Alaska Fisheries Technical Report Number 56

Estimated Abundance of Adult Fall Chum Salmon in the Upper Yukon River, Alaska, 1997

February 2000

Region 7
U.S. Fish and Wildlife Service • Department of the Interior

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Key words: fall chum salmon, *Oncorhynchus keta*, mark, recapture, Darroch, population estimate, selective sampling, Yukon River, fish wheel, tag

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February 2000

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The correct citation for this report is:

Underwood, T. J., S. P. Klosiewski, J. A. Gordon, J. L. Melegari, and R. J. Brown. 2000. Estimated abundance of adult fall Chum salmon in the upper Yukon River, Alaska, 1997. U.S. Fish and Wildlife Service, Fairbanks Fishery Resource Office, Alaska Fisheries Technical Report Number 56, Fairbanks, Alaska.

Abstract

We conducted a mark-recapture experiment and used Darroch's two-sample, stratified model to estimate the number of fall chum salmon migrating up the Yukon River, above the Tanana River, Alaska, from July 21 to September 28, 1997. Two fish wheels, located on opposite banks of the river, were used to capture fish; 18,631were marked with spaghetti tags and released. A second pair of fish wheels, located 50 km upstream near the Village of Rampart, Alaska, was used to recapture marked fish; 40,978 fall chum salmon were captured and examined for tags, from July 22 to September 28. Excluding multiple recaptures, 1,872 fish were recaptured. Most tagged fish were caught within the week when they were marked. Primary (spaghetti tags) and secondary tags (fin clips) were used to determine tag loss; no tag loss was documented. Fish randomly mixed between banks between the tagging and recapture sites. The probabilities of recapture, the product of the probabilities of capture and movement, were associated with a fish's length and sex during the third and eighth weeks of tagging, suggesting the potential for biased estimates. However, bias resulting from differential recapture probabilities was deemed insignificant; differences between the sum of individual estimates by sex and length classes, and the combined sex and length class estimate were negligible. Statistical analyses did not detect any other selective sampling. Our estimate of 369,546 ± 17,386 (95% CI), was within 15% of an independent estimate for the upper Yukon River of 430,493 fish. The 1997 results reaffirm the conclusion drawn in 1996, that a mark-recapture experiment based on the Darroch model provides a viable means for estimating the abundance of fall chum salmon in the upper Yukon River.

Table of Contents

List of Tables

List of Figures

Introduction

In 1985 the governments of the United States and Canada signed a treaty concerning transboundary Pacific salmon *Oncorhynchus* spp. (Pacific Salmon Commission 1986). The Pacific Salmon Treaty recognized the unique nature of the Yukon River fishery and directed the Pacific Salmon Commission to take steps to clarify the issues and establish a means to manage the fishery cooperatively and equitably (Pacific Salmon Commission 1986). In keeping with this broad directive, the governments of Canada and the United States amended the Pacific Salmon Treaty in 1995 to specifically address Yukon River issues (Pacific Salmon Commission 1995). The amended portion of the Treaty, known as the Interim Agreement, was allowed to expire in 1998; nevertheless, it is still the paradigm under which management agencies currently function. The Interim Agreement resulted in the formation of an international management structure for the Yukon River called the Yukon River Panel (Panel). In 1996, the Panel supported (in concept) the study described below for estimating the number of fall chum salmon in the Yukon River above the confluence with the Tanana River.

The study was originally conceived to provide weekly or biweekly population estimates of fall chum salmon, and to ultimately apportion these estimates to various drainages in the United States and Canada based on radiotelemetry and genetic results. The first step in this study was to determine the feasibility of using fish wheels to capture sufficient numbers of fish to conduct a mark-recapture experiment on fall chum salmon. Fish wheels have been used successfully on other large rivers as a capture method for tagging studies (Meehan 1961; Merritt and Roberson 1986; Eiler 1990) and for mark-recapture experiments (Greenough 1971; McGregor et al. 1991; Cappiello and Bromaghin 1997). Researchers initiated this study on the Yukon River in 1996 and demonstrated that the mark-recapture model developed by Darroch (1961) could be applied to data collected with fish wheels on the Yukon River upstream of the Tanana River, Alaska (Gordon et al. 1998). The point estimate produced in 1996 (654,000 ±41,800) was within 8% of an independent estimate, based on escapement and harvest data collected upstream of the study site (Gordon et al. 1998). Precise weekly estimates were also generated. Although the study was deemed successful in the initial stages, additional work was needed to gain confidence in the results.

During 1996 staff identified some potential problems, improvements, and additional research questions that needed to be addressed (Gordon et al. 1998). Results from analysis of 1996 data indicated that stratification by length and sex may be necessary to generate unbiased estimates (Gordon et al. 1998), but the lack of length and sex data on unmarked fish captured at the recovery site precluded stratification based on sex and/or length. In 1997, a more rigorous sampling regime was implemented at the recapture site to permit stratification by sex and length. Gordon et al. (1998) also recognized inconsistencies associated with the assessment of a fish's color as a measure of maturity or "distance" to spawning sites, and the assessment of a fish's condition as a measure of its ability to complete its spawning migration. Better criteria were needed to make data from these assessments useful.

Another potential problem was identified by cooperators in Canada in 1996; recapture-to-capture ratios (R/C) collected at escapement projects on the Fishing Branch and mainstem Yukon Rivers were extremely low, 0.0008 and 0.003, compared to the observed ratio of 0.03 for fish captured in our study. The data collected in Canada suggested problems with our sampling methods that were not detected by statistical analysis, or alternatively that our sampling caused mortality, or stressed fish in a way that prevented them from reaching the spawning grounds. A number of other hypotheses were identified (Table 1). Actions were taken in 1997 to investigate causes of the discrepancy between R/C ratios in our study and in Canada and to more rigorously document R/C ratios throughout the basin. One specific action was a thorough examination of tag loss/retention because tag loss was a likely explanation.

Addressing the above problems was necessary to assess the potential for biased estimates, and to evaluate the effects of changes in sampling protocols before radiotelemetry and genetics could be used to apportion the run to specific drainages as originally envisioned (Gordon et al. 1998). Finally, it was not known how annual variation in run size might affect the viability of using a mark-recapture experiment to estimate the abundance of fall chum salmon in the upper Yukon River.

The purpose of this year's study was to estimate the annual return of fall chum salmon, to improve the quality of the estimate, and to increase our knowledge in its use. Thus, we repeated the experiment with the modifications suggested in Gordon et al. (1998) and discussed above. The resulting report, below, documents the changes made in sampling procedures; provides additional investigation of selective sampling and bias and an estimate of the abundance of upper Yukon River fall chum salmon in 1997; and documents our effort to define and discover causes behind the reported low R/C ratios in Canada.

Study Area

The Yukon River (Figure 1) is the fifth largest drainage in North America, encompassing an area of approximately 855,000 km^2 (Bergstrom et al. 1995). Three of the tributaries that join the Yukon River are major rivers themselves, each approximately 1,000 km long. They are the Koyukuk, Tanana and Porcupine Rivers, joining the Yukon at 800, at 1,100, and at 1,600 km from the mouth.

The upper Yukon River, upstream from the Tanana River, is almost 2 km at its widest point and flows at 6-12 km per hour. Due to the glacial origins of some of its tributaries the Yukon River is silty during the summer, but clear during the 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 early November and the ice remains until May of the following year.

Two study sites were maintained on the mainstem of the 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. The recapture site was 50 km upstream from the marking site, near the village of Rampart, Alaska.

Methods

Assumptions of the Estimator

The study was designed as a two-sample, temporally stratified mark-recapture experiment. We used Darroch's (1961) model to generate weekly and total estimates of fall chum salmon in the upper Yukon River. The study design also allowed for stratification by river bank, sex, and length. Assumptions regarding the application of the Darroch's model in this study were discussed by Gordon et al. (1998) and are listed below:

1. Closure: all fish in the recapture strata must have been present in one of the marking strata, and all fish in the marking strata must be present in one of the recapture strata.

2. No tag loss: fish must retain their mark and be correctly identified.

3. All fish in a given recapture event, marked and unmarked, have equal probability of capture.

4. All fish, marked and unmarked, of a given marking stratum have the same probability distribution of movement to the recapture strata.

5. Fish captured and marked on the north and south banks mix randomly with respect to bank orientation between release at the marking site and capture at the recapture site.

Although Darroch's model allows for spatial and temporal stratification, we had to add assumption 5. In 1996 we found that recapture histories of fish tagged at north and south bank fish wheels were linearly dependent. This linear dependence produced unrealistic abundance estimates, i.e., those with negative capture probabilities. Thus, we could use only temporal stratification; our estimates could be biased if fish did not mix randomly with respect to bank orientation.

One untested assumption remained: that of closure. Examination of closure will depend on radio telemetry data to be provided in 1998 (John Eiler, National Marine Fisheries Service, Auke Bay Laboratory, personal communications). Until these data are available, closure was assumed because adult salmon migrate upstream from the ocean to spawn, thus passing the marking site before reaching the recapture site. In addition, a preliminary evaluation of movement to the recapture strata based on 50 radio-tagged fish showed minimal (2%) drop-back or mortality (John Eiler, National Marine Fisheries Service, Auke Bay Laboratory, personal communications).

Marking Site Sampling Procedures

Two-basket fish wheels (wheels) equipped with padded chutes and live holding boxes were used to capture chum salmon at the marking site (Figure 2). Wheel baskets at the marking site were approximately 3.0 m wide and dipped to a depth of 4.5 m below the water's surface. Nylon seine netting was installed on the sides of the baskets to minimize injury to fish as they were lifted clear of the water. Closed cell foam padding was placed along the chute and ramp on the path to the holding boxes to reduce impact injury to fish. Holding boxes were 2.4 m long, 1.2 m deep, and approximately 1 m wide. The walls and floors of the holding boxes contained many 5 cm diameter holes to allow a continuous flow of water while preventing heavy current that could impinge on weakened fish.

Wheels were placed across from each other on the north and south banks of the river. Wheel placement relative to shore was determined by the depth of the dip on the shoreward edge of the baskets. This edge was positioned to sweep within 30 cm of the bottom. Wheels were moved relative to shore as the water level rose or fell to maintain the same proximity to the bottom. A lead, in the form of a submerged picket fence, was placed between the wheel and the shore to direct fish towards the dipping baskets.

