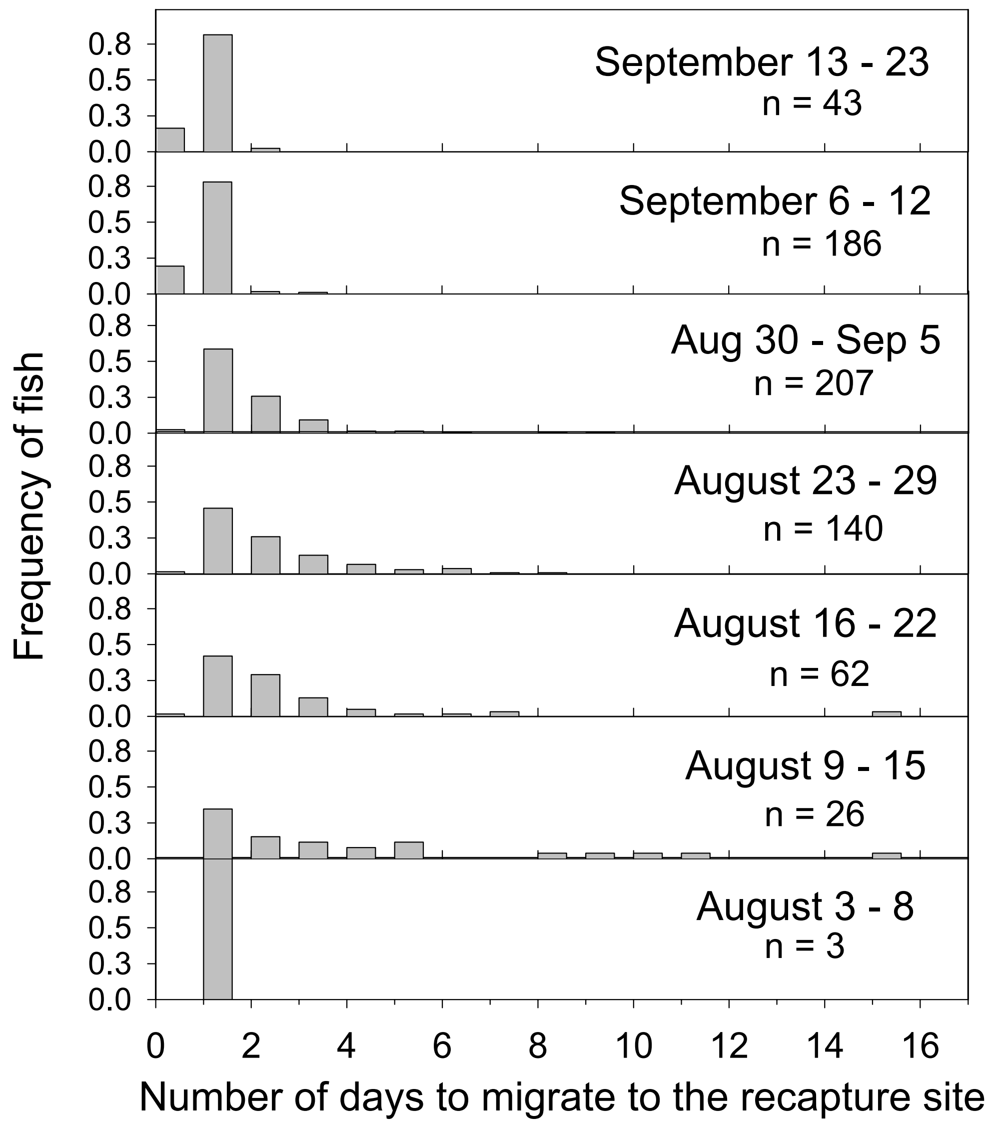

Figure 3.— Estimated migration time (d) for tagged fall chum salmon between the marking and recapture sites, by statistical week, on the Yukon River, Alaska, August 3 to September 21, 1998. Histograms represent proportion of recaptured fish. Estimated migration times greater than or equal to 15 d were combined in the 15+ d category.

