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Estimated Abundance of Adult Fall Chum Salmon in the Middle Yukon River, Alaska, 2002

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by

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Disclaimers

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Abstract

Mark and recapture data were collected to estimate the abundance of fall chum salmon (*Oncorhynchus keta*) during 2002 in the middle Yukon River. A seasonal abundance estimate and weekly strata estimates of migrating fall chum salmon were generated for a period of approximately seven weeks between 29 July and 18 September. Fish were captured using two fish wheels for marking and one fish wheel for recovery. The mark and recovery sites were separated by a distance of 52 km. Spaghetti tags were applied to 5,518 fish at the marking sites. Throughout the season, 15,361 fish were examined for marks at the recovery site, and excluding multiple recaptures, 435 of these fish were recaptured with unique tag numbers. We checked all captured fish at the recovery site for primary and secondary marks, and found no evidence of tag loss. Likelihood ratio tests indicated an equal probability of recapture for fish marked and released at the north and south bank marking wheels. Logistic modeling of the probability of recapture showed no differences based on sex, length, or the interaction term. We concluded that no further stratification, beyond temporal weekly stratification, was required to produce an accurate estimate. Using a Darroch estimator, the estimated abundance of fall chum salmon migrating through the mainstem of the Yukon River in 2002 was 196,186 (SE 12,546). Additionally, we conducted a video recapture feasibility study concurrently with the effort of our recapture crew. When recapture rates of crew-generated data were compared to those of video recapture data, we found little difference between the two methods. The abundance estimate based on video-generated data (189,052; SE 12,505) accounted for only 1,454 (< 1%) more fish than the estimate generated from crew data (187,598; SE 12,148) for the same time period (strata 2-7). These results suggest that it is feasible to switch to a video-recapture system in the future without compromising the accuracy of the abundance estimate.

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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 middle Yukon River above the confluence with the Tanana River, Alaska. The study was designed as a two-event, temporally stratified mark-recapture experiment. We used the Darroch (1961) estimator to generate weekly in-season and annual estimates of fall chum salmon abundance in the middle Yukon River. Results from the first two years of the study established that the Darroch 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 the in-season and annual abundance estimates provided by the Rampart Rapids project have become an important component of the 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 fall chum salmon population estimate generated by the mark-and-recapture study, and the associated statistical analyses used to test some of the assumptions of the estimator during 2002. Additionally, we address the feasibility of using video-image capture technology to document recaptures and reduce the project budget.

Study Area

The Yukon River is the fourth largest river basin in North America with a drainage area of more than 855,000 km^2 (Brabets et al. 2000). Three of the tributaries of the Yukon River are major rivers themselves. These tributaries, the Koyukuk, Tanana, and Porcupine Rivers, span 91,000, 114,737, and 117,000 km^2, respectively (Brabets et al. 2000).

The middle Yukon River, upstream of 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. Water temperature measured at the Rapids site in 2002 averaged 14.7 °C throughout the tagging season with a high of 18.9 °C and a low of 9.3 °C (Dave Daum, U.S. Fish and Wildlife Service, unpublished data). The river usually 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

Fish Wheel Schedule and Placement

Under contract with the U.S. Fish and Wildlife Service, Stan Zuray and Paul Evans ran and maintained fish wheels at the marking and recovery sites, respectively, throughout the season. At the marking site, two fish wheels were placed across from each other on the north and south banks of the river (Figure 1) near Rapids camp. The marking wheels were run as needed to accommodate the marking schedule, from Monday through Saturday each week. A single recovery wheel was run 24 hours a day, seven days a week at the recapture site. The recovery wheel was located near the village of Rampart on the north side of the river (Figure 1).

Fish wheel placement (Figure 2) 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 toward the dipping baskets. The river at the marking sites was deeper than at the recapture site, so the fish wheels were sized accordingly. Baskets on the marking wheels were approximately 3.0 m wide and dipped to a depth of 4.5 m below the water surface, and baskets on the recapture fish wheel were approximately 2.5 m wide and dipped 3.0 m below the water surface.

Marking Site Sampling Procedures

Marking took place from 29 July to 14 September 2002, between Monday and Saturday every week (Table 1). To spread capture effort throughout the day, fish were tagged during four daily sessions (0800, 1200, 1600, and 1900 hrs ADT). During each marking session the crew spent an approximately equal amount of time at the north and south wheels. Our initial goal was to tag 400 fish per day, thus at least 50 fish per wheel, per session. However, the low number of returning fall chum salmon prevented us from reaching this goal throughout the 2002 field season. Unlike in earlier years of this study, fish wheels were not operated to capture fish when the crew was not present.

