Estimated Abundance of Adult Fall Chum Salmon in the Middle Yukon River, Alaska, 2000-2001

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by

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Abstract

Mark and recapture data were collected to estimate the abundance of fall chum salmon *Oncorhynchus keta* during 2000 and 2001 in the middle Yukon River. In 2000, weekly and seasonal estimates were generated only in the first quarter of the run based on historic run timing, July 31 to August 19. In 2001, weekly and seasonal estimates were generated for eight weeks at the marking site, July 30 to September 15. Fish were captured using two fish wheels for marking and one fish wheel for recovery. Marking and recovery sites were separated by a distance of 52 km. Spaghetti tags were applied at the marking sites to 4,222 fish in 2000 and 8,490 fish in 2001. Concurrent to marking, 4,492 and 12,182 fish, respectively, were examined for marks at the recovery site. Excluding multiple recaptures, 304 and 501 fish, respectively, were recaptured with unique tag numbers. Because we only used one recovery wheel, analyses regarding selective sampling and potential bias changed from past years when two recovery fish wheels were used. Likelihood ratio tests of the equality of probability of recapture based on the bank of release indicated that no differences existed in either year. Logistic modeling of the probability of recapture showed no differences based on sex, length, or the interaction term for either year. We concluded that no further stratification, beyond temporal weekly stratification, was required. Using a Darroch estimator, the estimated abundance was 38,979 (SE 2,080) for the partial season in 2000 and 201,766 (SE 9,578) for 2001. The total population migrating past the study site declined between 1996 and 1998 but appears to have stabilized at a low level. Weekly estimates of abundance generated in 2000 and 2001 were similar to estimates obtained in 1998 and 1999 for similar operational weeks.

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Introduction

In 1996, the U.S. Fish and Wildlife Service began an effort to estimate the size of 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 Darroch (1961) estimator could be applied successfully to the conditions found on the Yukon River (Gordon et al. 1998; Underwood et al. 2000a). The project has operated annually since 1996, and abundance estimates provided by the Rampart Rapids project have become an important component of the annual run monitoring program for fall chum salmon (Underwood et al. 2000b; JTC 2001). The study site has also provided a platform for additional research of fish that use the Yukon River as a migration corridor, as suggested by Link and English (1999). In this report we document the population estimates generated by the mark and recapture study during the years 2000 and 2001 and the associated statistical analyses used to test some of the assumptions of the estimator.

Study Area

The Yukon River is the fifth largest drainage in North America with 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; the Koyukuk, Tanana, and Porcupine rivers 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 the winter. The region experiences a continental climate with long, cold winters and brief, warm summers. Air temperatures below freezing are common from September through April. The river generally freezes by late October or November, and the ice remains until May of the following year.

The study site was located on the mainstem Yukon River upstream from the Tanana River confluence (Figure 1). The site was selected to minimize capture of fall chum salmon returning to the Tanana River drainage, which constitutes the only known 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 52 km upstream from the marking site near the village of Rampart, Alaska.

Methods

Assumptions of the Estimator

The study was designed as a two-event, temporally stratified mark-recapture experiment. We used the estimator of Darroch (1961) to generate weekly and total estimates of fall chum salmon abundance in the middle Yukon River. Assumptions of the Darroch estimator are discussed by Darroch (1961) and Seber (1982). Past application of the Darroch model in this study and approaches to testing model assumptions are discussed by Gordon et al. (1998) and Underwood et al. (2000a, 2000b). Some statistical procedures previously used to test model assumptions were modified in 2000 to increase consistency across temporal strata, to reduce the chances of obtaining spurious test results, and to accommodate the reduction of recovery wheels from two to one.

Marking Procedures

General procedures common to both years are described below and are followed by a description of changes made in 2001. Protocol changes were made to minimize handling and to accommodate a new study on delayed handling mortality initiated that year. Fish wheels used for capturing fish were placed across from each other on the north and south banks of the river (Figure 2). Fish 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. Fish 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. Fish were captured and marked from Monday through Saturday each week. Tagging was conducted from July 31 to August 19 in 2000 and from July 30 to September 15 in 2001. The experiment in 2000 was shortened because of uncertainty about delayed mortality coupled with the projected weakness of the run in that year (Underwood et al. 2000a, 2002).

Operation of the fish wheel and tagging balanced the conflicting needs, to tag approximately 300 fish per day, to spread the release of tagged fish throughout the day, and to minimize holding time. Unlike previous years, fish wheels were not operated overnight to bolster the catch during times of low abundance at the start and the tail of the migration. Generally, crews tagged fish starting at four different sessions during a day (usually at 0800, 1200, 1600, and 1900 hours ADT) and attempted to mark about 75 fish each session with a individually numbered spaghetti tag. Tagging effort was distributed approximately evenly between the two marking fish wheels. Upon capture, fish were netted from the live box using a dip net, handled for data collection, marked, and released. Fish length, mid-eye to fork of tail, was measured. Data were recorded via a hand-held electronic data logger. Descriptions of recorded data including a header line common to multiple fish and data rows for individual fish can be found in Appendix A. The tags were applied using hollow applicator needles. Recaptured tagged fish were handled the same as unmarked fish except lengths were not recorded and no new tag was applied. Care was taken to minimize handling time and trauma.

When catch appeared to substantially exceed the goal of 75 fish per work session, a systematic sample of the catch was tagged. For example, upon arriving at the fish wheel the crew might estimate that 150 fish were present in the live box and so every second fish would be tagged. Sub-sampling ended when the live box was emptied even if the goal of 75 fish per work session was exceeded. Sub-sampling became a rare event compared to the years 1997 to 1999 because we were able to start and stop the fish wheel operations when the crew arrived or departed, respectively. Fish with major injuries, defined as injuries thought to impede migration, were released without processing.

In 2001, changes in the fish processing and data recording were necessary because a study of capture and handling mortality was initiated. Important to the study was the need to have a range of holding times and an accurate measure of holding times. At the start of the season, a more accurate holding time was recorded by including additional wheel start and stop times (data header lines) during each tagging session. In previous years when a crew arrived at an operating fish wheel, they would enter the wheel start time and proceed to process fish until the quota was met. This meant that only an average holding time could be generated for each fish. The new protocol required an additional header line be entered after the fish box was first emptied if the wheel ran prior to the crew's arrival and a new header line was entered on the hour. In addition, several new definitions were added to the categorical variable, "Capture status", to distinguish among groups of fish, Appendix B. Subsequently, many fish were captured with zero or minimal time in the live box and the data reflected that fact. Finally, a left pelvic fin clip, a secondary mark used in some previous years, was again applied to all tagged fish in 2001.

An in-season review of the processing protocol on August 23, 2001, generated concerns regarding the companion study of handling effects. Holding times had been reduced via incremental changes in operations since 1996, but a wide range of holding times was judged necessary for the study of handling effects. In addition, the distinction between fish that had or had not been held was blurred by the practice of capturing a fish from the chute and holding it within the dip net in the live box while waiting for another fish to be processed.