Tagging commenced on July 21 and ceased on September 20 at both marking wheels. Fish were marked from Monday through Saturday. Operation of the wheel balanced the need to tag approximately 400 fish per day, with the need to spread those tagged fish throughout the day, and the need to minimize holding time. Wheels were run as long as 24 hours per day during times of low catch rates to fewer than 6 hours on days when catches were high. Generally, crews tagged fish at four different times on most days (usually at 0800, 1200, 1600, and 1900 hrs ADT) and attempted to mark about 100 fish each trip. Wheel operation was minimized to meet the goal of 100 fish per work session. When the catch appeared to substantially exceed the goal of 100 fish per session, a systematic sample was taken. For example, upon arriving at the fish wheel the crew might estimate that 150 fish were present in the livebox and so every third fish would be excluded from tagging. Recaptured tagged fish were handled the same as unmarked fish except no new length was recorded and no new tag applied. Fish with major injuries (described below) were released. Sampling ended when the live box was emptied even if the goal of 100 fish per work session was exceeded.

Fish were dipnetted, handled, and released so as to minimize handling time, stress, and trauma. Fall chum salmon were marked with individually numbered spaghetti tags applied with hollow applicator needles. We recorded length, sex, tag number, condition and color categories, and release times for all marked fish. Length, mid-eye to fork (MEL), was measured to the nearest cm. Sex determination was based on several external indicators, including the condition of the kype and teeth, abdominal distention, the size of the adipose fin, and the condition of the vent. Fish with major injuries (as described below) were released untagged and the next fish was selected.

A condition index was developed to determine which fish received tags, and as a means to test for behavioral differences that may accompany a fish's condition. The three condition categories were defined as good, minor injury, or major injury (Table 2). All chum salmon categorized as being in good condition or having a minor injury were tagged.

A color index was developed based upon the degree of spawning coloration or other secondary spawning characteristics exhibited by individual fish. This index was developed as a possible indicator of distance, either temporal or geographic, to the spawning grounds. The categories were defined as silver, light, and dark (Table 3).

Recapture Site Sampling Procedures

The river at the recapture site was wider and shallower than at the marking site, so the wheels were sized accordingly. Baskets on the recapture wheels were approximately 2.5 m wide and dipped to a depth of 3.0 m below the water's surface. The south bank wheel was placed about 2 km downstream from the north bank wheel.

Recapture procedures carried out by a contractor and discussed below included recording information on marked and unmarked fish; sampling for sex and length data to allow stratification of the estimate; and sampling designed to estimate tag loss. First, fish were checked for primary marks while in the dip net; the numbers of marked and unmarked fish were tallied; tag numbers and release times were recorded; and the fish were released. Some recaptured fish escaped from the net into the river prior to having their tag number read; in these cases fish were assigned to a statistical week of marking based on the composition of known tags. Second, length, sex, condition, and color were recorded from a sample of approximately 150 fish per statistical week. The fish were collected so that the data were spaced throughout the week on at least three days (e.g., Monday, Wednesday and Friday, 50 fish from each day). When a day was selected for sampling, a systematic sample was taken from each live box. For example, data were collected from every 11th fish until the box was empty. The integer used for sample selection was based on the previous day's catch divided by 50 and then rounded down. When the target number was reached prior to emptying the live box, sampling continued until the live box was emptied. Finally, a second sample was taken to examine tag loss in a subsample of 100 fish per day (approximately) from the first live boxes emptied. These fish were examined for the presence of primary and secondary marks. When high densities of fish were encountered, a systematic sample was taken to reduce the number of fish handled (e.g., every third fish was examined). Three tallies were recorded: (1) number of fish examined in the sample, (2) number of fish with primary and secondary marks, and the (3) number of fish with only a secondary mark. Again, sampling proceeded until the live box was empty.

Sampling commenced at both recapture wheels on July 22 and ceased on September 28. Recapture wheels were operated 24 hours a day, seven days a week. The holding box was usually emptied at least four times per day; the frequency varied depending on the density of fish in the box. The contractor was instructed to make every effort to maintain the live box so that the number of fish never exceeded 200 fish.

Analysis of Tagging and Recovery Wheel Data

Migration times.— Migration times were calculated for all fish tagged and released at the marking wheels and caught 50 km upstream in the recapture wheels. Migration time for each recaptured fish was calculated as follows.

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

where

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

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

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

Since we did not know the exact time of day when fish were caught in the recapture wheels, the midpoint of r and g, i.e., $(r - g)/2$, was used to calculate the migration end time.

Migration times were also calculated for tags returned by upriver fishermen and by Canada's Department of Fisheries and Oceans (DFO) fisheries projects. Tags that were accompanied by dates and location of harvest were used to calculate migration times and migration rates. Migration rates were calculated as the distance from the tagging site to the recapture site, in river km (Schultz et. al. 1993), divided by migration time. Migration times were calculated to the nearest day (1200 hr as a midpoint) because often only the day and not the time of recapture was known.

Tag retention.— Data on the presence of primary and secondary marks from fish recaptured at the recapture site were used to estimate tag retention (tag loss) between the marking and recapture sites. During sampling at the recapture fish wheels (described above) tallies were collected of total fish examined, fish with primary and secondary marks, and fish with only secondary marks.

Assessment of condition and color classifications. An assessment of the crew's ability to classify fish by condition and color (Tables 2 and 3) was conducted in light of inaccuracies described by Gordon et al. (1998). Using fish that were tagged, released, and recaptured at the marking wheels, the condition and color classification data were examined for consistency between the first and second examinations.

Equal probability of capture and movement to recapture strata.— Tests could not be developed to determine (1) if all fish had an equal probability of capture at the recapture site, or (2) if all fish had the same probability distribution of movement between marking and recapture wheels. Instead, we determined if the recapture probabilities, Darroch's ψ_{ij}'s (i.e., the product of probability of movement to recapture strata, θ_{ij}, and capture probabilities, p_j) were the same for all marked fish of release stratum i. Given that

$$c_{ij} = a_i \, \theta_{ij} \, p_{rj} = a_i \, \psi_{ij} \, , \qquad \textbf{(2)}$$

where

c_{ij} = number of marked fish released during week i that were recaptured for the first time during week j (the implicit and untestable assumption is that marked and unmarked fish behaved similarly),

and

a_i = number of marked fish released during the ith week at the marking site,

we were able to use the recapture data to perform this analysis.

Multinomial logistic regression, using generalized logits (Agresti 1990) was used to model the probability of recapture as a function of a fish's sex and length. In choosing a model, we used a likelihood-ratio test to compare the fitted model with a simpler one and then removed parameters one by one until we 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 ($P \leq 0.05$). Next, a comparison was made between the full model and the main effects model, i.e., one containing sex and size. 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 grouped into statistical weeks (Table 4). At the marking site statistical weeks began on Monday and ended on Saturday. At the recapture site statistical weeks began on Tuesday and ended on Monday to allow for migration time from the marking site. Separate analyses were performed for each marking week, i.e., stratum.

Random mixing.— Following Agresti (1990, section 7.4.1), we used a log-linear model to test if north and south bank marked fish had randomly mixed between the marking and recapture sites. We combined data from marking weeks to increase power, but controlled for a stratum effect. Combining the data and performing simple 2-factor tests of independence would have led to improper weighting of the data and possibly erroneous conclusions (Christensen 1990). Performing this log-linear analysis, conditioned on statistical week, is analogous to performing the Cochran-Mantel-Haenszel Test (Agresti 1990).

Abundance estimate.— Following Darroch (1961), the estimate of the number of unmarked fish migrating through our study area, $\hat{n}$, was estimated by

$$\hat{n} = b'C^{-1}a, \tag{3}$$

where

a	=	a vector with elements a_i, the number of tagged fish released in stratum i;
C	=	a matrix with elements c_{ij}, the number of tagged fish released in stratum i that were recaptured at the recovery site during recovery week j; and
b	=	a vector with elements b_j, the number of untagged fish captured at the recovery site during recovery stratum j.

With four exceptions, we followed the same procedures used by Gordon et al. (1998) for estimating weekly and total abundance, their variances, and statistical bias. For the exceptions, we first had to estimate the elements of C because 24 fish were recaptured but their tag numbers were not recorded. Although we knew when these fish were recaptured, we did not know when they were tagged. Consequently, we estimated the number of fish tagged in stratum i and recaptured in recovery stratum j as:

$$\hat{c}_{ij} = c_{ij} + u_j \frac{c_{ij}}{\sum_{i'=1}^{n} c_{i'j}} \tag{4}$$

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, we had to estimate $\mathbf{u}_j$ because we wanted to generate separate abundance estimates for male and female fish and for different length classes of fish, but we recorded the sex and length from only a sample of untagged fish captured at the recovery site. We estimated this simply by multiplying $\mathbf{u}_j$ by the proportion of fish of a given sex and length class in the sample taken during stratum *j*.

Third, 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, had passed the tagging site before the start of the experiment. This violates the assumption of closure; if true and left uncorrected, this violation would bias our estimates upwards. Thus, we used data from the second and third weeks of the study, and the methods used by Cappiello and Bruden (1997) to estimate the proportions of unmarked fish that passed the marking site after the study began, and that were captured in the recovery wheels upstream during the first week of the study, to correct these numbers (Table 5). The assumption was that marked and unmarked fish travel between marking and recapture sites at the same rate. 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 before the study was completed (Table 6).

Lastly, we generated abundance estimates for 2-, 3-, 5-, and 7-day intervals, as well as for the whole season. This allowed us to examine potential bias due to violation of the assumption that all marked and unmarked fish in a recapture stratum have equal probabilities of capture.

CPUE versus estimated abundance.— Relative abundance was measured by the catch per unit effort (CPUE), number of fish in a 24 hour period. At the marking site the amount of time the wheel fished varied from 24 hours to less than 6 hours per day so catches were expanded to 24 hours. At the recapture site wheels were run 24 hours per day so no expansion was necessary. Marking and recapture wheel CPUE plotted by date were compared to corresponding abundance estimates. Cumulative CPUE date and corresponding cumulative abundance estimates were also plotted by date.

Analysis of Recapture-to-Capture Ratios

Nine hypotheses (Table 1) were developed to explain and test why recapture-to-capture ratios (R/C) were lower in upper-basin areas at our recovery site at Rampart, Alaska. Five hypotheses were addressed by protocol changes or specific efforts to collect the data needed to evaluate each as discussed below (Table 1, incomplete reporting, #1 ; dilution from immigration of the unmarked tails of the run, # 2; tag loss, # 3; selective sampling for or against one stock, # 4; and induced mortality, # 8). The remaining hypotheses 5-7 and 9 of Table 1 were not addressed in 1997.

Incomplete reporting.— To address incomplete reporting, we trained people living along the river, at eight locations upstream of the recapture site, to collect R/C data during 1997. In contrast, R/C data were available from two sources in Canada and were collected incidental to work during other projects, in 1996. In addition, during 1997, data were also collected from subsistence fishermen. Data received included tallies of total catch and number of fish with primary marks.