While processing individual fish we collected information on length and sex, clipped the adipose fin as a secondary mark, and applied an individually numbered and color-coded (Table 2) spaghetti tag. Length measurements (cm) were taken from mid-eye to tail fork. Sex was determined based on external morphological characteristics. The entire adipose fin was clipped with a pair of scissors, and spaghetti tags were applied through the muscle at the posterior base of the dorsal fin with a hollow applicator needle. After application, the spaghetti tag was knotted within a 3 mm of the insertion point. Some marked fish were released directly into the river, whereas others were held for specified blocks of time as part of a related study. Recaptured tagged fish, at the marking site, were handled in the same manner as unmarked fish, except that lengths were not recorded and no new tag was applied. Fish with major injuries, defined as injuries thought to impede migration, were released without processing. Care was taken to minimize handling time and trauma for all fish caught or handled.

All marked fish were part of a concurrent study focused on the delayed impact of holding on migrating fall chum salmon, which was initiated in 2001 (Bromaghin and Underwood, in preparation). To accommodate the need for a wider range of holding times for this study, our marking schedule was designed to hold fish that were captured at the first wheel visited during each marking session. To avoid wheel-or bank-related bias we alternated the starting location daily. Held fish were captured directly from the chute and placed in the live-box after they were processed and marked. Unmarked fish that escaped into the live-box during a holding period were given a common tag number that did not overlap with deployed tag numbers. Assigning a common tag number for all unmarked fish in the live-box allowed us to calculate fish density in the live-box during each holding session. When reaching half of the allocated session time, the crew stopped marking at the first wheel and proceeded to the second wheel, leaving the tagged fish in the live-box to extend their holding time. At the second fish wheel, during the same session, fish were netted directly from the chute and immediately released into the river after they were marked. At the end of most sessions, the crew revisited the first fish wheel and released the tagged fish being held in the live-box; however, fish held during the first daily session were released at the beginning of the next session. Groups of held fish were released by opening the live-box door, allowing fish to swim into the river.

Recapture Site Sampling Procedures

At the recovery site, the fish wheel was run 24 hours a day from 30 July to 18 September 2002 (Table 1) with exceptions for maintenance and damage repair. The crew tended the fish wheel from 0500 to 2300 hours, with the exception of one-hour breaks at approximately 0900, 1300, and 1800 hours. Recapture procedures carried out by the crew included: (1) tallying marked and unmarked fish; (2) recording tag numbers and colors for marked fish; (3) sub-sampling for sex and length data; and (4) photographing a subset of the recaptured fish to document any tag loss. Fish netted from either the chute or live-box were examined for primary (spaghetti tag) and secondary (adipose fin clip) marks. When possible, the crew used dip nets to capture fish directly from the chute. Otherwise, fish passed through the chute into the live-box and were removed by dip net. Fish accumulated in the live-box during times when the crew was not tending the fish wheel or when several fish came through at the same time. The live-box was emptied at the beginning of every shift and maintained empty while the crew tended the fish wheel, except for short periods when multiple fish came through the wheel at the same time. All fish captured with either primary or secondary marks were considered recaptures.

Approximately 150 fish were sub sampled for sex and length data each week. To reach this goal, 50 fish were measured during three days of the week (Monday, Wednesday, and Friday or Saturday). Additionally, we photographed the first 15 fish captured every day to investigate the possibility of tag loss and the crew's efficiency in detecting tags. At times of low fish capture we sometimes spread our photo sampling period between two shifts to meet our daily goal.

Data Collection

Data were recorded via a handheld electronic data logger at both the marking and recovery sites. Descriptions of categories of recorded data for the marking and recovery site can be found in Appendix A and B. All data in numeric form (lengths, dates, etc.) were directly entered, and all other data were assigned numeric codes (sex, color, etc.). Tagged fish that were recaptured but escaped before their tag could be read were coded as having a recovery tag number of 55555.

Data stored on the handheld data logger were downloaded daily to a laptop computer for processing and storage. All files were transmitted from the data logger to the computer in ASCII file format, saved, and backed up. Additionally, separate written records of hourly start and stop times with tallies of marked and unmarked fish, fish with missing primary marks, and tag numbers were kept in a water-resistant notebook to verify data entered into the data logger. Our catch-per-unit-effort data (e.g. number of hours fished and the number of marked and unmarked fish captured) were summarized in a separate file and sent to the Alaska Department of Fish and Game daily throughout the season.