Project operations were modified starting August 24 to alleviate those concerns. Fish that could not be immediately processed were allowed to slide down the chute into the live box. To accommodate the need for a wider range of holding times, two tagging protocols were implemented on an alternating schedule. During a work session, the crew would man one wheel and only tag fish captured from the chute, prior to the fish entering the live box. Fish were tagged and then placed into the live box for holding. When approximately half the desired number of fish were tagged, the crew would stop the wheel and proceed to the second wheel leaving fish in the live box to extend the holding time. At the second fish wheel the usual tagging protocol was followed. When the target number of fish had been tagged, the crew would revisit the first fish wheel and release the tagged fish being held in the live box. The group release time from the first wheel was entered in the data header line. Group release was carried out by dipping fish from the live box. Later in the season a live box door was added and group release was accomplished by opening the door in the live box so fish could swim out. The crew alternated the first wheel visited among sessions within a day and among days to avoid potential differences between banks or wheels.

Recapture Site Sampling Procedures

The river at the recapture site was wider and shallower than at the marking site, so the fish wheels were sized accordingly. Baskets on the recapture fish wheel were approximately 2.5 m wide and dipped to a depth of 3.0 m below the water's surface and within 30 cm of the bottom. Changes in operations from previous years included a reduction in the number of recapture fish wheels from two to one starting in the year 2000 and in 2001, the addition of a field crew at Rampart to reduced holding times. Recapture procedures carried out by a contractor in 2000 or crew in 2001 and discussed in detail below include: 1) tallying marked and unmarked fish; 2) recording the serially numbered tag; 3) sub-sampling for sex and length data designed to allow stratification of the estimate; and 4) sampling designed to estimate tag loss.

In 2000, recovery site sampling commenced at the fish wheels on July 31 and ceased on August 26. Recapture wheels were operated 24 hours a day, seven days a week. At the recapture site, sampling strata started on Tuesday and concluded on Monday to allow for migration time between the marking and recovery sites. The recovery sampling was accomplished working from a boat moored next to the live box. The frequency of emptying fish from the box depended on the catch rates encountered. The holding box was emptied at least two times per day on most days, and the contractor was instructed to make every effort to maintain the live box so that the number of fish stored did not exceed 200. Fish were netted from the live box and every fish was examined for the primary mark. All fish with a primary mark were considered recaptures. Data collected at the recovery site were similar to that of the marking site (Appendix A). Tag numbers were recorded as five-digit integers. "Capture status" during 2000 was recorded as unmarked or recaptured fish. Length and sex data were collected from a sub-sample of all fish captured.

The sub-sample consisted of approximately 150 fish per week. The fish were measured and the length and sex recorded. The fish were collected through the week on at least three days (preferably Monday, Wednesday, and Friday or Saturday, approximately 50 fish from each day). When a day was selected for sampling, a uniform sample was taken from the live box, until the box was empty. For example, data were collected from every eleventh fish. The integer used for sample selection was based on the previous days catch divided by 50 and then rounded down. If the target number was reached prior to emptying the live box, the sub-sampling was not stopped until the live box was emptied.

During 2000, data recording at the site was accomplished using pencils and data sheets. Once per week a biologist would travel to the study site and examine the data sheets, after which the data would be entered into electronic format via a hand-held data logger. For verification, the data would then be printed, proofed, corrected, and the process repeated two more times.

During 2001, changes in protocols stemmed from the placement of a crew of technicians who collected data, rather than a contractor, and the initiation of a handling effects study. Sampling commenced at the fish wheels on July 30 and ceased on September 18. Similar to the contractor in past years, technicians worked from a boat that was moored to the fish wheel. However, instead of two to four sampling periods per day, technicians would tend the fish wheel from 0500 to 2300 hours each day, with the exception of one-hour breaks at approximately 0900, 1300, and 1800 hours. Two crews were used each day, a morning and an evening shift.

Procedures at the recovery wheel were as follows: Upon arriving at the fish wheel, a data header line was started in the electronic data logger for fish sharing common wheel start and wheel stop times (Appendix A). The crew would empty the live box by dipping fish out with a net, checking for primary and secondary marks, and tallying unmarked, marked, and tag loss fish. The tag numbers would be determined and recorded for each tagged fish and entered into the data logger. The capture status definitions for 2001 (Appendix B) were used as discussed above. A separate written record of hourly start and stop times with tallies of marked and unmarked fish, fish missing primary marks, and tag numbers were kept in a water resistant notebook to verify data entered into the data logger.

The data stored on the hand-held data logger were downloaded daily to a laptop computer for processing and storage. Daily summaries of the number of hours fished, the number of marked and unmarked fish captured, and the occurrence of tag loss were prepared. The summaries were then compared to the written notebook to look for discrepancies.

Analysis of Tagging and Recovery Wheel Data

Travel time.— We calculated travel times for all fish released at the marking wheels and subsequently caught 52 km upstream in the recapture wheel. For those fish caught more than once at either location, the time of release from the last capture in the marking fish wheels and the time of first capture at the recapture fish wheel were used when calculating travel time. If the exact time that fish were caught in the recapture wheel was unknown, the midpoint between the earliest possible capture time and the time of release was used as an approximation. Travel time was calculated as:

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

where

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

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

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

Sex- and length-based probability of recapture.— The need to stratify abundance estimation by either sex or length was assessed by modeling a response variable, constructed as a composite of the time between the marking and recapture events and an indicator of whether or not a fish was recaptured, as a function of sex and length. The response variable was defined to be 0 for those marked fish that were not recaptured. For those fish that were recaptured, the response variable was defined as the sum of 1 and the difference between the stratum number of recapture and the stratum number of release. For example, the response variable for a fish marked in stratum 2 and recaptured in stratum 4 would have the value 3. This multinomial response variable contains more information than a binomial indicator of recapture and protects against the potential for differences in travel time between the sites that could be masked by compensating changes in capture probabilities. Such an event would indicate a need for stratification but would not be detected using a binomial indicator response variable.

A generalized linear model (McCulloch and Searle 2001) of the response variable was constructed with the stratum of release, sex, length, and a sex*length interaction as explanatory variables. The distribution of the response variable was assumed to be multinomial, and a cumulative logit link function (Agresti 1990) was used. While the validity of the logit link can not be directly verified, it is an extremely flexible model. The stratum of marking was included as a categorical variable, essentially acting as a nuisance parameter to absorb potential temporal changes in the overall efficiency of the recapture wheel. Likelihood ratio tests (Stuart et al. 1999) were used to develop the most parsimonious model of the data using a significance level of " = 0.01. A final model containing only the stratum of marking as an explanatory variable was suggestive that stratification by either sex or length was not necessary.