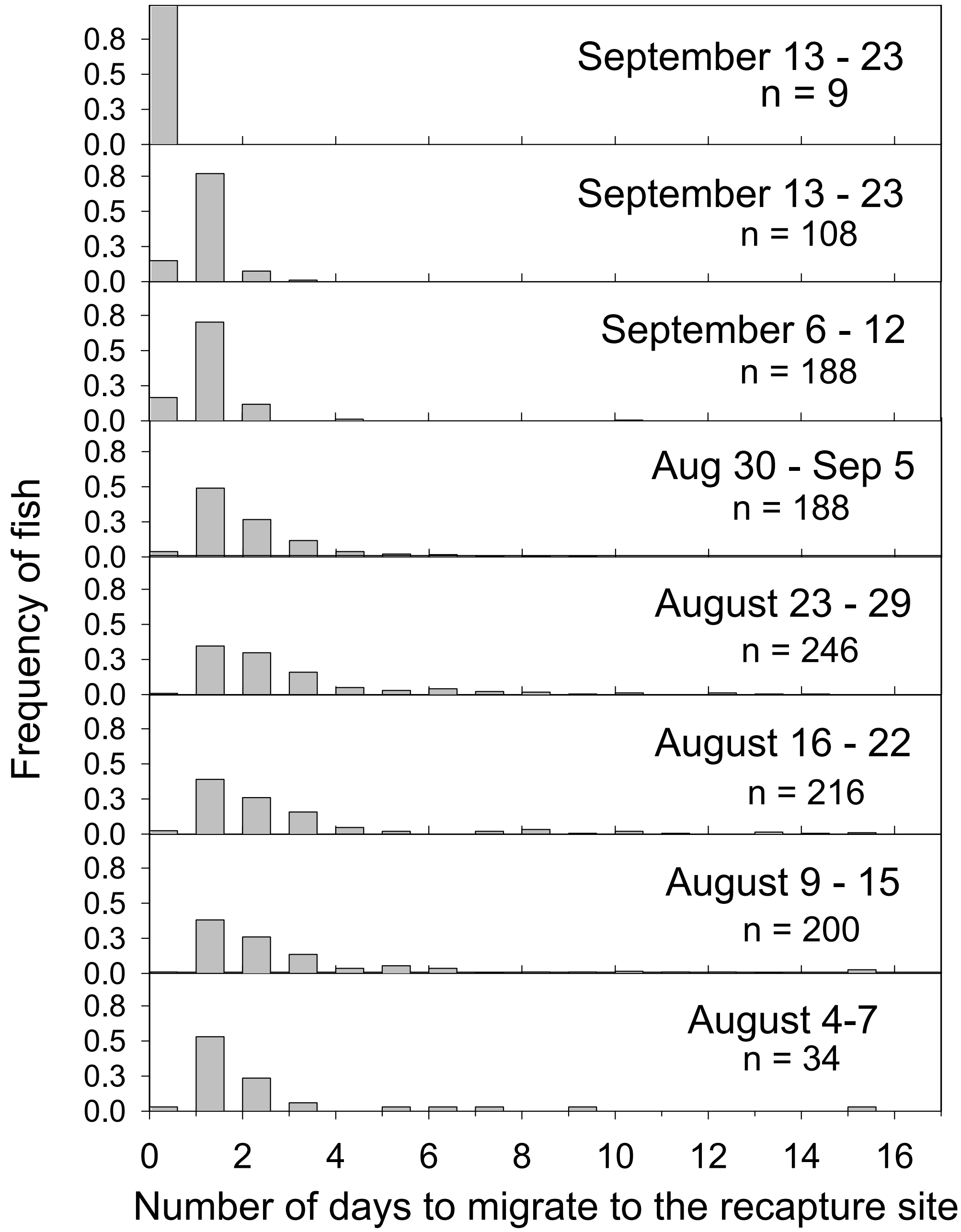

Figure 4.— Estimated migration time in days (d) for tagged fall chum salmon between the marking and recapture sites, by statistical week, on the Yukon River, Alaska, August 4 to September 23, 1999. Histograms represent proportion of recaptured fish. Estimated migration times greater than or equal to 15 d were combined in the 15+ d category.