Video Recapture Procedures

A video image capture system was installed on the recovery fish wheel using equipment described by Fliris (2001) and Zuray (2001a). A camera was mounted above the chute and video images of fish passing through the chute were captured. A lightweight door with a magnetic switch was placed at the end of the chute. When the door was opened, the switch tripped and initiated video capture, then sent the images to a laptop computer using Salmonsoft Fishcap 1.3.4 software. The system was set to capture 15 video frames per second (6 before the trigger event, 1 during the event, and 8 after the event) for each capture event. The video system ran continuously, and created a new file every 12 hours. Files were taken back to camp daily for review. Fish were tallied from the video files using review software (Salmonsoft FishRev 1.3.5). Numbers of marked and unmarked chum salmon and tag colors for marked fish were recorded and compiled for each sampling day.

Analysis of Tagging and Recovery Wheel Data

Travel time.—Travel times were calculated 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 fish were caught in the recapture wheel was unknown, the midpoint between the earliest and latest possible capture times was used as an approximation.

Sex- and length-based probability of recapture.—The need to stratify the abundance estimate by either sex or length was assessed by modeling a response variable that was constructed as a composite of travel time between the marking and recapture events and an indicator of whether or not a fish was recaptured. 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 helps protect against the possibility of differences in travel time between the sites being 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. Although the validity of the logit link cannot be directly verified, the model is quite flexible. The stratum of marking was included as a categorical variable, essentially acting as a nuisance parameter to absorb 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 $\alpha = 0.01$. A final model containing only the stratum of marking as an explanatory variable suggested that stratification by either sex or length was not necessary.

Recapture probability by bank of release and mixing.—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.—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:

$$\hat{c}_{ij} = c'_{ij} + u_j \frac{c'_{ij}}{\sum_{k=1}^{n} c'_{kj}},$$

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 the recovery wheel 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, to adjust for migration-rate-related bias we followed standard methods (Cappiello and Bruden 1997) and used data from the first two strata and the two strata immediately preceding the last stratum to reduce the untagged catches 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.

Video recovery data.—To assess the feasibility of switching to a video recapture system we compared video- and crew-generated recovery data and the associated abundance estimates. For these comparisons, we used video and crew recovery data from the beginning of the second stratum to the last day of the seventh stratum, and used the Darroch estimator to generate weekly and seasonal abundance estimates. The first stratum was not used because the video data were not complete for that week.

Results

Summary of Tagging and Recovery Fish Wheel Data

In the seven weeks of tagging, 5,518 fall chum salmon were captured and released with uniquely numbered spaghetti tags (Table 3). Of the fish tagged, 256 were caught twice, and 15 were caught three times. Male fish made up 49% of the overall catch, but the percentage of males varied by weekly stratum ranging from 43% to 56% (Table 4). Lengths for males ranged from 48 to 72 cm and lengths for females ranged from 48 to 69 cm (Table 4). Holding time was recorded as 0 minutes for fish that were caught off the chute, immediately tagged, and released. Thus, holding times ranged from 0 to 9 hours 38 minutes, with a mean of 1 hour 25 minutes and a median of 51 min. Fish held in the live-box and those released immediately represented 53% and 47% of marked fish, respectively. More detailed results from the holding experiment will be presented by Bromaghin and Underwood (In preparation).

Fall chum salmon captured at the recovery site totaled 15,361, and 435 of these fish were marked recaptures. We recaptured 422 fish once, eight fish twice, and one fish three times. Four fish escaped before their tags could be read and were apportioned over multiple marking strata (Table 5). A sub sample for sex and length data was collected from 1,962 fish at the recovery site. Males made up 55% of the total catch, but the male contribution ranged from 50% to 62% among the strata. Length measurements for male fish ranged from 53 to 73 cm and those for females ranged from 48 to 70 cm. To document the possibility of tag loss and crew efficiency in detecting tags, a total of 531 fish were photographed. We found no evidence of tag loss; all fish captured at the recovery site had both a spaghetti tag and an adipose fin clip, or no evidence of either a tag or fin clip.

Analysis of Mark and Recapture Data

Travel time.—During 2002, the mode travel time for tagged fish traveling between the marking and recovery site was 2 days. The fastest travel time recorded was 20 hours and the maximum was 18 days 19 hours. The range in travel times varied among strata. Of the tagged fish, 86% took 4 days or less to travel between the two sites (Figure 3).