This approach to assessing the need to stratify by sex or length was somewhat different than that taken in past years. Prior to 2000, models similar to that just described were fit separately to the data from each marking stratum. One disadvantage to that approach was that very different, or even contradictory, models can result. If the response variable changes as a function of either sex or length, one would expect to observe such changes in all strata. The modeling approach used in 2000 and 2001 allowed for temporal changes in the underlying recapture rate, but it required deviations due to sex or length to operate consistently across strata. The expected consequence of this change in modeling approaches was to maintain the ability to detect any underlying relationships that existed, while minimizing the potential for obtaining significant test results that may be caused by small sample sizes or otherwise might be judged as spurious.

Recapture probability by bank of release, mixing.— Prior to 2000, the assumption of mixing between banks was tested using a Cochran-Mantel-Haenszel test (Agresti 1990) of the bank of marking versus the bank of recapture, with the stratum of marking as a stratification variable. Use of a single recapture wheel precluded use of that same test in 2000 and 2001. A likelihood ratio test (Stuart et al. 1999) was used to test the hypothesis that the probability of recapture did not depend on the bank of marking. The reference, or full, model was a generalized linear model (McCulloch and Searle 2001) with the interaction of marking stratum and recapture status as the explanatory variable. The reduced model contained the stratum of marking as the only explanatory variable. In both cases, recapture status was modeled as a binomial indicator variable, and an identity link was used. Inclusion of the bank of marking in both models allowed the overall capture rate to vary temporally due to factors other than the bank of marking. A non-significant test suggested that the two marking wheels could be considered as a single marking site for purposes of abundance estimation.

Abundance estimate.— Following Darroch (1961), we estimated abundance by stratum and total abundance for all the strata sampled at the marking site with some differences to previous years (Gordon et al. 1998; Underwood et al. 2000a; Underwood et al. 2000b). A substantially shortened sampling schedule during 2000 made it impossible to produce a total abundance estimate comparable to work in previous years. In 2001, the marking was shortened slightly because the whole effort has become an in-season management study with management decisions made by September 15. Thus, additional sampling would hold little value.

As in prior years, a small number of marked fish can be expected to escape before their tag numbers can be read, and their stratum of marking is, therefore, unknown. Such fish are apportioned to marking strata based upon the distribution of marking strata among those marked fish whose tags are read during the same recapture stratum. Consequently, the number of fish tagged in marking stratum *i* and recaptured in recovery stratum *j* was estimated as:

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

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.

An unknown number of the untagged fish captured in recovery wheels at the beginning and end of the study may have passed the tagging site before or after the start of the experiment, depending on the distribution of travel time and dates of wheel operations at the two sites. This violates the assumption of closure which, if true and left uncorrected, would bias abundance estimates upward. Thus, as in past years, we used the methods of Cappiello and Bruden (1997) and migration rate data from the first two strata and the two strata immediately preceding the last stratum to reduce the number of untagged fish at the recapture site early and late in the season. Similarly, the number of fish marked and released during the last stratum was reduced to alleviate positive bias caused by tagged fish that likely passed the recovery site after the study was completed. The assumption implicit in this method was that marked and unmarked fish travel between marking and recapture sites at the same rate.

Results

Summary of Tagging and Recovery Fish Wheel Data

Sampling 2000.— During 2000, marking began on July 31 but was halted August 19 at what would be considered the quarter point of the run based on average run timing (Table 1). The project was halted because of a perceived low run and uncertainty regarding handling mortality due to live box conditions at the marking and recovery fish wheels. In the three weeks of marking, 4,222 fall chum salmon were tagged and released (Table 2). Of the fish tagged, 458 were captured twice, 42 were captured three times, and 4 were captured four times at the tagging site. Forty-eight percent of the marked fish were males. Fish lengths ranged from 49 to 72 cm. Holding times at the marking site ranged from 1 min to 4 h 56 min, with mean and median holding times of 1.18 h and 1.10 h, respectively. It should be noted that fish could often be processed faster than 1 per minute, but limitations of the data loggers prevented more precise recording.

The fish wheel at the recovery site sampled 24 h per day from August 1 to August 26 (Table 1) except during brief periods for maintenance or when drift caused damage. Chum salmon examined for marks numbered 4,492, and of those, 304 were first-time recaptured fish with unique tag numbers (Table 2). Eight fish escaped before their tag number could be read.

Sex and length data were collected from 372 fish (Table 2). Males made up 49% of catch. Length measurements ranged from 49 to 70 cm. At the recovery site, informative holding times could not be generated for comparison to the marking site because of differences in operations at the two sites; however, the holding times were substantially longer at the recovery site. The percentage of tagged fish in the catch, as adjusted for travel time and multiple recoveries, over the three weeks sampled was 10%, excluding multiple recaptures. Within the three weekly strata, the percentage of marked fish ranged from 8.5% to 16%. Of the recaptured fish at the recovery site, 256 were caught once, 47 were caught twice, and 1 fish was caught three times. None of the fish were found to have lost their primary mark.

Sampling 2001.— During 2001, marking began on July 30 and continued through September 15 (Table 3). In the seven weeks of tagging, 8,490 chum salmon were captured and released with uniquely numbered spaghetti tags (Table 4). Of the fish tagged, 488 were caught twice, 27 were caught three times, and 1 fish was caught four times. Male fish made up 45% of the overall catch, but the percentage of males varied by weekly stratum ranging from 37% to 48%. Lengths ranged from 47 to 72 cm. Holding time was recorded differently in 2001 because fish caught off the chute, immediately tagged, and released were considered to have zero holding time where in previous years the minimum holding time would have been one minute. Thus, holding times for the year 2001 ranged from 0 to 5 h 46 min, with a mean of 43 min and a median of 24 minutes. Fish held in the live box versus those released immediately totaled 6,008 and 2,479, respectively.

At the recovery site, the fish wheel ran 24 hours per day from July 31 to September 18 with exceptions similar to the previous year for maintenance and damage repair. Chum salmon captured at the recovery site totaled 12,182 fish and included 504 recaptured fish with unique tag numbers (Table 4). Fish recaptured once totaled 490 and 11 were recaptured twice. Three fish escaped before their tags could be read. Sex and length data were collected from a sub-sample for 1,679 fish (Table 4). Males made up 51% of the total catch, but the male contribution ranged from 43% to 58% among the strata. Length measurements ranged from 46 to 70 cm. The percentage of tagged fish in the catch, as adjusted for travel time and multiple recoveries, over all strata was 4.1% but ranged from 3.5% to 5.5% within individual stratum. No fish were found to have lost their primary mark.

Analysis of Mark and Recapture Data

Travel times.— During 2000, the mode travel time for a tagged fish to swim the 52 km between the marking and recovery sites was two days. The minimum and maximum travel times were 20.4 h and 14 d, 6 h. Travel times were heavily skewed to the right (Figure 3) with a median time of 2 d. Of the tagged fish recaptured, 90% took less than 5 d to travel between the two sites.