Immigration of unmarked fish.— To address immigration of unmarked fish as an explanation for the low R/C ratios in Canada, sampling began ten days earlier in 1997 than it did in 1996. In 1996 tagging began on August 1, reportedly after the first group of fall chum salmon passed the marking site. These circumstances may have allowed large numbers of unmarked fish to pass the marking site, without being exposed to sampling, thereby effectively reducing the proportion of tagged fish upstream. Similarly, based on the estimate of fish passage the last week in 1996 (Gordon et al. 1998), it appeared that the study ended while the run was still fairly strong. This too would contribute to low R/C ratios in Canada. Thus, in 1997, we monitored catch per unit effort and examined the estimate of the last week of tagging to determine whether or not fish passage had tapered off during the last week. By using both of the above actions in 1997, the effect caused by the immigration of unmarked fish was reduced or at least purposefully monitored.

Tag loss.— The addition of a secondary mark to all tagged fish during the processing protocol allowed us to examine tag loss in upstream areas. Trained individuals at the eight locations (as mentioned above) sampled catches of subsistence and commercial fishers, and of research projects. They recorded total catch, fish with primary marks, and fish with only secondary marks.

Selective sampling.— Selective sampling can occur in two ways. First, a portion of all stocks is unavailable for sampling (based on sex or length, which were described above, or another characteristic not identified). Second, an individual stock or stocks are unavailable for sampling. We examined the second of these possibilities. Testing the hypothesis of selective sampling for one or more stocks beyond our recapture site required R/C ratios to be collected from all known spawning stocks. If a number of stocks had R/C ratios far below the seasonal average and this was based on stock-specific sampling, one could reason that somewhere else in the drainage one or more stock must have R/C ratios higher than the seasonal average. The collection of data on most spawning stocks was incidental to the sampling described above; however, special efforts had to be directed towards two additional spawning areas, the Chandalar and Sheenjek rivers. Carcass surveys were conducted on these rivers during two days in October, 1997. Data recorded included location, total number of fish examined, total number of fish with primary or secondary marks, and tag numbers if present.

Effects of repeated capture.— The effect of handling fish was examined by comparing the probabilities of capture upstream. Two contingency table analyses were done to determine if the probability of tag recovery was associated with a fish's capture history. The contingency tables were used to examine counts of recaptured fish versus fish not recaptured subsequent to one, two, three, or more than three capture-and-release experiences. The first test examined fish capture histories at the marking site versus fish subsequently caught at the recapture site at Rampart, Alaska. The second test included fish capture histories at both the marking and recapture sites versus fish final recovery upstream of Rampart, Alaska.

A second examination of the effect of repeated capture focused on cumulative holding times during processing. Cumulative holding time, an estimate of the total time spent in the live box at the four wheels, was calculated by summing all holding times a fish experienced. Holding time was calculated as follows:

$$Holding\ Time = \frac{(r - g)}{2} \qquad \textbf{(5)}$$

where

r	=	date and time, to nearest minute, of a marked fish's release at a wheel, and
g	=	date and time, to nearest minute, of the beginning of a sampling period at a wheel.

Cumulative holding time was plotted against the distance to final capture.

Results

Analysis of Tagging and Recovery Wheel Data

From July 21 through September 20, 1997, 18,631 fall chum salmon were tagged at the marking wheels. Lengths of tagged fish ranged from 47 to 73 cm MEL. Males made up 48% and females 52% of the tagged fish. Holding times during tagging ranged from 0.05 to 18.4 h with the mean, median, and mode holding times of 4.3, 3.5, and 3.2 h. From July 22 to September 22, 40,978 fall chum salmon were examined for primary marks at the recapture sites. Excluding multiple recaptures, 1,872 marked fish were recaptured. On average fewer than 5% of the fish were recaptured more than once at the recapture site.

Migration times.— Modal estimated migration time between the marking and recapture wheel for tagged fish was 2 d or less in each statistical week (Figure 3). Estimated migration times for individual tagged fish ranged from less than 1 d in week 7 to 40 d in week 1. Variation in estimated migration time decreased from statistical week 1 to 9. Approximately 90% of tagged fish released during week 1 took 4 d or less to reach the recapture wheels. In week 9 approximately 90% of the tagged fish released took 2 d or less to reach the recapture wheel.

Approximately 1,050 tags were returned by subsistence and commercial fishers throughout the Yukon River drainage. Of these, 989 were returned from sites upriver of the tagging location. Tags were returned from locations greater than 1,300 km upriver of the tagging site including the Kluane and the Fishing Branch Rivers in Canada. Tags were returned from as far downriver as the village of Kaltag, 452 km away.

Migration rates were calculated for 379 tagged fish harvested in upriver fisheries, or captured in fisheries projects in Canada. The mean migration rate of harvested tagged fish was 36 km/d (SE = 0.5) with a range of 16 to 111 km/d. The mean migration rate from the marking wheels to the recapture wheels near Rampart was 30.3 km/d. The mean migration rate of 36 km/d was used to estimate migration time in days from the marking wheels to different locations upriver (Table 7).

Tag retention.— No evidence of tag loss was observed. A total of 9,697 fall chum salmon were examined for secondary marks, i.e., fin clips, at the recovery wheels at Rampart, Alaska. Of the 575 fish having secondary marks, all had their primary mark, the spaghetti tag.

Assessment of condition and color classifications.— Classification between the mark and second assessment was inconsistent for condition and color in the fish sampled in the first three weeks of sampling (n = 908). Thirteen percent of individual fish originally classified as being in good condition, and 44% originally classified as having a minor injury were reclassified differently upon recapture (Table 8). For color, 67, 14, and 31% of the silver, light, and dark colored fish classified differently upon recapture (Table 9). Based on these data, condition and color data were not collected after August 11 and were eliminated from further analysis.

Equal probability of capture and movement to recapture strata.— Violations of the assumption of the equal probability of recapture were noted, but appeared to have little effect on the estimate. Differences between the full model and the model with just the intercept (Table 10) indicated that sex and length helped predict recapture in statistical weeks 3 ($P = 0.05$) and 8 ($P = 0.01$). Further analysis of those two weeks using the full and main effects model indicated the interaction between size and sex helped predict recapture in week 3. No significant interaction was detected for week 8, allowing the interaction term to be dropped. Likewise, including both main effects added little explanatory over the best single effect model (Table 10), leaving us to decide on a model that included only length. The likelihood-ratio statistic, $G^{2,}$, was greater for length than for sex (Table 10); both variables explained more variation in recapture than the intercept-only model. Parameters estimates are presented in Table 11. The results indicated that stratification by sex and/or length may reduce bias of the weekly estimates.

Random mixing.— Marked fish randomly mixed between release at the marking site and recapture at the north and south bank recapture wheels (Table 12, $G^2 = 11.40$, $P = 0.18$). No interaction between banks and weeks was detected ($G^2 = 4.92$, $P = 0.67$). In addition, once the interaction term was dropped no main effects were significant. Interpreted as a indication of random mixing, the data indicated that no stratification of the estimate by bank is required.

Abundance estimates.— Tabulated data (Table 13) were used to generate weekly and seasonal estimates as well as those estimates further stratified by sex and length (Table 14). The seasonal estimate was not significantly different from estimates stratified by sex, sex and length, and length. The estimates based on further stratification were within 2.5% of the corresponding bootstrap result (Table 15). The similar results indicated that bias based on sex or length is negligible, supporting the statistical analyses above.

Estimates were also generated using alternative temporal strata, 2-, 3-, 4-day in addition to the 7-day strata described above (Table 16). Temporal strata at the marking and recapture sites were changed in unison. These estimates were similar to each other and indicated that the estimate is robust to changes in capture probabilities based on the selection of the duration of the temporal stratification. Confidence intervals for the shorter time periods were wider than for estimates with longer time periods because finer stratification increases the number of parameters being estimated and reduces sample size within the strata. Probability of capture within a strata varied more widely in 2 d strata than in longer strata (Figure 4).

CPUE versus estimated abundance.— Marking and recapture wheel CPUE plotted by date were compared to corresponding abundance estimates (Figure 5). The measures of relative abundance tracked well except that Darroch estimates tend to lead CPUE in time and indicate future direction regarding increases and decreases. In a few instances the estimate and CPUE disassociated, for example on July 22 and August 18. Also, an individual wheel's CPUE and estimated abundance were more likely to disassociate than the combined CPUE total from two wheels.

Analysis of Recapture-to-Capture Ratios

The R/C ratios based on tag recovery at 13 sites upstream of the recapture wheel indicated an inverse relationship with distance (Table 17). Using these data, several of the potential explanations for observed low R/C ratios were examined directly and by inference.

Incomplete reporting.— Incomplete reporting was addressed by designing a planned effort to gather data from upstream areas and training personnel in recognizing primary and secondary marks on fish. No change in the relationship (R/C vs. distance) between 1996 and 1997 was observed by adding to the number of observations. For example, the change in R/C values between the recapture wheels at Rampart, Alaska, and the DFO fish wheels located on the Yukon River mainstem near the border was a decrease of 80%.

Immigration of unmarked fish.— Tagging was initiated on July 21, two weeks earlier than during 1996 and continued until September 20, when the run had substantially declined. The final weekly estimate in September declined to 21,800 fish per week (5% of the total estimate in 1997) from 39,500 fish the previous week. In addition, CPUE declined from 397 fish/ 24h on September 13 to 171 fish / 24 h on September 20 in a steady decline. In contrast, final weekly estimates during 1996 remained over 69,000 fall chum salmon or 10% of the total estimate in 1996 (Gordon et al. 1998).

Tag loss.— Tag loss was specifically examined at eight sites ranging from 52 to 1402 km upstream of the tagging location. No fish were found to have lost their primary marks at these locations (Table 18). Fish were collected throughout the season at two of the sampling locations, while at the other sites fish were sampled over shorter time segments.

Selective sampling.— Misallocation of tags by over-or underrepresenting one or more stocks was examined by collecting data representing all known major spawning areas. The R/C values listed (Table 17) do not indicate values higher than the proportion found at the recapture site of 5.0 % with one exception where the sample size was low.

Effects of repeated capture.— A history of repeated capture at the tagging wheels was found not to affect the probability of recapture ($X^2 = 6.93$, d.f. = 3, and $P = 0.07$) when the final capture was at the recovery site at Rampart, Alaska (Table 19). In contrast, when the recapture histories included repeated captures at all wheels versus final capture upstream from the recovery site, the probability of recapture differed significantly from their expected values ($X^2 = 36.04$, d.f. = 3, and $P = 0.001$); fish captured two or three times were half as likely to be recaptured upriver (Table 20).

Plots of total holding time in the fish wheel live box versus distance to final capture offered no additional insight to explain the low R/C ratios upstream (Figure 6). Total holding times for fish with one or more captures ranged from less than 1 h to 44 h with a mode of 3.15 h and median of 3.77 h.