Sex and length-based probability of recapture.—During 2002, capture data from 5,504 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 ($P = 0.035$), then length ($P = 0.967$), and finally sex ($P = 0.023$). From these results, we concluded that no stratification based on the sex- or length-related bias was necessary.

Recapture probability by bank of release and mixing.—During 2002, a total of 5,518 uniquely tagged fish was released from the marking site: 2,355 (43%) fish from the north bank fish wheel and 3,163 (57%) from the south bank. At the recovery site, 185 (43%) and 246 (57%) fish that were tagged from the north and south bank tagging sites respectively, were captured (excluding 4 fish that were recaptured but escaped before their tag number could be read). The log likelihood comparison of full and reduced models indicated no difference in the probability of capture based on the fish wheel of release ($X^2 = 2.36$, df= 7, $P = 0.94$). From these results, we concluded that no stratification based on the bank of release was required.

Abundance estimate.—We performed post hoc adjustments to the fish catch data to account for potential bias associated with migration time (Tables 3 and 6) and multiple recaptures (Table 5), but no adjustments were made for sex- or length-related biases because none were detected. The resulting 2002 crew-generated mark-and-recapture data truncated for migration rates and multiple recaptures included 5,511 chum salmon tagged at the marking fish wheels and 14,476 fish examined for marks at the recovery fish wheel, including 435 tagged fish. Four tags with unidentified numbers were assigned to a marking stratum, as discussed previously (Table 5). Based on crew recapture data (Table 7) an estimate of 196,186 (SE 12,546) was calculated for the seven strata between July 30 and September 18, 2002 (Table 8). Estimates from individual strata ranged from 7,739 to 62,888 fall chum salmon.

Comparison of video and crew recapture data.—Video recovery data (Table 7) were collected during 1,048 hours of fish wheel capture operation from August 6 to September 18. Between the second and last strata, a total of 15,491 and 14,860 fall chum salmon were examined for external colored tags, using video capture files and crew data, respectively (Table 9). The video recapture system detected 631 more fish than the crew. In this time period, the video system detected 558 more unmarked fish and 18 more marked fish than the crew (Table 9). The presence or absence of tags could not be determined for 55 fish (<1%; Table 9) due to the orientation of the fish when the images were captured. The color of only one tag form video images was misidentified based on a direct comparison with crew data for the same time period. The abundance estimate generated from video data (189,052; SE 12,505) was similar to the abundance estimate generated from crew data (187,598; SE 12,148) for 2002 (Table 8).

Discussion

Using a Darroch estimator and a two-event, temporally stratified mark-recapture experiment we estimated that 196,186 (SE 12,546) fall chum salmon migrated through the mainstem Yukon above the Tanana River confluence in 2002. Post hoc evaluations of bank-, sex-, and length-related bias suggested that no further stratification, beyond weekly stratification, was required to produce a reliable estimate. However, adjustments were made for migration timing at the beginning and end of the season for removal of multiple recaptures from the data set. Comparisons of our estimate and run reconstructions with data from other projects indicated that our estimate was approximately 15% lower than the combined figure for subsistence harvest (upstream of study area within the United States), tributary escapement (Chandalar, Sheenjek, and Fishing Branch Rivers), and Canadian border passage of fall chum salmon (Table 10). In previous years, our estimates have ranged from being approximately 8% lower to 14% higher than run reconstructions. Annual differences between our estimate and run reconstructions may be attributed, at least in part, to bias related to shutting the project down before the entire migrating population of fall chum salmon have passed the project sites, and to variation in the accuracy of the escapement counts and Canadian border fish passage estimates that are used for these comparisons.

In addition to our annual estimate we evaluated the feasibility of switching to a video recovery operation. When recapture rates of crew-generated data were compared to those of video recapture data, we found little difference between the two methods. The abundance estimate based on video-generated data (189,052; SE 12,505) accounted for only 1,454 (< 1%) more fish than the estimate generated from crew data (187,598; SE 12,148) for the same time period (strata 2-7). The small difference between the two estimates can be attributed to variation in efficiency in detecting fish (marked and unmarked) that jumped out of the live box, and to method-specific counting errors. For example, our data suggest that crew members more accurately identified the presence of tags, but were unable to detect fish that jumped from the live-box unless the jumping occurred when they were tending the wheel.