During 2001, the mode travel time for tagged fish traveling between the marking and recovery site was two days. The fastest travel time recorded was 21 h and the maximum was 18 d 3 h. Travel times were again heavily skewed to the right (Figure 4). The range in travel times appeared to shrink as the season progressed, although sample size also may have had an effect. Of the tagged fish, 89% took 4 d or less to travel between the two sites.

Sex- and length-based probability of recapture.— During 2000, capture data from 4,221 tagged fish were used to model the recapture probability response variable, controlling for release strata, as a function of fish sex, length, and an interaction term. All three terms were ultimately excluded from the model. The interaction term, sex*length, was dropped first ($P = 0.12$), then length ($P = 0.23$), and finally sex ($P = 0.17$). Thus, we concluded that no difference in the probability of recapture based on fish sex or length was present, and no further stratification based on sex or length was required to obtain an unbiased estimate.

In 2001, the same analysis used capture data from 8,484 fish. The interaction term was dropped ($P = 0.19$) first, then sex ($P = 0.83$), and finally, length ($P = 0.73$). Again, we concluded that no difference in the probability of recapture based on fish sex or length was present, and no stratification based on those factors was necessary.

Recapture probability by bank of release, mixing.— During 2000, crews released 1,802 tagged chum salmon from the north bank fish wheel (43%), and 2,420 were released from the south bank fish wheel (57%). At the recovery site, 304 fish with known tag numbers were recaptured, 134 (44%) from the north tagging fish wheel and 170 (56%) from the south. Results of a likelihood ratio test indicated that no difference in probability of capture existed between the two marking fish wheels ($O^2 = 1.79$, df= 3, $P = 0.62$). From these results, we concluded that no stratification based on the bank of release was necessary.

During 2001, 4,084 (48%) fish were from the north bank fish wheel and 4,406 (52%) were from the south bank. At the recovery site, 235 (47%) and 266 (53%) tagged fish were recovered from the north and south bank tagging sites, respectively. The log likelihood comparison of full and reduced models indicated no difference in the probability of capture based on the fish wheel of release ($O^2 = 6.82$, df= 7, $P = 0.45$). From these results, we concluded that no stratification based on the bank of release was required.

Abundance estimates.— The data set for abundance estimation in 2000 (Table 5) adjusted for migration rates included 4,222 fish tagged at the marking fish wheel and 2,950 fish examined for marks at the recovery fish wheel that included 304 tagged chum salmon (no multiple recaptures) and eight fish with unknown tags numbers were assigned to a stratum based on the proportion of tags from each release week in the catch. Days were pooled into three strata mainly to collapse the extended recovery site sampling to more closely approximate the marking wheel operation. These fish were assigned to strata as discussed above. The calculated estimate of 38,979 (SE 2,080) fish was generated for the three weeks sampled. Weekly estimates were quite variable ranging from 8,123 to 21,583 fish (Table 6). Under average run timing the three weeks sampled would represent the first quarter of the run; however, the variability of run timing can be quite large, precluding an estimate for the entire season. The project was halted soon after the first major pulse of fall chum salmon arrived at the study site.

The 2001 mark and recapture data (Table 7) with all adjustments included 8,482 chum salmon tagged at the marking fish wheel and 11,816 fish examined for marks at the recovery fish wheel including 504 tagged fish. An estimate of 201,766 fish (SE 9,578) was calculated for the seven strata between July 30 and September 15, 2001. Estimates from individual strata ranged from 13,480 to 46,780 salmon (Table 8).

Discussion

The precipitous decline in fall chum salmon abundance documented in the first three years of the study, 1996 to 1998, appears to have halted, and the population migrating past the tagging site has remained at a relatively low but stable level since 1998 (Figure 5). This only provides a partial picture of total population levels and productivity. Fishery managers have been very active and have taken significant actions during those years to reduce harvest downstream of the study site including the cessation of commercial harvest of fall chum salmon and significant reductions in subsistence opportunities. These management actions appear to have been somewhat effective in stabilizing the level of escapement in the Yukon River drainage above the confluence of the Tanana River based on the data presented here.

Population estimates at the Rampart-Rapids during 1996-2001 have fallen below and above estimates based on the sum of four escapement projects upstream and the estimated harvest (Table 9). Most years estimates were below escapement, but have been within 15% each year. Escapement to tributaries not monitored would widen the difference in all years raising the possibility that the estimate could be biased low. An estimate bias low by 15-20% would account for approximately 30,000 to 40,000 additional fish at a population level of 200,000. Equally valid and equally unproven is an alternative hypothesis that the cumulative error of the upstream escapement monitoring projects could be bias themselves. While the estimate presented here is still useful, especially as an inseason number, it would be helpful to understand the cause of the differences in case corrective measures could be initiated.

Future goals for the project stem mainly from its acceptance as a useful tool to managers of the fishery. The project is currently very expensive because substantial manpower is used to reduce holding times and minimize associated mortality from handling. Link and English (1999) correctly stated that management projects must minimize costs for them to be sustained for the long term. Currently, we are working to replace the recovery site crew with a computer-based video image capture system that would meet both the requirements of low cost of operation and minimized fish holding times. These systems have been successfully used to gather catch-per-unit-effort (CPUE) data at the marking site fish wheel (Zuray and Underwood 2000; Zuray 2001). Increasing the quality of data from presence-absence used in CPUE to categorical data necessary to make population estimates requires the recognition of batch marks, tags by color, or contrasting marks. For the most part, image quality and quantity will be key to success but appear reasonably attainable (Dave Daum, U.S. Fish and Wildlife Service, Fairbanks Fish and Wildlife Field Office, personal communication). Attempts to implement a video system will be made in the coming years.

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Appendix A: Marking Site Data Collection

The header line consisted of data common to multiple fish and was entered once upon reaching each fish wheel during each session. Variables of the header line were as follows:

Location	Wheel start date	Wheel start time	Wheel stop date
Wheel stop time	Total unmarked fish		

Dates and times related to wheel operations were manually input by the person using the data logger. Data specific to each fish were entered separately from header data and included:

Tag number	Capture status	Sex	Length	Time tagged
Release time				

The variable "tag number" was a five digit sequential number printed on the 35 cm spaghetti tag. The tags also bore a mailing address. The variable "capture status" described the fish's condition of tagging as it entered the fish wheel, either already tagged or a new fish currently untagged. The length, mid-eye to fork (MEL), was measured to the nearest cm. The 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. The variable "release time" was automatically recorded via a query of the data logger's internal realtime clock.