Discussion

The ability to obtain precise weekly estimates from a major sub-basin of the Yukon River presents unique opportunities to learn about the spawning stocks and potentially, to manage fisheries upstream more effectively. The weekly population estimates investigated here could be an important index for the sub-basin, but equally important, they provide a platform for other techniques to exploit, for example, radiotelemetry and genetic analysis. Radiotelemetry can track salmon to individual drainages with 99% reliability (Eiler 1995) allowing the potential of weekly estimates that could be partitioned by drainage. Radiotelemetry also provides the ability to identify as yet unrecognized spawning areas (Eiler et al. 1992). Genetic analysis also holds great potential to exploit the information generated by the weekly estimates, given a significant breakthrough regarding genetic markers needed to separate upriver stocks (Beacham et al. 1988; Wilmot et al. 1992; Wilmot et al. 1994). Genetic sampling during the mark-and-recapture program could provide percentage stock composition by week through a mixed stock analysis. Inseason analysis of stock composition as the run travels through Alaska could give Canadian fishery managers a picture of the stocks that will be available for harvest that much earlier and substantially more accurately than is now available.

Potential benefits described above depend heavily on the accuracy and precision of the estimate. Data collection in 1997 improved our confidence in the abundance estimates in most aspects while identifying the need for investigation of a few other areas. Much of the additional effort focused on the assumptions required for use of the estimator. For example, the assumption of tag retention is important and has received insufficient attention (Seber 1982). Significant tag loss could add bias to weekly and seasonal estimates. In addition, tag loss was one possible explanation of the low R/C ratios found upriver. Thorough investigation of tag retention/loss at the recovery site 52 km upstream revealed that no tag loss was observed and the assumption was met. In addition, no fish processed two or more times at the marking wheel were found to have lost a tag. This makes sense because time and distance between mark and recapture are minimal compared to studies where recapture occurs on distant spawning grounds. In comparison, the potential for tag loss in this study is minimized. Finally, tag loss was not found in upstream areas despite extensive effort. These findings are similar to those reported for fall-run chum salmon (Cappiello and Bromaghin 1997; Cappiello and Bruden 1997) from the Tanana River, a tributary of the Yukon River.

Mortality or downstream movement of tagged fish would violate the assumption of closure. Others researchers have included a correction for mortality of 5 to 10% (Milligan, et al. 1986; Cappiello and Bromaghin 1997). Gordon et al. (1998) did not use a correction because the data available from radio telemetry indicated correction was unwarranted. In 1996, of 50 radio tagged fish released at the tagging site 48 fish moved past a tower 11 km above the release site, one fish regurgitated its tag after recapture at the marking site, and one fish was not relocated (John Eiler, National Marine Fisheries Service, Auke Bay, personal communication). No fall chum salmon spawning areas are known to occur between the marking and recapture sites.

The mean migration rate of 36 km/d, based on travel between the marking and recovery fish wheels, was higher than the mean migration rate of 26 km/d reported by Cappiello and Bromaghin (1997) for fall chum salmon in the upper Tanana River. However, similar migration rates have been reported by others. Milligan et. al. (1986) reported average migration rates of 30.5 - 35.7 km/d for chum salmon during a mark-recapture study, and an average rate of 37.9 during a telemetry study in the upper Yukon River in Canada. Buklis and Barton (1984) also estimated a similar migration rate of 37 km/d in the lower Yukon by comparing mean dates of passage between different test-fishing sites.

The assessment of condition and color continued to be plagued by inconsistency despite apriori definitions for each category and efforts to train crew members, as suggested by Gordon et al. (1998). The categories were to be used to evaluate the temporal or spatial distance from spawning. Part of the problem was that the technicians must evaluate multiple continuous traits to assign each fish to a category. These traits do not vary consistently with each other. For example, one fish may be fully scaled, silver, and have a developed kype; the next fish may have absorbed scales, be yellow, and have little kype development. The result is opposing indication of maturity or "closeness" to spawning. Alternatively, fishermen told us that fish change color in the live box although we had no way to quantitatively test this hypothesis. As in1996 (Gordon et al. 1998), attempts to use these categories were ended.

Analysis of probability of recapture data suggested some evidence that bias in sampling occurred. Statistical analysis revealed limited violations of the assumptions of probability of recapture based on length and sex for a second year in a row. The similarity of results between years adds some confidence in the procedure; however, the statistical analysis of bias described above falls short of ideal because of the inseparable association of the probabilities of capture and movement (Seber 1982), Darrochs's ψ_{ij}'s (i.e., the product of probability of movement to recovery strata, θ_{ij}, and capture probabilities, p_j). These associated probabilities could vary within ψ_{ij}, in essence canceling each other out while change in the overall value remains nonsignificant. Modeling presented by Gordon et al. (1998) showed that the potential for substantial bias was small if θ_{ij} varies, but if p_j varies, the bias can be large. Therefore, one cannot be certain that bias is small despite the statistical tests. In view of the finding of limited violations regarding sex and length found in both years (Gordon et al. 1998; this study), one can see the need to further investigate any indication of a potential for bias, thus highlighting the necessity of having the ability to stratify by length and sex.

The advantage gained in 1997 by the ability to stratify by sex and length becomes apparent when stratification is used to reduce any bias based on those characteristics. When the seasonal estimate was compared to the seasonal estimate generated by stratifying by sex and/or length, the estimates were quite similar, indicating bias was negligible. In contrast, inadequate data in 1996 required Gordon et al. (1998) to model the potential effects of bias, with the conclusion that bias was likely to be small. The addition of the 1997 data supported the hypothesis of Gordon et al. (1998) that violations measured statistically are likely due to differential movement between temporal strata rather than to size-or sex-based selective sampling.

Similarly, the length of the temporal strata used had little effect on the estimates. Temporal strata duration was manipulated to produce estimates based on 2-, 3-, 4-, and 7-day strata length (Table 16). Despite the constantly changing probability of recapture (Figure 4), in apparent violation of the assumption of constant probability of capture, our data appear robust to the need of constant wheel efficiency within a stratum. The various estimates have different strata length, but the results were similar.

As in 1996, the estimate generated from mark-recapture data compared favorably with an independent estimate compiled from escapement and harvest data. Estimates of fall chum salmon escapement unrelated to this study are made in four portions of the Yukon River drainage. Escapement estimates from these four locations, plus harvest between the Tanana River and the location of escapement, can be used as an alternate minimum estimate of fall chum salmon (Table 21). The project data used represent the majority of the known spawning stocks and harvest in the Yukon River drainage above the Tanana River. Our 1996 estimate was low by approximately 8%; 654,296 versus 708,812 fish of the independent estimate. Our 1997 estimate was low by 15%; 369,547 versus 430,493 fish. The consistent difference, our estimate being less, compared to the other escapement projects may or may not be significant. The cause remains unclear, but further work on the issue should be a focus for additional study.

Recapture-to-capture ratios reported from Canada in 1996 needed further investigation because two hypotheses (Tables 1, 4 and 5) suggest a potential for bias in the run estimate and another suggests substantial mortality caused by handling fish. Several potential hypotheses for low R/C were addressed in 1997. Incomplete reporting, and immigration of unmarked fish were addressed with changes in procedure. Those procedural changes had no effect on the trend of decreasing R/C ratios upstream observed in 1997 which was similar to that found in 1996. Tag loss also appears to be negligible even into the upper Yukon River Basin. Observations of R/C ratios representing the various spawning stocks and drainages are less robust, but still add to the picture. Among the drainages no observations indicated overrepresented stock that might balance the low values found in most areas. To reasonably explain the low R/C values based on misallocation to one or more stocks, somewhere within the drainage, R/C values higher than the seasonal average would need to be observed. Although large numbers of fish were examined, carcass surveys were considered only a "snapshot" of the true R/C ratio for the drainage. No observations were gathered in the Black River drainage, thought to be a minor spawning tributary, and the possibility of mainstem spawning remains; however, the data available indicate reduced R/C ratios occur drainage-wide. This analysis only examined misallocation based on stock. A remaining possible hypothesis of misallocation (Table 1, hypothesis #5) based on factors other than stock (length, sex, migration path, etc.) needs to be kept separate because the analysis requires different data.

One additional hypothesis was examined using the 1997 data, that of differential mortality between marked and unmarked fish (Tables 1, 8). Repeated captures did have an effect on the probability of recovery upstream of Rampart, but did not affect the probability of recapture at Rampart where results of the recovery strata for the Darroch estimator were tallied. Thus we conclude that the mortality was delayed at least several days. We also conclude that some mortality is associated with the processing of fish. The implication of induced mortality is significant because not only does the current project handle more than 60,000 fish in some years, but several other test wheels are being used to gather management data throughout the Yukon River. Mortality caused by these studies needs to be carefully investigated and should be a high priority.

Handling-caused stress and resulting mortality in fish are well documented (Stichney 1983; Adams 1990; Wedemeyer 1990). The mortality caused by handling can be delayed (Stichney 1983) and the effects cumulative (Wedemeyer 1990) which explains the observed R/C ratios found upriver. Direct investigations into fish wheel stress and morbidity have not been well documented. Possible causes of elevated stress include physical capture by the wheels, holding time in the live box, crowded conditions within the live box, handling procedures, and tagging. Given the popularity of fish wheel CPUE as a monitoring tool, it appears prudent to investigate possible ill effects further. Investigation into each possible cause may lead to changes in procedures that would eliminate mortality (though not yet proved) or reduce it to an acceptable level.

Conclusions

Data collected in 1997 substantially advanced our knowledge about the use of the Darroch estimator to estimate the number of fall chum salmon migrating in the Yukon River above the confluence with the Tanana River. We concluded that bias based on violations of equal probability of recapture based on sex and length were negligible. Some questions remain, e.g., the phenomena of progressively lower R/C ratios in the drainage above the recovery site. Several hypotheses remain to be tested regarding this question and these should be investigated further. In addition, some question remains regarding difference between our estimate and that based on harvest and escapements. However, the preponderance of our data indicated that precise and credible estimates can be generated from varying run sizes of fall chum salmon. Furthermore, genetic analysis and radio telemetry can be added to the project with reasonable hope that the weekly estimates can be partitioned into sub-basins.

Acknowledgments

We would like to recognize the contribution of the seasonal technicians, J. Moreland, P. Anselmo, R. Morris, and J. Tilley. Numerous other individuals provided assistance in field operations including L. Devany, K. Russel, B. Spearman, S. Murley, D. Pearson, Leslie Reiz, K. Holland, and M. Gendron. We thank M. Millard, R. Simmons, and K. Kimbrel for their supervisory and administrative oversight. S. Zuray and P. Evans operated and maintained the fish wheels for us and did and excellent job. Refuge Information Specialist P. Williams of Beaver and A. Peters, resident of Fort Yukon, provided data on recapture rates from the Fort Yukon area. We thank I. Boyce from DFO Canada for providing data from Yukon Territory. For external review we thank C. Krueger, J. Eiler, J. Pella, and J. Bromaghin

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Table 1.— Hypotheses possibly explaining differences in R/C ratios (recapture/capture) found between the recovery fish wheel and the two projects in Canada. Some of the hypotheses seem unlikely for several reasons, but are included for discussion.