Based on the comparable results from the video-recapture estimate and crew estimate we recommend implementing video capture as the primary recapture system. Making this change would have associated drawbacks and benefits. The drawbacks of using a video image recovery system include: (1) losing the ability to identify individual fish using serially numbered tags and associated statistical analyses; (2) less accuracy in detecting tags, depending on the position and orientation of captured fish; and (3) replacing a simple counting system (manual) with one that is dependent on technology in a remote setting. The first drawback cannot be entirely overcome, but will be mitigated by using color coded tags that serve as batch marks for weekly strata. The second drawback is not a major concern because only 10 of 463 (2%) opportunities to see a tagged fish with video were missed. The third drawback, dependence on technology, is not a major concern due to the success of using this system in catch-per-unit-effort projects on the Yukon River between 1999 and 2002 (Fliris 2000, 2001, 2002; Zuray and Underwood 2000, Zuray 2000, 2000a, 2000b, 2001a, 2001b, and 2002a, 2002b).

We believe that the benefits of using a video recovery system out-weigh the drawbacks. Switching from a crew-based recovery effort to video image recovery is desirable primarily because it will eliminate the need to hold and handle fish at the recovery site. Secondary reasons to advocate the switch include: (1) the potential to reduce the project budget by decreasing the number of personnel needed at the recapture site; (2) the addition of a permanent video record of fall chum salmon and other fish species passing through the wheel; and (3) improved accuracy of recovery wheel data, especially when considering the number of marked and unmarked fish that were detected by the video system but were unaccounted for in the crew counts in 2002. Therefore, we believe that replacing a manual counting system with a video recovery system will provide an equally reliable and accurate abundance estimate while also reducing the cost.

To effectively manage this project we have continuously adapted our protocol to address concerns associated with our sampling methods. During the past three years we have conducted concurrent studies to investigate the impact of holding fall chum salmon for prolonged periods. Based on results from this study (Bromaghin and Underwood, in preparation), we have greatly reduced the amount of time that we hold fall chum salmon at the marking and recovery wheels. Implementing a video recapture system is our most recent attempt to reduce the impact of holding and handling captured fish at the recovery site.

Active in-season management may play an important role in preventing population decline of fall chum salmon in future years. The precipitous decline of fall chum salmon documented in the first three years of the study, 1996 through 1998, appears to have halted, and the population migrating past the tagging site has remained at a relatively low but steady level since 1998 (Figure 4). To prevent harvest-related population decline fishery managers have actively reduced harvest rates throughout the Yukon River drainage by closing commercial harvest of fall chum salmon since 1998 and significantly reducing subsistence opportunities when needed. To assess appropriate times to open and close the subsistence fishery, Yukon River fishery managers rely upon available data on run timing and abundance throughout the drainage. The location of our study site makes this project particularly valuable for in-season management of the fisheries in the mid and upper regions of the Yukon River. Furthermore, this project provides the only in-season mainstem estimate of fall chum salmon abundance upstream of Pilot Station before the Canadian border.

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References

Agresti, A. 1990. Categorical data analysis. Wiley, New York.

Brabets, T. P., B. Wang, and R. H. Meade. 2000. Environmental and hydrologic overview of the Yukon River Basin, Alaska and Canada. U.S. Geological Survey, Water-Resources Investigations Report 99-4204.

Bromaghin, J. F., and T. J., Underwood. In preparation. Evidence of residual effects from tagging Yukon River fall chum salmon in 2001. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report Number XX, Anchorage, Alaska.

Cappiello, T. A., and D. L. Bruden. 1997. Mark-recapture abundance estimate of fall-run chum salmon in the Upper Tanana River, Alaska, 1996. Alaska Department of Fish and Game, Regional Information Report 3A97-37, Anchorage, Alaska.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241-260.

Fliris, B. 2000. Installation and operation of video storage equipment for purposes of providing accurate catch-per-unit-effort data from the Yukon River Sub-district 5-A test fishwheel. A final report to the Yukon River Panel, Anchorage, Alaska.

Fliris, B. 2001. Modification of video storage equipment for purposes of providing accurate catch-per-unit-effort data from the Yukon River Sub-district 5-A test fishwheel. A final report to the Yukon River Panel, Anchorage, Alaska.

Fliris, B. 2002. Annual catch-per-unit-effort data collected by Yukon River Sub-district 5-A test fishwheel project. A final report to the Yukon River Panel, Anchorage, Alaska.

Gordon, J. A., S. P. Klosiewski, T. J. Underwood, and R. J. Brown. 1998. Estimated abundance of adult fall chum salmon in the upper Yukon River, Alaska, 1996. U. S. Fish and Wildlife Service, Fairbanks Fishery Resource Office, Alaska Fisheries Technical Report 45, Fairbanks, Alaska.