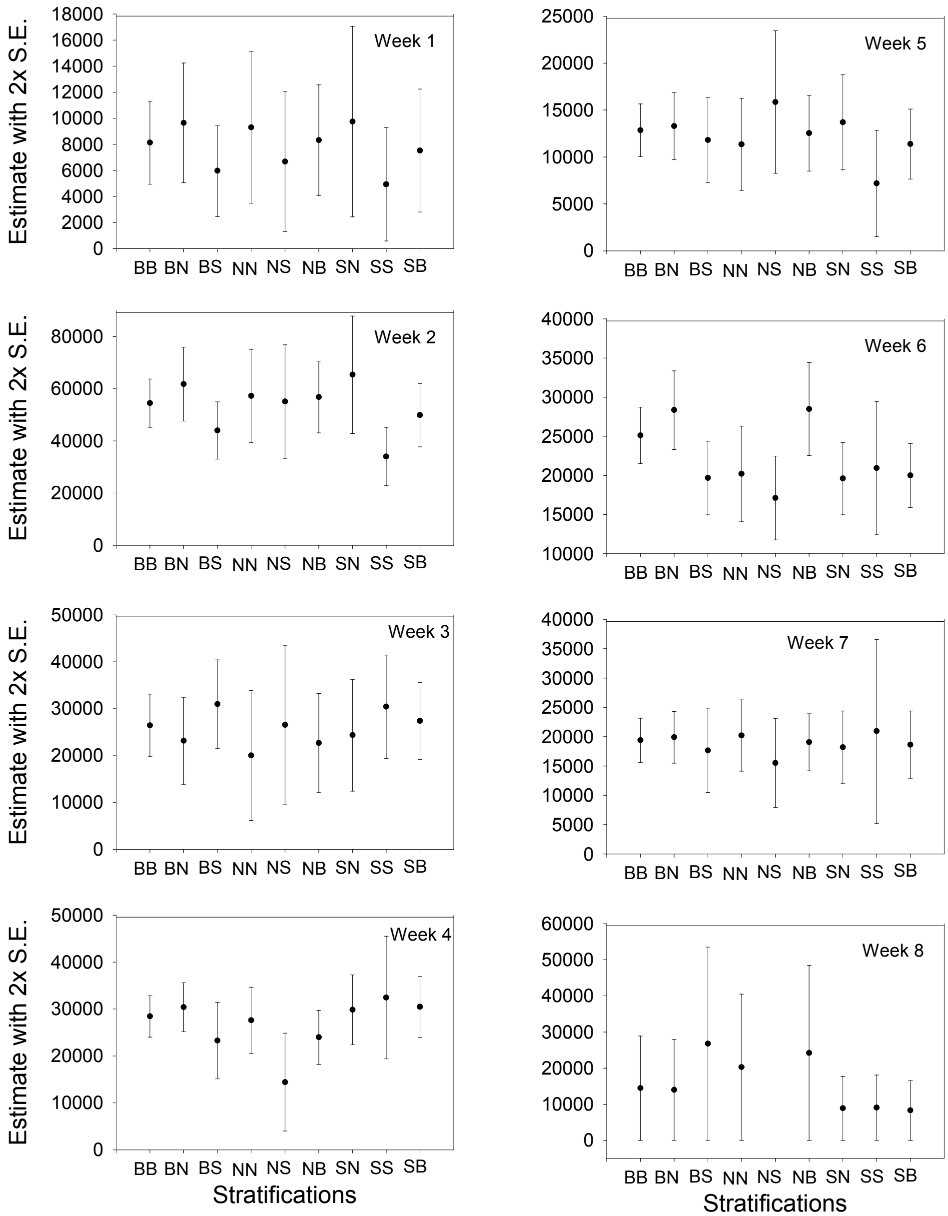

Figure 5.— Weekly estimates and bounds using the nine possible combinations of mark and recovery fish wheels. A two letter label on the x-axis describes the wheels used. The first letter represents the marking wheels and the second letter the recovery wheels, both (B), north (N) or south (S). Thus, "BN" stands for both marking wheels, but only the north recovery wheel.