1. Incomplete reporting of tag returns.

2. Immigration of unmarked fish: The tails of the spawning distribution were not tagged allowing for dilution of tagged fish by fish not subjected to sampling.

3. Tags are lost from marked fish.

4. A portion of the run at the marking and recovery site was not sampled due to selective sampling: a specific stock or stocks were unavailable to the sampling gear.

5. A portion of the run at the marking and recovery site was not sampled due to selective sampling: a portion of all stocks of fish was unavailable to the sampling gear.

6. Sampling gear that reported the low R/C ratios did not sample a portion of the run. This is the same as number 4 above, but not at the marking and recovery fish wheels used for the estimate.

7. Differential harvest: tagged fish were harvested at a higher rate than untagged fish.

8. Induced mortality: tagged fish died at a higher rate than untagged fish because of handling stress or capture injury.

9. Trap shyness: tagged fish avoid sampling gear upriver.

10. Combinations of any of the above.

Table 2.— Features used by crews to determine the condition of fish caught by the fish wheels.

Category	Definition
Good	Fish appeared to have no injuries or fungal infections.
Minor Injury	Fish had an observable injury such as a cut, an abrasion, or a fungal infection that did not appear to hinder its migration.
Major Injury	Fish had a deep wound impacting muscle function, gill plate torn off, bleeding from the gills, head partially destroyed, tail missing, or extensive fungal infections that penetrated the dermal layer and exposed muscle tissue.

Table 3.— Index of color was defined as three categories, silver, light, and dark. These definitions were based on experience gained in 1996. Technicians were trained in categorizing fall chum salmon. Two people usually saw each fish and a consensus formed as to the observation recorded.

Category	Definition
Silver	Fish that showed little or no spawning coloration, with vertical barring absent or barely visible in places, and that had pale and translucent pelvic and anal fins, no kype formation, and large, silvery scales dominating the back and sides.
Light	Fish that showed definite vertical barring, with minimal tooth development (few or no large). Males had some silvery scales, but had darkened somewhat; had translucent pelvic and anal fins, in males minimal or developing dorsal humping and obvious kype formation; in females a firm belly with minimal distention.
Dark	Fish that were highly colored, with black, red and white vertical barring, pelvic and anal fins opaque black with distinct white tips, extreme tooth development apparent, in males highly developed dorsal humping and horizontal flattening and advanced kype formation, in females the belly is distended and soft.

Table 4.— Statistical week sampling dates of fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, July 21 to September 28, 1997. 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	Jul 21 through Jul 26
2	Jul 27 through Aug 2
3	Aug 3 through Aug 9
4	Aug 10 through Aug 16
5	Aug 17 through Aug 23
6	Aug 24 through Aug 30
7	Aug 31 through Sep 6
8	Sep 7 to Sep 13
9	Sep 14 to Sep 20
Recapture site	
1	Jul 22 through Jul 28
2	Jul 29 through Aug 4
3	Aug 5 through Aug 11
4	Aug 12 through Aug 18
5	Aug 19 through Aug 25
6	Aug 26 through Sep 1
7	Sep 2 through Sep 8
8	Sep 9 to Sep 15
9	Sep 16 to Sep 22

Table 5.— Estimated proportion of unmarked fish captured at the recovery site, that passed the tagging site during the mark-recapture experiment, and the observed and adjusted counts of unmarked fish captured at the recovery site during the first week of the study.

Date	Estimated proportion passing the marking wheels	Unmarked catch	Adjusted unmarked catch
Jul 21	0.00	52	0
Jul 22	0.07	210	14
Jul 23	0.57	139	79
Jul 24	0.79	153	121
Jul 25	0.91	173	157
Jul 26	0.95	279	265
Jul 27	0.98	318	313
Jul 28	0.99	384	381
Jul 29	1.00	331	331

Table 6.— Estimated proportion of marked fish passing the recapture site during the mark-recapture experiment and the observed and adjusted counts of marked fish released at the tagging site during the last week of the study.

Date	Estimated proportion passing the recapture wheels	Marked fish	Adjusted marked fish
Sep 15	1.0	297	297
Sep 16	1.0	293	293
Sep 17	0.997	360	359
Sep 18	0.97	357	347
Sep 19	0.93	285	265
Sep20	0.41	339	140
Sep21	0.00	0	0

Table 7.— Estimated migration time (days) from the marking wheels to various upriver locations. Estimated migration time was calculated using the mean migration rate (km/d) from tag returns. River mileages to each location were from Schultz et. al. (1993).

Location	Migration time (days)
Stevens Village	5
Beaver	9
Fort Yukon	12
Sheenjek River (mouth)	14
Circle	15
U.S. Can. Border (Porcupine R.)	22
U.S. Can. Border (Yukon R.)	22
Old Crow YT	24
Dawson YT	26

Table 8.— Classification of fall chum salmon marked and recaptured in marking wheels on the Yukon River, Alaska, July 21 to August 11, 1997.

	Recapture assessment (row %)		
Marking assessment	Good	Minor injury	Total
Good	665 (87)	100 (13)	765
Minor injury	63 (44)	80 (55)	143
Total	728	180	908

Table 9.— Consistency of color classification of fall chum salmon marked and recaptured in marking wheels on the Yukon River, Alaska, July 21 to August 11, 1997.

	Recapture assessment (row %)			
Marking assessment	Silver	Light	Dark	Total
Silver	3 (33)	6 (67)	0 (0)	9
Light	1 (0.1)	626 (86)	105 (14)	732
Dark	0 (0)	55 (31)	112 (67)	167
Total	4	687	217	908

Table 10.— Results of logistic regressions of capture histories on sex and length, mid-eye to fork length (cm), of fall chum salmon migrating past the marking and recapture wheels on the Yukon River, Alaska, July 21 to September 28, 1997. Comparisons are between the intercept (no characteristics included) and full (length, sex, and the interaction) models, the full and main effects (length and sex) models, and between the main effects and best single effect (length 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	676.33	665.24		11.43	6	0.08
2	1127.71	1117.77		9.94	6	0.13
3	635.39	623.05		12.46	6	0.05
4	1582.42	1573.32		9.29	6	0.16
5	1673.85	1664.74		9.30	6	0.16
6	1868.25	1860.26		8.50	6	0.20
7	1756.54	1753.23		3.25	6	0.35
8	1916.43	1904.93		11.50	6	0.01
9	1525.96	1522.48		3.48	3	0.32
	Full	**Main effects**				
3	623.05	631.27		8.22	2	.02
8	1904.93	1905.02		0.089	2	0.96
		Best single effect				
	Main effects	**Sex**	**Length**			
8	1905.02	1909.57		4.55	1	0.10
8	1905.02		1908.01	2.99	1	0.22
	Intercept	**Sex**	**Length**			
8	1916.43	1909.57		6.86	1	0.03
8	1916.43		1908.01	8.42	1	0.02

Table 11.— Parameter estimates from the logistic regression of capture histories on size, mid-eye to fork length (MEL, cm), and sex of fall chum salmon migrating past the marking and recapture wheels on the Yukon River, Alaska, July 21 to September 27, 1997. In the fitted model, when $k = 0$, Pr = probability that a marked fish was not recaptured; when $k = 1$, Pr = probability that a marked fish was recaptured during week $j = i$; and when $k = 2$, Pr = probability that a marked fish was recaptured during week $j = i + 1$. $SEX = 1$ for females and $SEX = -1$ for males. $\alpha_0 = \beta_{10} = \beta_{20} = \beta_{30} = 0$.

Marking	Parameter estimates							
week, i	α_1	α_2	β_{11}	β_{12}	β_{21}	β_{22}	β_{31}	β_{32}
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	-4.84	-10.62	0.03	0.11	-3.31	-10.18	0.05	0.17
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-
8	-1.83	-6.20	-	-	-0.13	-0.87	-	-
9	-	-	-	-	-	-	-	-

Fitted model -

$$Pr\{recapture\ history = k\} = \frac{e^{(\alpha_k + \beta_{1k}\, MEL\ +\ \beta_{2k}\, SEX\ +\ \beta_{3k}\, MEL\ SEX)}}{\sum_{h=0}^{2} e^{(\alpha_h + \beta_{1h}\, MEL\ +\ \beta_{2h}\, SEX\ +\ \beta_{3h}\, MEL\ SEX)}}$$

Table 12 .— River bank capture histories of tagged Yukon River fall chum salmon at the marking and recapture sites, July 1 to September 24, 1998.

		Recaptured fish (row %)	
Marking week	Marking bank	North bank	South bank
1	North	28 (60)	19 (40)
	South	25 (57)	19 (43)
2	North	29 (72)	11 (28)
	South	60 (65)	33 (35)
3	North	14 (88)	2 (12)
	South	34 (65)	18 (35)
4	North	65 (78)	18 (22)
	South	90 (69)	41 (31)
5	North	69 (73)	25 (27)
	South	81 (64)	45 (36)
6	North	107(84)	20 (16)
	South	123(79)	33 (21)
7	North	92 (85)	16 (15)
	South	128(83)	27 (17)
8	North	100(76)	32 (24)
	South	144 (76)	45 (24)
9	North	67 (74)	23 (26)
	South	109 (64)	61 (36)

Table 13.— Weekly capture histories of tagged fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, July 20 to September 24, 1997.

		Recapture week, j								
Marking week, i	Marked fish released, a_i	1	2	3	4	5	6	7	8	9
		Estimated number of fish recaptured the first time								
1	1095	81	8	0	0	0	2	0	0	0
2	2168	0	111	22	2	0	0	0	0	0
3	1246	0	0	50	16	5	1	0	0	0
4	2384	0	0	0	182	26	6	0	0	0
5	2455	0	0	0	0	173	46	1	0	0
6	2458	0	0	0	0	0	266	15	3	0
7	2514	0	0	0	0	0	0	253	10	1
8	2319	0	0	0	0	0	0	0	315	6
9	1701[a]	0	0	0	0	0	0	0	0	258
		Percentage of fish recaptured first time								
		92.0	96.0	94.7	95.2	96.2	96.7	96.8	94.5	93.6
		Estimated unmarked fish, b_j								
		1224[b]	1729	746	5803	4830	6211	6383	5707	2622
		Recaptured fish with unknown tag numbers								
		1	0	0	3	3	4	5	6	2

[a] Adjusted downward from actual number of marked fish that were released at the tagging site to account for marked fish that passed the recovery site after the study ended.