JTC (United States/Canada Yukon River Joint Technical Committee). 2001. Yukon River salmon season review for 2001 and Technical Committee report. Whitehorse, Yukon Territory, Canada.

Link, M. R., and K. K. English. 1999. Long-term, sustainable monitoring of Pacific salmon populations using fishwheels to integrate harvesting, management, and research. Pages 667-674 *in* E. E. Knudson, C. R. Stewart, D. D. MacDonald, J. E. Williams, and D. W. Reiser, editors Sustainable fisheries management: Pacific salmon. Lewis Publishers, New York.

McCulloch, C. E., and S. R. Searle. 2001. Generalized, linear, and mixed models. John Wiley and Sons, New York.

Stuart, A., J. K. Ord, and S. Arnold. 1999. Kendall's advanced theory of statistics, Vol. 2A, 6th edition. Arnold, London.

Underwood, T. J., S. P. Klosiewski, J. A. Gordon, J. L. Melegari, and R. J. Brown. 2000a. 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 56, Fairbanks, Alaska.

Underwood, T. J., S. P. Klosiewski, J. L. Melegari, and R. J. Brown. 2000b. Estimated abundance of adult fall chum salmon in the middle Yukon River, Alaska, 1998-1999. U. S. Fish and Wildlife Service, Fairbanks Fishery Resource Office, Alaska Fisheries Technical Report 57, Fairbanks, Alaska.

Zuray, S.C., and T. J. Underwood. 2000. Development of video technology to measure catch-per-unit-effort using a fish wheel on the Yukon River, Alaska. A final report to the Yukon River Panel, Anchorage, Alaska.

Zuray, S. 2000a. Stored video images as an alternative to fishwheel live boxes for the collection of Chinook catch-per-unit-effort data using a fishwheel on the Yukon River, Alaska. A final report to the Yukon River Panel, Anchorage, Alaska.

Zuray, S. 2000b. Stored video images as an alternative to fishwheel live boxes for the collection of fall chum catch-per-unit-effort data using a fishwheel on the Yukon River, Alaska. A final report to the Yukon River Panel, Anchorage, Alaska.

Zuray, S. 2001a. Rampart-Rapids summer catch-per-unit-effort video monitoring - 2001 using a fishwheel on the Yukon River, Alaska. Federal Subsistence Fishery Monitoring Program Annual Project Report FIS 01-197, U.S. Fish and Wildlife Service, Office of Subsistence Management, Fishery Information Service Division, Anchorage, Alaska.

Zuray, S. 2001b. Rampart-Rapids fall catch-per-unit-effort video monitoring - 2001 using a fishwheel on the Yukon River, Alaska. A final report to the Yukon River Panel, Anchorage, Alaska.

Zuray, S. 2002a. Rampart-Rapids summer catch-per-unit-effort video monitoring - 2002 using a fishwheel on the Yukon River, Alaska. Federal Subsistence Fishery Monitoring Program Annual Project Report FIS 01-197, U.S. Fish and Wildlife Service, Office of Subsistence Management, Fishery Information Service Division, Anchorage, Alaska.

Zuray, S. 2002b. Rampart-Rapids fall catch-per-unit-effort video monitoring - 2002 using a fishwheel on the Yukon River, Alaska. A final report to the Yukon River Panel, Anchorage, Alaska.

Appendix A. Data collected for the Yukon River fall chum salmon tagging project, 2002.

Marking and Recovery Data
Session data
Wheel location
Start month
Start day
Start hour
Start minute
Stop month
Stop day
Stop hour
Stop minute
Number unmarked
Initials of crew member
Marking data
Tag number (5-digit)
Recapture code (see Appendix B)
Fish color (silver, light, dark, unknown)
Fish sex (male, female, unknown)
Fish length
Release time
Marking site holding data
Group release hour
Group release minute
Recaptured fish data
Tag number (five-digit)
Recapture code (see Appendix B)
Release time
Recovery site sub-sampling data
Tag number (5-digit)
Recapture code (see Appendix B)
Fish sex (male, female, unknown)
Fish length
Release time

Appendix B. Expanded list of capture status codes.

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

Table 1.— Sampling stratum dates for Yukon River fall chum salmon tagging and recovery efforts, Alaska, 2002.