Appendix B: Expanded List of Capture Status Codes

In 2001 an expanded list of definitions of the variable "capture status" was used to more closely record the time each fish was held in the live box. These codes were assigned as the fish came onto the chute or as the crew found the fish (in the case of dead fish). The same codes were used at both the marking and recovery sites. The codes were as follows:

Code 1 – Unmarked fish netted from the live box
Code 2 – Marked fish netted from the live box
Code 3 – Unmarked fish netted from the live chute, did not enter live box before netting
Code 4 – Marked fish netted from the live chute, did not enter live box before netting
Code 5 – Unmarked fish found dead
Code 6 – Marked fish found dead

Table 1.— Sampling strata and dates of fall chum salmon tagging and recovery efforts on the Yukon River, Alaska, July 31 to August 26, 2000.

Original stratum	Dates	Adjusted stratum
	Marking site	
1	July 31 through Aug 6	1
2	Aug 7 through Aug 13	2
3	Aug 14 through Aug 19	3
	Recapture site	
1	Aug 1 through Aug 7	1
2	Aug 8 through Aug 14	2
3	Aug 15 through Aug 21	3
4	Aug 22 through Aug 26	3

Table 2.— Summary of Yukon River fall chum salmon tagged and released at the marking site; and at the recovery site, the number examined, recaptured, and sub-sampled for biological data, July 31 to August 26, 2000.

	Marking site		Recovery site (by recovery stratum)		
Stratum	Bank of fish wheel	Number released	Number unmarked	Number recaptured	Sub-sampled
1	North	391	659	58	99
	South	557			
2	North	675	573	92	100
	South	918			
3	North	736	2,948	162	173
	South	945			

Table 3.— Sampling strata and dates of fall chum salmon tagging and recovery efforts on the Yukon River, Alaska, July 30 to September 15, 2001.

Original stratum	Dates	Adjusted stratum
	Marking site	
1	July 30 through Aug 5	1
2	Aug 6 through Aug 12	2
3	Aug 13 through Aug 19	3
4	Aug 20 through Aug 26	4
5	Aug 27 through Sep 2	5
6	Sep 3 through Sep 9	6
7	Sep 10 through Sep 15	7
	Recapture site	
1	July 31 through Aug 6	1
2	Aug 7 through Aug 13	2
3	Aug 14 through Aug 20	3
4	Aug 21 through Aug 27	4
5	Aug 28 through Sep 3	5
6	Sep 4 through Sep 10	6
7	Sep 11 through Sep 18	7

Table 4.— Summary of Yukon River fall chum salmon tagged and released at the marking site; and at the recovery site, the number examined, recaptured for the first time, and sub-sampled for biological data, July 30 to September 15, 2001.

	Marking site		Recovery site (by recovery stratum		
Stratum	Bank of fish wheel	Number released	Number unmarked	Number recaptured	Sub-sampled
1	North	209	748	33	257
	South	544			
2	North	843	3,469	139	303
	South	887			
3	North	670	2,137	97	209
	South	778			
4	North	771	2,301	104	372
	South	923			
5	North	814	1,894	76	178
	South	672			
6	North	528	790	43	199
	South	369			
7	North	249	339	12	161
	South	233			

Table 5.— Data set for estimating the Abundance of fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, July 31 to August 19, 2000.

Marking stratum, i	Marked fish released, a_i	Captured during stratum, j			Fish not recaptured
		1	2	3	
		Recaptured the first time			
1	948	58	10	2	878
2	1,593	0	82	25	1,486
3	1,681	0	0	135	1,546
		Unmarked fish (estimated) , b_j			
		439	41	1,734	

Table 6.— Seasonal and stratum estimates, standard error (SE), coefficients of variation (*CV*), probability of capture (*P*), and SE of *P* of the 2000 run of fall chum salmon at the marking site. The season was truncated due to low runs and uncertainty about handling mortality on the project.

		Abundance			Capture probability		
Stratum	Stratum date	Estimate	SE	CV	Estimate	SE	CV
1	Jul 31 - Aug 6	8,123	1002	0.12	0.117	0.014	0.12
2	Aug 7 - 13	9,273	1075	0.12	0.172	0.020	0.12
3	Aug 14 - 19	21,583	1,831	0.08	0.078	0.007	0.09

Table 7.— Data set for estimating the abundance of fall chum salmon migrating past the marking and recapture sites on the Yukon River, Alaska, July 30 to September 15, 2001.

Marking stratum, i	Marked fish released, a_i	Captured during stratu, j							Fish not recaptured
		1	2	3	4	5	6	7	
		Recaptured the first time							
1	753	33	32	1	0	0	0	0	687
2	1,730	0	107	11	1	0	0	0	1,611
3	1,448	0	0	85	18	2	0	0	1,343
4	1,694	0	0	0	85	16	1	0	1,592
5	1,486	0	0	0	0	58	4	0	1,424
6	897	0	0	0	0	0	38	3	856
7	474	0	0	0	0	0	0	9	465
		Unmarked fish (estimated) b_j							
		604	3,372	2,115	2,257	1,894	772	298	

Table 8.— Seasonal and stratum estimates, standard error (SE), coefficients of variation (CV), probability of capture (*P*), and SE of *P* of the 2001 run of fall chum salmon at the marking site.

		Abundance			Probability of capture		
Stratum	Stratum date	Estimate	SE	CV	Estimate	SE	CV
			Seasonal estimate				
1-7	Jul 30 to Sep 15	201,766	9,578	0.05			
			Stratum estimates				
1	Jul 30 to Aug 5	14,535	2,464	0.17	0.052	0.009	0.17
2	Aug 6 - 12	46,780	5,051	0.11	0.037	0.004	0.11
3	Aug 13 - 19	32,286	3,788	0.12	0.045	0.005	0.11
4	Aug 20 - 26	38,516	4,607	0.12	0.044	0.005	0.11
5	Aug 27 to Sep 2	40,010	5,796	0.14	0.037	0.005	0.14
6	Sep 3 - 9	16,159	2,907	0.18	0.056	0.010	0.18
7	Sep 10 - 15	13,480	4,722	0.35	0.035	0.012	0.34

Table 9.– Comparision of the Rampart–Rapids abundance estimate and an estimate comprised of two components, escapement from four upstream project and estimated harvest upstream of the tagging site.