[b] Adjusted downward from actual number to account for unmarked fish captured more than one time and for unmarked fish that passed the marking site before the beginning of the mark-recapture experiment.

Table 14.— Weekly estimates and those by sex, sex and length, and length. Sampling weeks are listed in Table 4.

Stratification	Week *i* 1	2	3	4	5	6	7	8	9	Total
Estimate not stratified by sex or length										
Weekly estimate	17,642	33,577	11,894	76,226	58,962	47,992	62,950	42,154	18,150	369,547
Estimate stratified by sex										
Females	10,252	21,401	5,685	38,694	23,972	18,485	24,026	22,886	9,972	175,374
Males	7,473	13,467	5,761	37,630	34,934	29,533	37,974	19,184	8,581	194,536
Total	17,725	34,868	11,446	76,324	58,906	48,019	62,000	42,070	18,553	369,910
Stratified by sex and length										
Females<56 cm	1,382	2,617	3,398	6,011	3,745	2,763	9,544	10,955	5,951	46,367
>=56cm	9,260	18,753	1,552	34,098	20,308	16,643	14,654	11,689	3,993	130,950
Total Females	10,642	21,370	4,951	40,109	24,053	19,406	24,198	22,644	9,944	177,317
Males<59 cm	1,736	2,408	807	818	7,074	8,772	16,223	8,159	4,176	50,174
Males >=59 and <62 cm	2,023	3,445	1,843	12,387	8,974	10,234	9,414	7,341	2,812	58,473
Males >=62 cm	3,528	7,374	3,119	24,592	19,275	10,510	12,523	3,938	1,848	86,707
Total Males	7,286	13,226	5,770	37,797	35,323	29,516	38,160	19,438	8,836	195,354
Total	17,929	34,596	10,720	77,907	59,377	48,922	62,358	42,082	18,780	372,671
Stratified by length										
<55 cm	1,726	2,025	13,239	4,229	3,035	3,470	12,101	9,766	6,052	55,644
>=55 and <60 cm	5,710	12,628	3,349	14,318	21,467	23,289	31,309	20,265	8,620	140,953
>60 cm	9,430	18,365	5,209	59,076	33,730	21,654	19,999	11,585	3,436	182,482
Total	16,865	33,018	21,797	77,622	58,232	48,413	63,409	41,615	18,108	379,079

Table 15 .— Weekly population estimates ($\hat{N}_i$) of fall chum salmon migrating past the marking site on the Yukon River, Alaska, July 20 to Sep 28, 1997. $\bar{N}_i$ = mean of bootstrap estimates, Bias = Bias / $\bar{N}_i$, $\hat{p}_{ci}$ = estimated marking site capture probability, $\bar{p}_{ci}$ = mean marking site capture probability from bootstrap estimates, $\hat{p}_{rj}$ = estimated recapture site capture probability, $\bar{p}_{rj}$ = mean recapture site capture probability from bootstrap estimates, % Bias = (difference between mean of bootstrap estimates and estimated value)/estimated value. Bootstrap estimates based on 1000 iterations.

	Statistical week and starting date									
	1	2	3	4	5	6	7	8	9	
	Jul 21	Jul 28	Aug 4	Aug 11	Aug 18	Aug 25	Sep 1	Sep 8	Sep 15	Total
				Population estimate						
$\hat{N}_i$	17,642	33,577	11,894	76,226	58,962	47,992	62,960	42,154	18,139	369,546
$\bar{N}_i$	17,914	33,882	11,818	76,748	59,221	48,062	63,258	42,291	18,233	371,426
SE	2,011	3,234	2,652	5,647	5,037	3,378	3,884	2,388	1,086	8,693
CV	0.112	0.095	0.224	0.074	0.085	0.070	0.061	0.056	0.060	0.023
% Bias	0.02%	0.01%	-0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
				Probability of capture at marking site						
$\hat{p}_{ci}$	0.062	0.065	0.105	0.031	0.042	0.051	0.040	0.055	0.094	
$\bar{p}_{ci}$	0.062	0.065	0.112	0.031	0.042	0.051	0.040	0.055	0.103	
SD	0.007	0.006	0.031	0.002	0.004	0.004	0.003	0.003	0.007	
CV	0.114	0.095	0.273	0.077	0.084	0.073	0.064	0.059	0.069	
% Bias	0.00%	0.00%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	
				Probability of capture at recapture site						
$\hat{p}_{rj}$	0.085	0.065	0.050	0.090	0.084	0.116	0.104	0.138	0.152	
$\bar{p}_{rj}$	0.085	0.066	0.050	0.090	0.084	0.116	0.104	0.138	0.151	
SD	0.010	0.008	0.007	0.007	0.006	0.007	0.006	0.007	0.009	
CV	0.120	0.117	0.147	0.080	0.077	0.060	0.060	0.054	0.057	
% Bias	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Table 16.— Population estimate ($\hat{N}$) of fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, July 21 to Sept 24, 1998. The mean estimate ($\bar{N}$) was the result of 1,000 bootstrap estimates. The difference between ($\hat{N}$) and ($\bar{N}$) or for statistical week 8 stratified by sex % bias is the percent difference between the stratified and unstratified estimate.

Strata	($\hat{N}$)	($\bar{N}$)	SE	CV	% Difference[a]
Bootstrap		371,426	8,693	0.023	0
Seven-day	369,546		8,682	0.023	-0.5%
Four-day	364,993		8,861	0.024	-1.7%
Three-day	374,702		9,134	0.024	0.9%
Two-day	371,605		9,494	0.025	0.05%

[a] Compared to the bootstrap estimate.

Table 17.— Summary of marked to unmarked (percent) at 13 sites distributed throughout the Yukon River drainage upriver from the Rampart Rapids tagging location. The sources of the data include both trained and untrained people. Fishers who were not trained were contacted by telephone.

Location	River km from tagging	Source	Number of fish examined	Number of fish with marks	Percent with marks
		Yukon River			
Rampart	52	Paul Evans (wheel)	39,685	1,984	5.0 %
Stevens Village	187	USFWS (drying racks)	131	10	7.5%
Chandalar River	474	USFWS (carcass)	1,414	43	3.0 %
Fort Yukon	437	USFWS (Williams)	1,240	36	2.9 %
Circle City	532	Brian Aspline	~5,000	86	~1.7%
Nation River	702	Tim Henry (net)	983	11	1.1 %
Eagle City	777	Mike Sager	2,500	32	1.3 %
Eagle City	777	Andy Bassich	2,700	32	1.2 %
Border wheel	795	DFO (wheel)	3,522	36	1.0%
Dawson	948	R&E Project (wheels)	6,651	34	0.5 %
		Porcupine River			
Sheenjek River	521	USFWS (carcass)	1,051	12	1.1 %
Old Crow	852	W. Josie (net)	700	19	2.7%
Fishing Branch	1402	DFO (weir)	26,620	168	0.6 %

Table 18.— Summary of fish examined for tag loss recorded in 1997 at eight sites in the Yukon River drainage above the Rampart Rapid tagging site from various locations of the upper Yukon River. The sources listed were selected and trained to look specifically for the loss of the primary mark (a spaghetti tag) and the presence of the secondary mark (a ventral fin clip).

Location	Source	Total fish examined	Marked fish	Reported Tag loss
Rampart	Paul Evans (wheel)	39,685	1,984	0
Fort Yukon	USFWS (Williams)	1,240	36	0
Nation River	Tim Henry	983	11	0
Eagle City	Mike Sager	2,500	32	0
Eagle City	Andy Bassich	2,700	32	0
Fishing Branch	DFO (weir)	5,837	--	1[a]
Border wheel	DFO (wheel)	3,522	36	0
Dawson	R&E Project (wheel)	6,651	34	0

[a] The supervisor reported this was most likely a clerical error not an actual lost tag.

Table 19 .— Chi-square analysis determined that capture history did not affect (P = 0.07) the probability of capture at Rampart, Alaska. Fish tagged and subsequently recaptured from the recovery fish wheels at Rampart, Alaska, or not recaptured, were tallied in groups of one, two, three, or four or more captures in the tagging fish wheels.

	Capture histories				Row totals (percent)
Value name	1	2	3	4	
		Recaptured			
Frequency	1,793	155	12	3	1,963 (10.5)
Expected value	1,775	171	16	1	
Cell chi-square	0.18	1.55	0.87	3.60	
		Not recaptured			
Frequency	15,054	1,471	137	7	16,669 (89.5)
Expected value	15,072	1,454	133	9	
Cell chi-square	0.02	0.18	0.10	0.42	
Column totals (percent)	16,847 (90.4)	1,626 (8.7)	149 (0.8)	10 (0.1)	18,632

Table 20 .— Chi-square analysis determined that capture history affected (P= 0.001) the probability of capture upstream of Rampart, Alaska. Capture histories of fish tagged and subsequently recaptured upstream of Rampart or not recaptured were tallied in groups of one, two, three, or four or more captures in the tagging fish wheels. Between the tagging site and recovery upstream of Rampart, no evidence of an effect from capture history was detected.

	Capture histories				Row totals (percent)
Value name	1	2	3	4	
		Recaptured			
Frequency	653	67	7	1	728 (3.9)
Expected value	591	121	14	1	
Cell chi-square	6.41	24.5	3.29	0.08	
		Not recaptured			
Frequency	14,483	3,044	344	33	17,904 (96.1)
Expected value	14,545	2,989	337	33	
Cell chi-square	0.26	1.0	0.13	0.00	
Column totals (percent)	15,136 (81.2)	3,111 (16.7)	351 (1.9)	34 (0.2)	18,632

Table 21.— Escapement estimates from four projects located upstream from the marking site and total harvest. The total point estimate from these four projects plus harvest is 15% higher than the estimate made by the Darroch method at the Rapids study site.