Stratum	Dates
	Marking site
1	July 29 through Aug 4
2	Aug 5 through Aug 11
3	Aug 12 through Aug 18
4	Aug 19 through Aug 25
5	Aug 26 through Sep 1
6	Sep 2 through Sep 8
7	Sep 9 through Sep 14
	Recapture site
1	July 30 through Aug 5
2	Aug 6 through Aug 12
3	Aug 13 through Aug 19
4	Aug 20 through Aug 26
5	Aug 27 through Sep 2
6	Sep 3 through Sep 9
7	Sep 10 through Sep 18

Table 2.— Color sequence of spaghetti tags used to mark Yukon River fall chum salmon, Alaska, 2002.

Week	Color
1	Dark forest green
2	White
3	Fluorescent pink
4	Dark forest green with white band
5	Light fluorescent green
6	White with black band
7	Dark forest green

Table 3.— Observed and adjusted daily values of Yukon River fall chum salmon marked and released at the Rapids marking site, Alaska, 2002.

Date	Marking stratum	Unadjusted releases	Adjusted releases	Proportion reaching recapture site
29-Jul-02	1	36	36.00	1
30-Jul-02	1	49	49.00	1
31-Jul-02	1	46	46.00	1
1-Aug-02	1	46	46.00	1
2-Aug-02	1	28	28.00	1
3-Aug-02	1	28	28.00	1
5-Aug-02	2	53	53.00	1
6-Aug-02	2	58	58.00	1
7-Aug-02	2	59	59.00	1
8-Aug-02	2	36	36.00	1
9-Aug-02	2	35	35.00	1
10-Aug-02	2	11	11.00	1
12-Aug-02	3	35	35.00	1
13-Aug-02	3	54	54.00	1
14-Aug-02	3	63	63.00	1
15-Aug-02	3	91	91.00	1
16-Aug-02	3	99	99.00	1
17-Aug-02	3	89	89.00	1
19-Aug-02	4	109	109.00	1
20-Aug-02	4	110	110.00	1
21-Aug-02	4	133	133.00	1
22-Aug-02	4	159	159.00	1
23-Aug-02	4	202	202.00	1
24-Aug-02	4	218	218.00	1
26-Aug-02	5	153	153.00	1
27-Aug-02	5	142	142.00	1
28-Aug-02	5	193	193.00	1
29-Aug-02	5	254	254.00	1
30-Aug-02	5	267	267.00	1
31-Aug-02	5	276	276.00	1
2-Sep-02	6	232	232.00	1
3-Sep-02	6	255	255.00	1
4-Sep-02	6	261	261.00	1
5-Sep-02	6	268	268.00	1
6-Sep-02	6	238	238.00	1
7-Sep-02	6	273	273.00	1
9-Sep-02	7	165	165.00	1
10-Sep-02	7	204	204.00	1
11-Sep-02	7	168	168.00	1
12-Sep-02	7	139	137.28	0.99
13-Sep-02	7	100	98.35	0.98
14-Sep-02	7	83	79.23	0.95
Total		5,518	5,511.86	

Table 4.— Summary of sex and length data for Yukon River fall chum salmon tagged and released at the marking site and recaptured at the recovery site, Alaska, 2002.

Stratum and sex	Number measured	Proportion within a stratum	Minimum length (cm)	Maximum length (cm)	Mean length (cm)	Standard error of mean length
1-female	103	0.44	52	65	59	0.26
1-male	130	0.56	55	68	61	0.25
2-female	112	0.45	53	67	59	0.26
2-male	139	0.55	53	68	61	0.26
3-female	244	0.57	52	66	60	0.18
3-male	186	0.43	48	70	62	0.24
4-female	430	0.46	51	66	59	0.14
4-male	497	0.54	51	72	62	0.15
5-female	633	0.49	49	69	59	0.12
5-male	647	0.51	50	71	62	0.12
6-female	828	0.54	50	69	59	0.11
6-male	697	0.46	51	71	62	0.12
7-female	460	0.54	48	67	58	0.13
7-male	398	0.46	50	70	61	0.17

Table 5.—Marking strata adjustment for recaptured Yukon River fall chum salmon with unknown tag numbers and multiple recaptured tagged fish, Alaska, 2002.

Recapture stratum	Marking stratum	Proportion from marking stratum	Multiple recapture adjustment	Number of fish
1	1	1	1	1
5	3	0.023	0.97	0.023
5	4	0.188	0.97	0.182
5	5	0.789	0.97	0.765
6	4	0.014	0.97	0.014
6	5	0.099	0.97	0.095
6	6	0.887	0.97	0.857
7	5	0.012	1	0.012
7	6	0.012	1	0.012
7	7	0.976	1	0.976

Table 6.— Observed and adjusted daily values for unmarked and recaptured Yukon River fall chum salmon captured at the Rampart recovery site, Alaska, 2002.