Description	1996	1997	1998	1999	2000	2001
	Years					
			Escapement projects			
Chandalar River	208,170	199,874	75,811	88,662	65,894	110,971
Sheenjek River	246,889	80,423[c]	33,058	14,229	30,084[b]	53,932
Fishing Branch River	77,278	26,959	13,564	12,094	5,053	21,635
Mainstem Border Passage	143,758	94,725	48,047	75,541	59,598	38,908
			Harvest above the study area			
Rampart	896	646	100	4,324	0	183
Steven's Village	991	1,585	1,076	20	10	20
Beaver	9	243	409	16	0	21
Fort Yukon	8,144	6,119	3,035	9,702	355	2,209
Circle	5,308	3,707	37	2,722	0	2,588
Central	132	0	0	0	0	0
Eagle	14,916	14,488	543	11,292	32	2,714
Chalkytsik	1,230	936	433	442	0	73
Other	505	421	50	65	1	0
Sum of Harvest	32,131	28,145	5,683	28,583	398	7,808
Sum of Escapement and Harvest	708,226	430,126	176,163	219,109	161,027	233,254
			Variance of Rampart-Rapids estimate from other totals			
Darroch estimate (this project)	654,296	369,547	194,963	189,741		201,766[a]
Percent difference	-7.7	-14.1	11	-13.5		-13.5

[a] This number should be considered a preliminary estimate of harvest pending completion of final project reports.
[B] Project ended early due to low water.
[c] High water from 29 August until 3 September 1997.

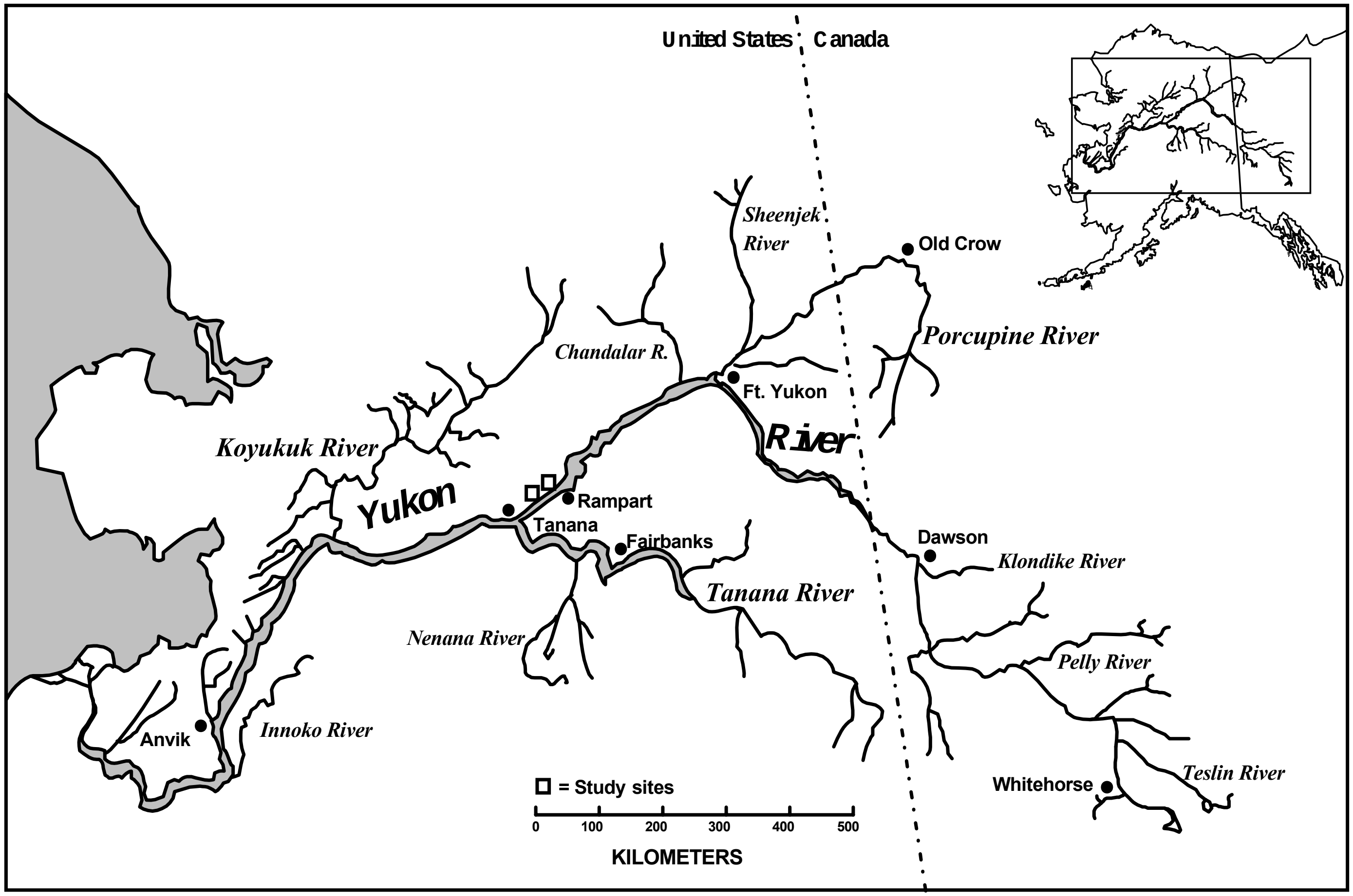

Figure 1.Yukon River drainage, boxes show project study site.