Location	Type	Estimate	95 % C.I. low	95 % C.I. high
Chandalar R.	Sonar	200,173	194,627	205,719
Sheenjek R.	Sonar	80,000		
Harvest upstream of Tanana in Alaska	Harvest survey	28,636		
Mainstem Yukon Canada	Mark-recapture	94,725	86,342	103,920
Fishing Branch	Weir	26,959		
Total escapement above tagging project.		430,493		

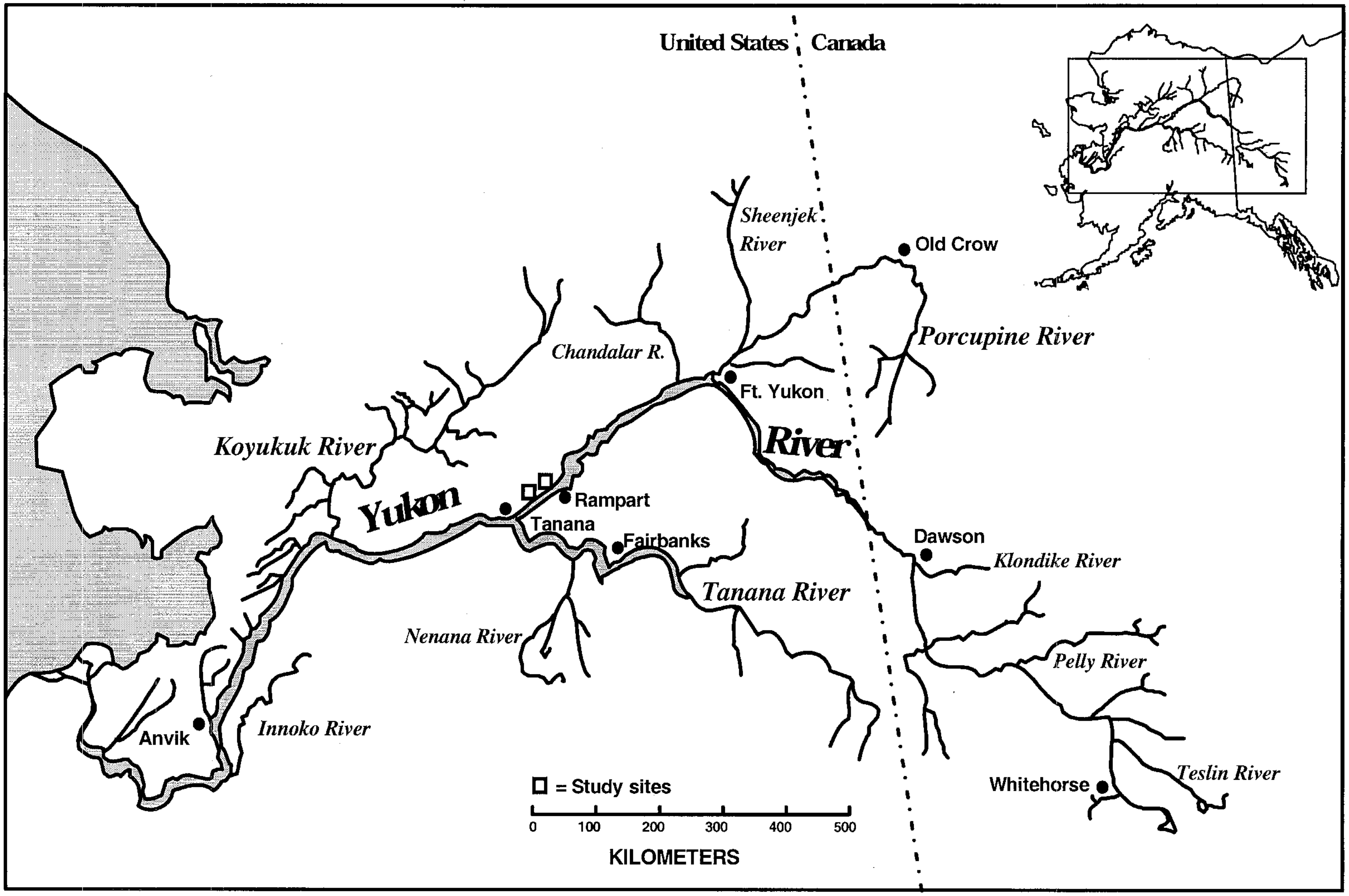
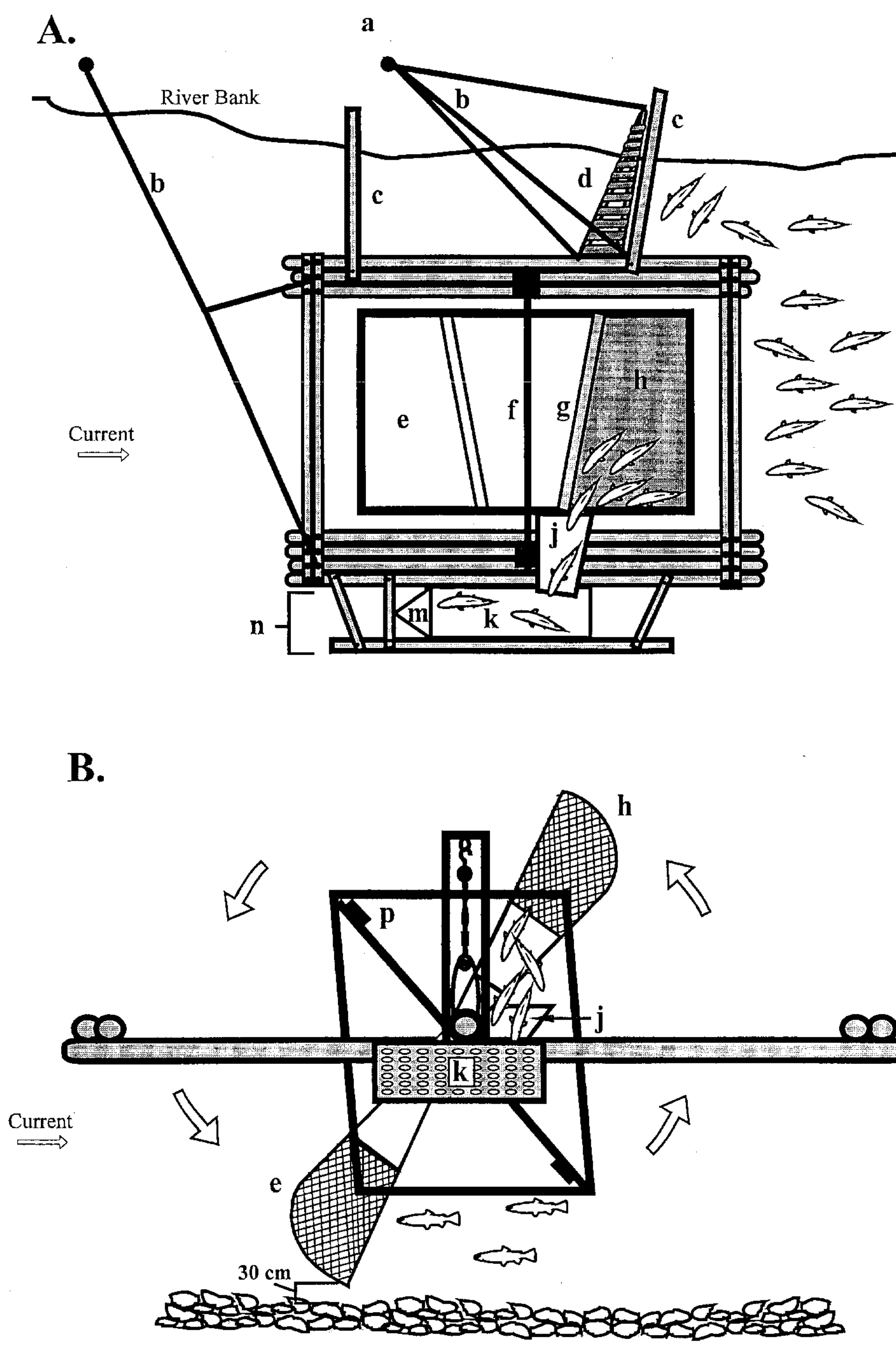


Figure 1.— Yukon River drainage showing project study sites. Open squares indicate study site locations.



a. deadman
b. cable
c. spar
d. lead
e. down basket
f. axle
g. ramp to chute
h. up basket
j. chute
k. live box
m. break water
n. boat mooring
p. paddle

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.

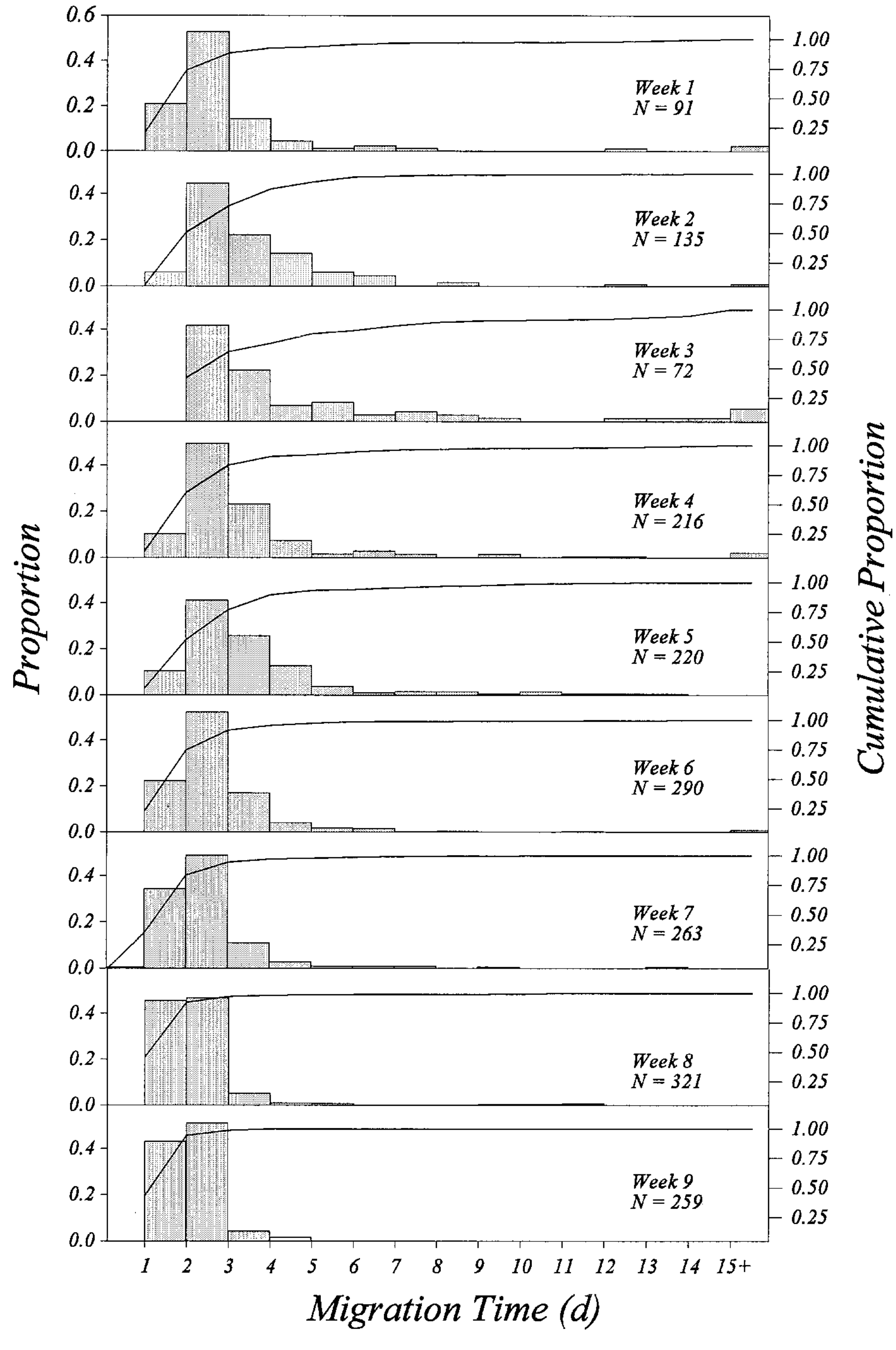


Figure 3.— Estimated migration time (d) for tagged fall chum salmon between the marking and recapture sites, by statistical week, on the Yukon River, Alaska, July 21 to September 27, 1997. Histograms represent proportion of recaptured fish. Solid lines represent cumulative proportion of recaptured fish. Estimated migration times greater than or equal to 15 d were combined in the 15+ d category.

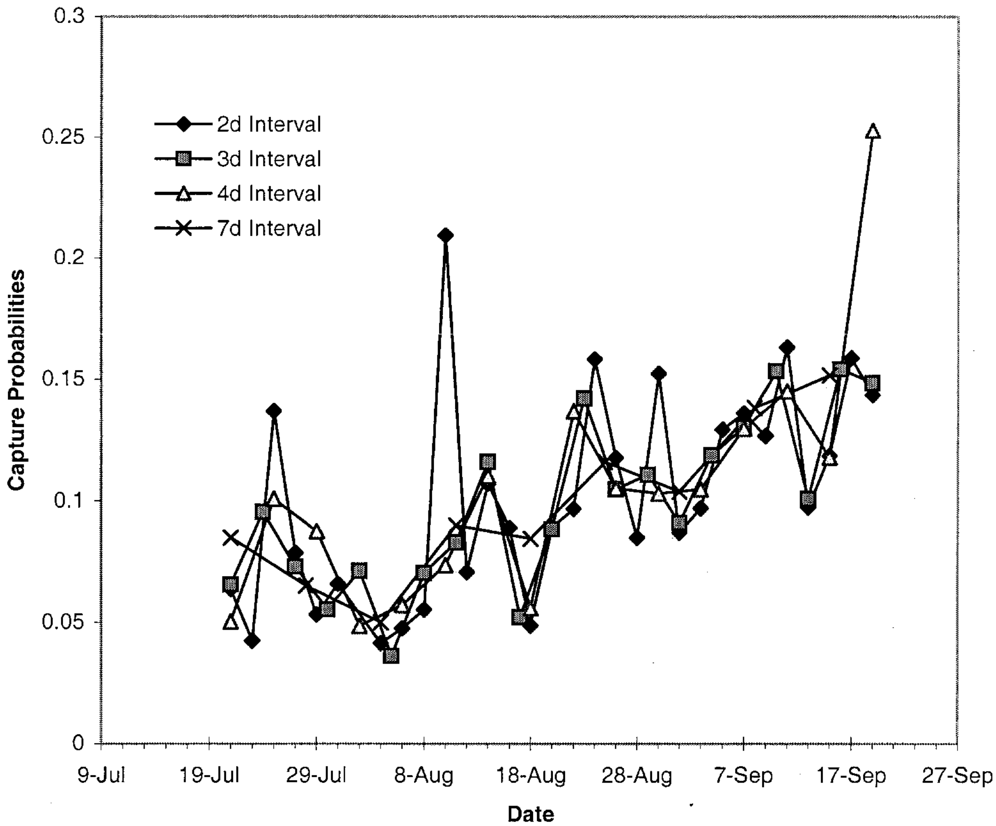
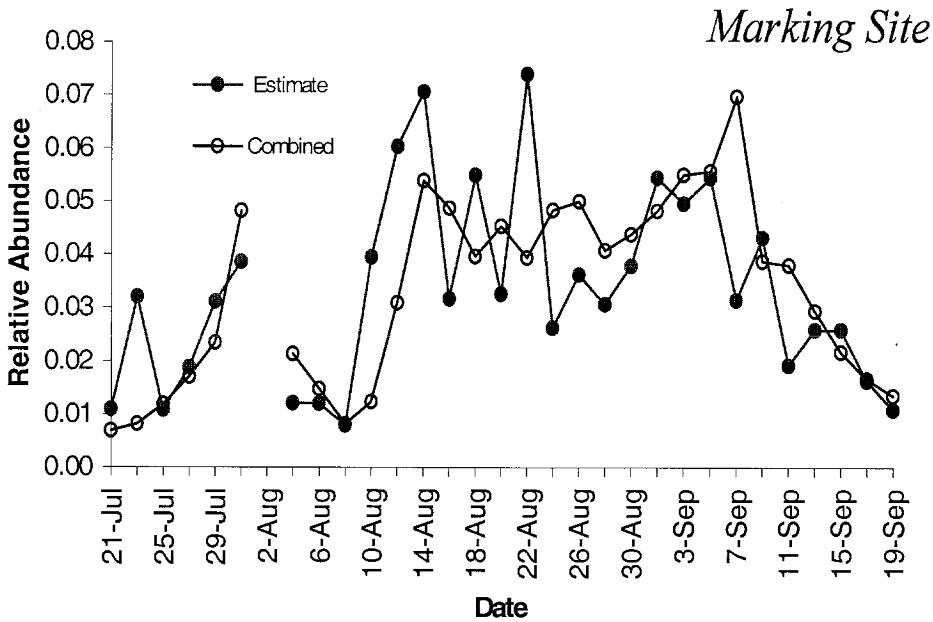


Figure 4.— Capture probability of two-, three-, four-, and seven-day strata plotted by date. The value for each stratum is plotted on the first day of the strata.



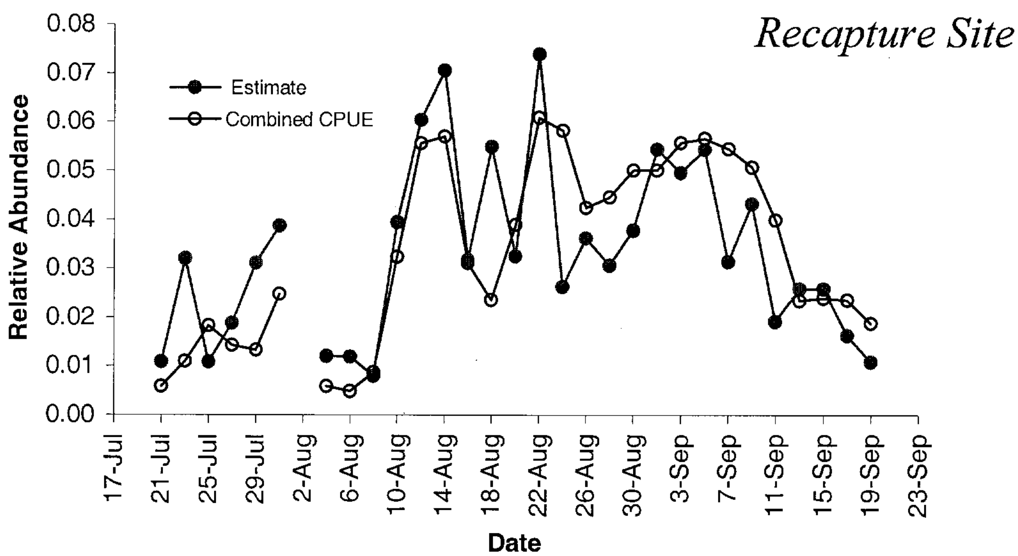


Figure 5.— Relative abundance CPUE of combined wheel catches versus estimates from 2 d strata Darroch model. Relative abundance is plotted by date at the marking site (top) and recapture site (bottom). Relative abundance was calculated as a proportion of the cumulative total as appropriate for the season.

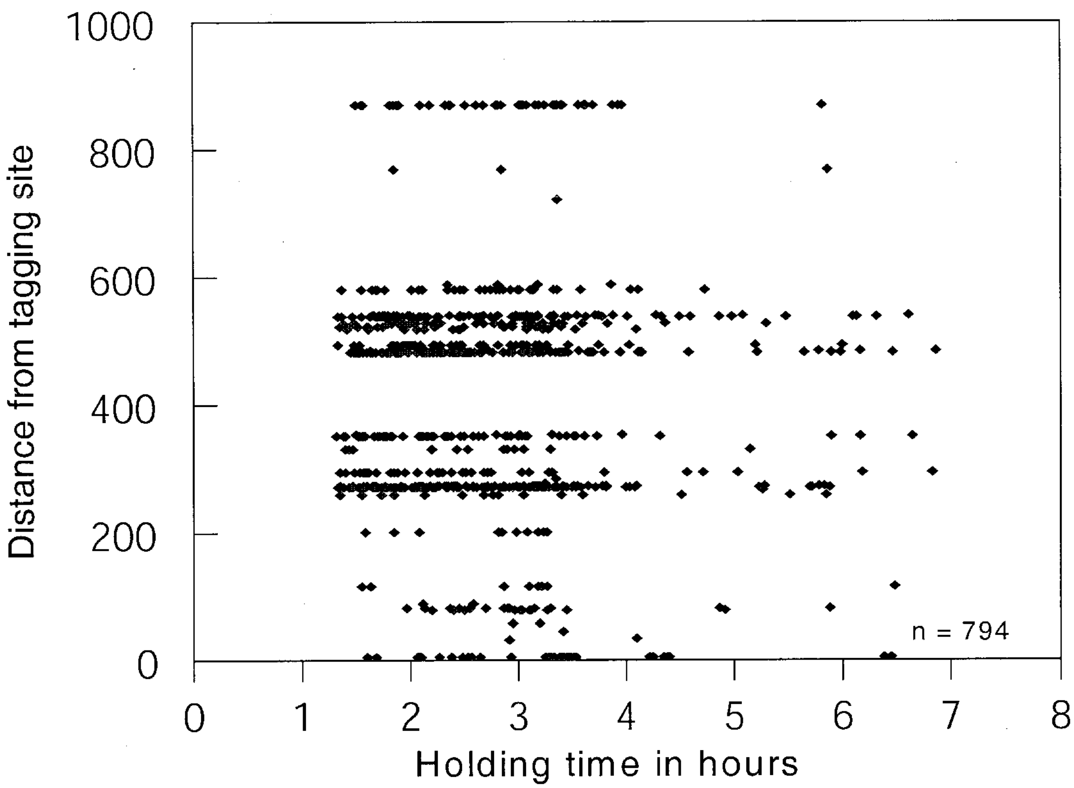


Figure 6.— Holding time versus distance (km) to capture of fish harvested in the Yukon River above Rampart, Alaska. A total of 794 fish could be assigned location from the tagging site from the information received from tag returns.