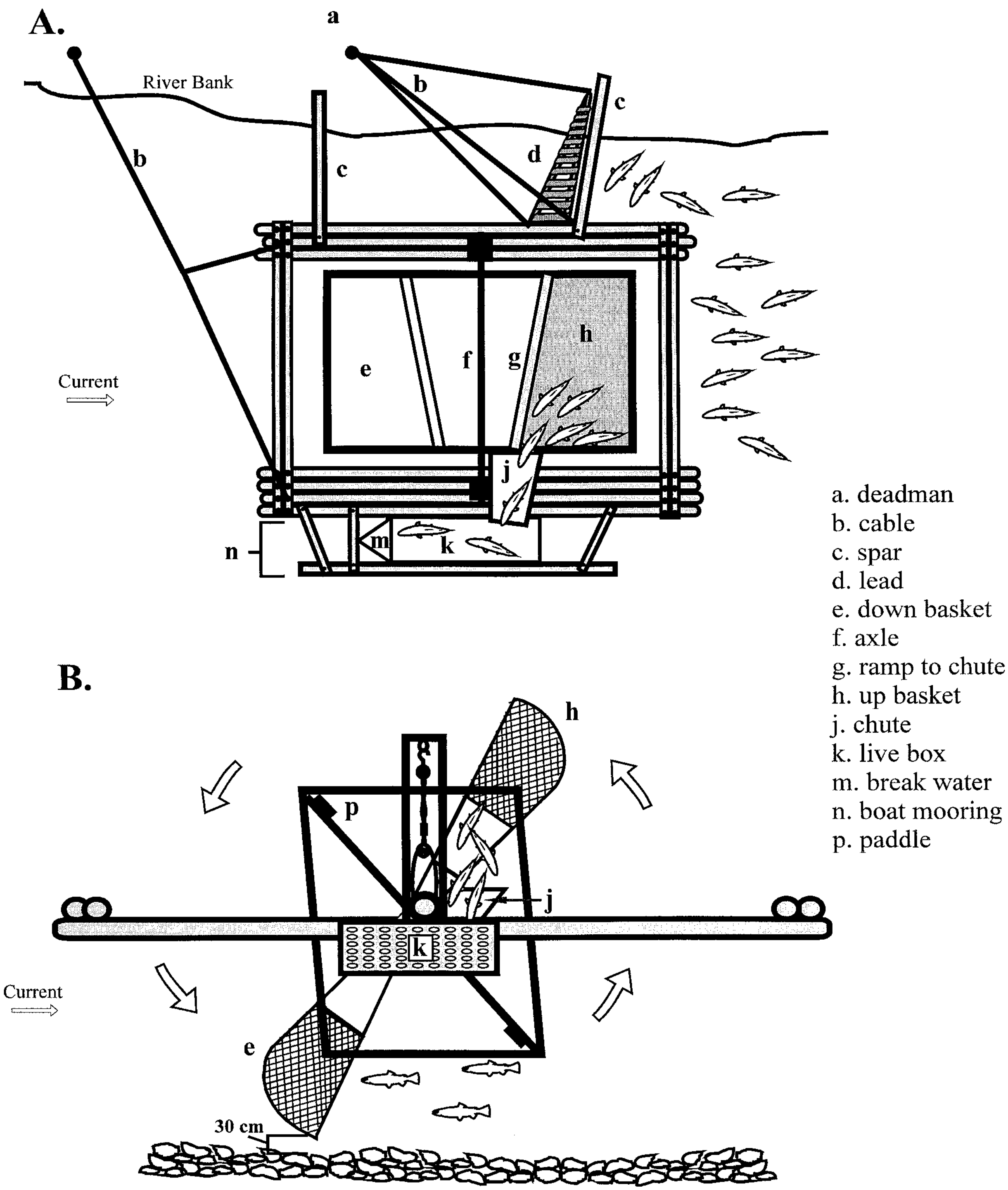

Figure 2.— Two-basket fish wheel equipped with padded chute and live holding box, used to collect fish during the marking and recapture events. A. Aerial view. B. Side view with arrows indicating the direction of wheel movement in response to the current.

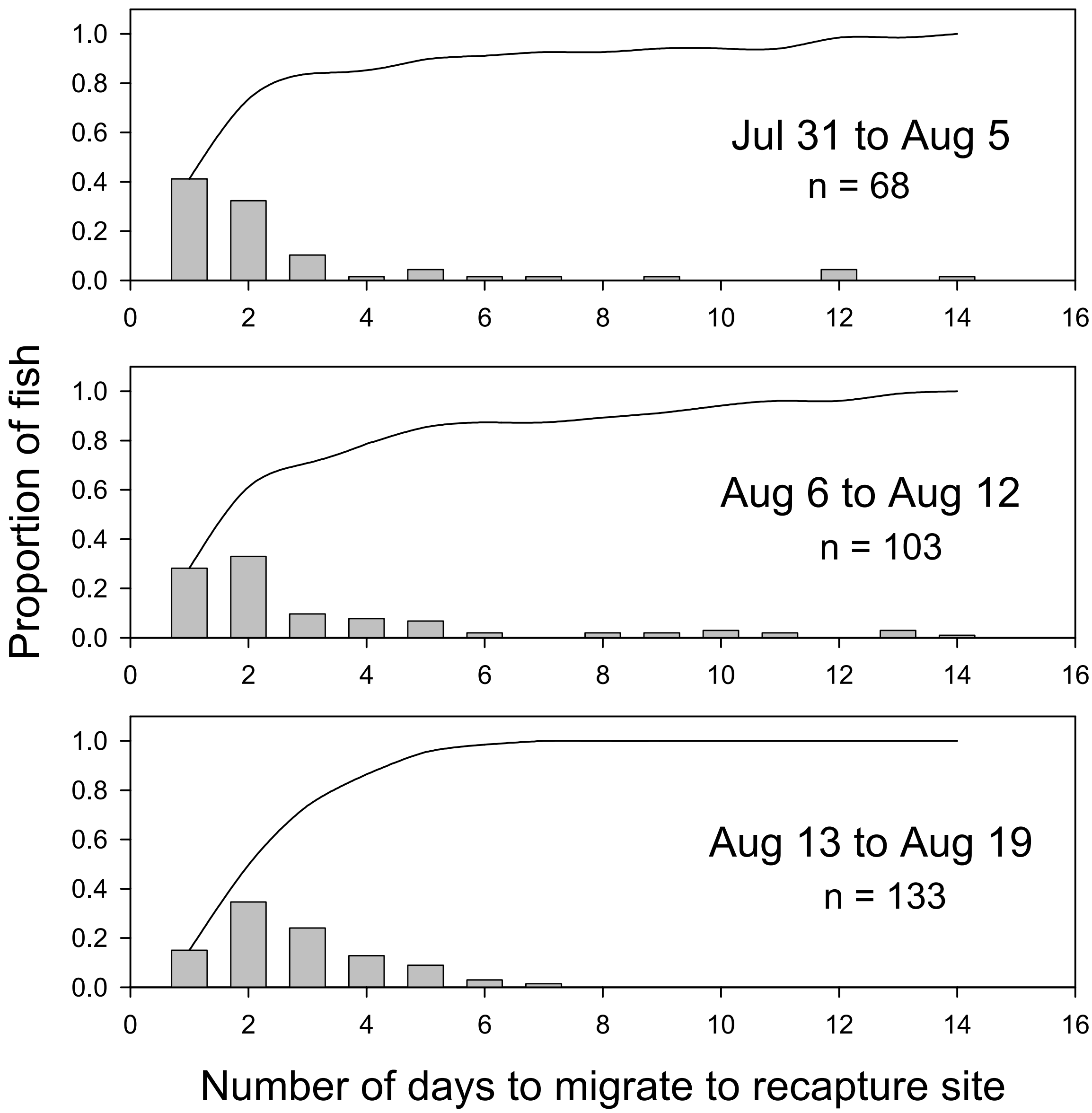

Figure 3.— Estimated migration time (d) for tagged fall chum salmon between the marking and recapture sites, by recovery stratum, on the Yukon River, Alaska, July 31 to August 19, 2000. Histograms represent proportion of recaptured fish and the line is the cumulative proportion.

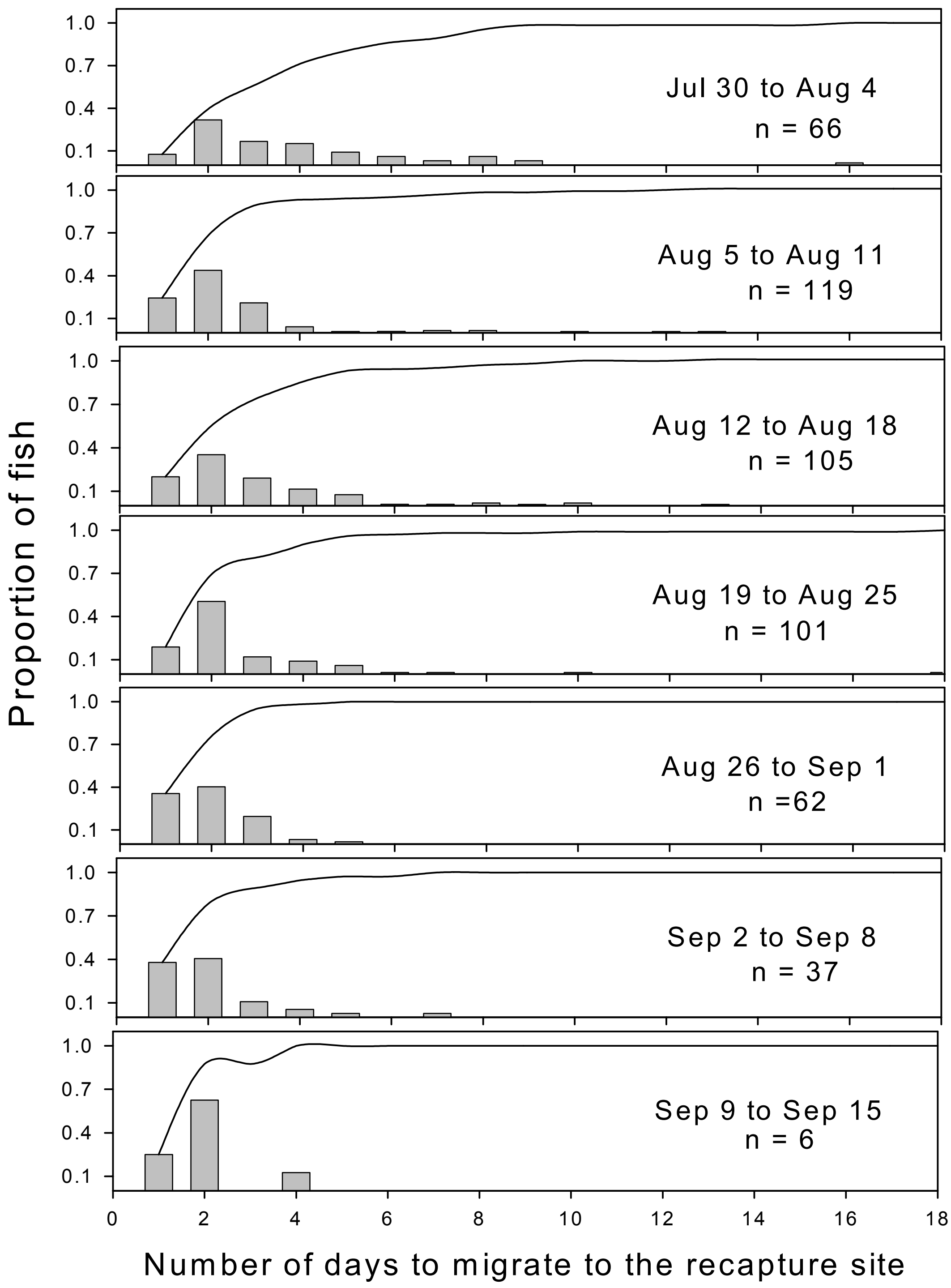

Figure 4.— Estimated migration time in days (d) for tagged fall chum salmon between the marking and recapture sites, by recovery stratum, on the Yukon River, Alaska, July 30 to September 15, 2001. Histograms represent proportion of recaptured fish and the line is the cumulative proportion.

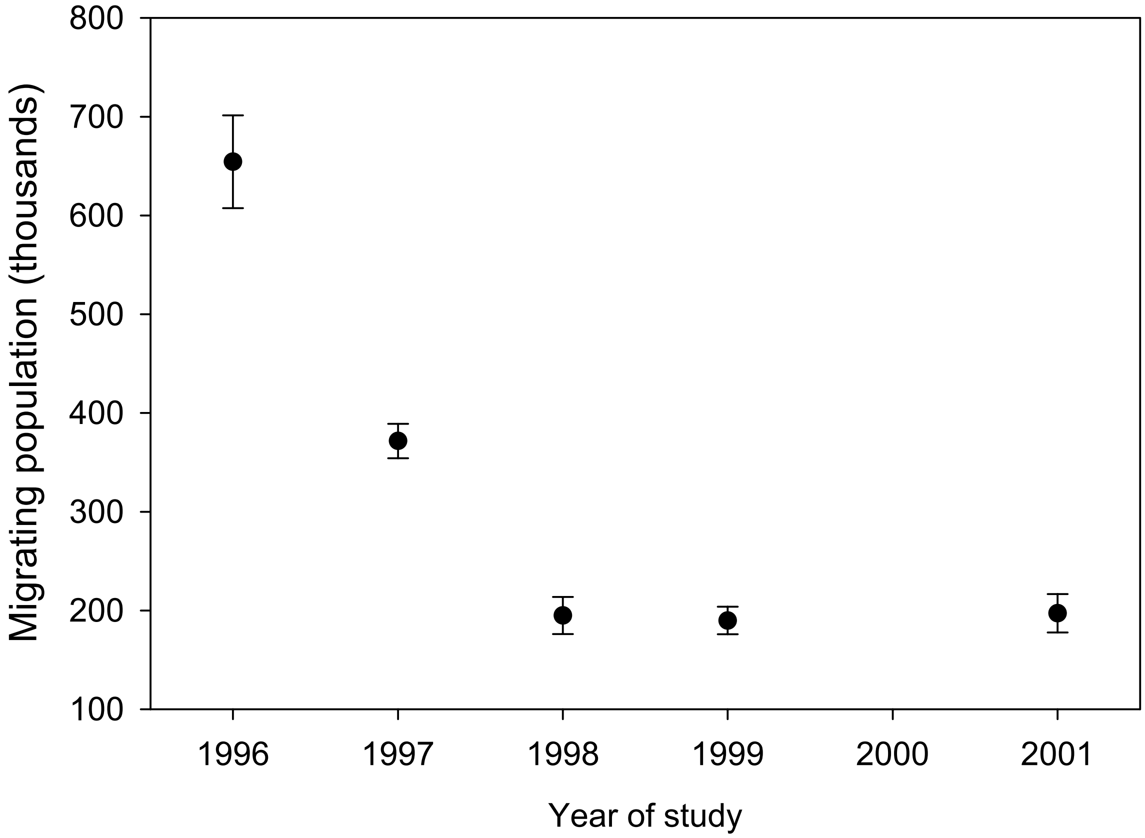

Figure 5.— Population estimates and 95% confidence intervals (2 × SE) at the study site for the years 1996 to 2001 excluding the year 2000. In the year 2000 a seasonal estimate was not generated because the project ran only through August 19.