Date	Recapture stratum	Unadjusted catch	Adjusted catch	Travel time adjustment	Multiple recapture adjustment
30-Jul-02	1	135	41	0.3	1
31-Jul-02	1	99	64	0.65	1
1-Aug-02	1	54	46	0.85	1
2-Aug-02	1	42	40	0.95	1
3-Aug-02	1	50	48	0.95	1
4-Aug-02	1	44	44	1	1
5-Aug-02	1	56	56	1	1
6-Aug-02	2	75	70	1	0.93
7-Aug-02	2	72	67	1	0.93
8-Aug-02	2	57	53	1	0.93
9-Aug-02	2	81	75	1	0.93
10-Aug-02	2	64	59	1	0.93
11-Aug-02	2	35	33	1	0.93
12-Aug-02	2	59	55	1	0.93
13-Aug-02	3	123	123	1	1
14-Aug-02	3	111	111	1	1
15-Aug-02	3	122	122	1	1
16-Aug-02	3	160	160	1	1
17-Aug-02	3	216	216	1	1
18-Aug-02	3	212	212	1	1
19-Aug-02	3	168	168	1	1
20-Aug-02	4	174	174	1	1
21-Aug-02	4	179	179	1	1
22-Aug-02	4	141	141	1	1
23-Aug-02	4	190	190	1	1
24-Aug-02	4	164	164	1	1
25-Aug-02	4	128	128	1	1
26-Aug-02	4	153	153	1	1
27-Aug-02	5	219	212	1	0.97
28-Aug-02	5	309	300	1	0.97
29-Aug-02	5	363	352	1	0.97
30-Aug-02	5	419	406	1	0.97
31-Aug-02	5	452	438	1	0.97
1-Sep-02	5	509	494	1	0.97
2-Sep-02	5	592	574	1	0.97
3-Sep-02	6	610	589	1	0.97
4-Sep-02	6	668	645	1	0.97
5-Sep-02	6	874	844	1	0.97
6-Sep-02	6	974	941	1	0.97
7-Sep-02	6	781	754	1	0.97
8-Sep-02	6	854	825	1	0.97

Table 6.— continued.

Date	Recapture stratum	Unadjusted catch	Adjusted catch	Travel time adjustment	Multiple recapture adjustment
9-Sep-02	6	851	822	1	0.97
10-Sep-02	7	536	536	1	1
11-Sep-02	7	653	653	1	1
12-Sep-02	7	582	582	1	1
13-Sep-02	7	311	311	1	1
14-Sep-02	7	382	382	1	1
15-Sep-02	7	218	218	1	1
16-Sep-02	7	225	130	0.58	1
17-Sep-02	7	180	29	0.16	1
18-Sep-02	7	200	15	0.07	1
Total		14,926	14,044		

Table 7.—Adjusted crew and video data sets of Yukon River fall chum salmon marked and recaptured in 2002, and associated estimates of unmarked fish. Multiple recaptures are not included.

	Capture stratum (number marked within each stratum)							
Stratum	**1 (233)**	**2 (252)**	**3 (431)**	**4 (931)**	**5 (1,285)**	**6 (1,527)**	**7 (852)**	**Fish not captured**
				Crew recapture data				
1	8	2	0	0	0	0	0	223
2	0	11	2	0	0	0	0	239
3	0	0	11	5	3	0	0	412
4	0	0	0	41	24	2	0	864
5	0	0	0	0	102	14	1	1,168
6	0	0	0	0	0	127	1	1,399
7	0	0	0	0	0	0	81	771
Total strata 1-7	8	13	13	46	129	143	83	5,076
Total strata 2-7	0	11	13	46	129	143	83	4,853
				Video recapture data				
2	0	13	2	0	0	0	0	237
3	0	0	11	4	3	0	0	413
4	0	0	0	42	24	3	0	862
5	0	0	0	0	105	15	1	1,165
6	0	0	0	0	0	133	2	1,392
7	0	0	0	0	0	0	93	759
Total	0	13	13	46	132	151	96	4,828
				Unmarked fish (estimated)				
Crew data strata 1-7	338	411	1,112	1,129	2,776	5,421	2,856	
Crew data strata 2-7	0	413	1,112	1,129	2,773	5,421	2,856	
Video data strata 2-7	0	457	1,140	1,151	2,906	5,690	3,194	

Table 8.—Crew- and video-generated seasonal and stratum estimates of abundance and the probability of recapture, with associated measures of precision, for the 2002 run of Yukon River fall chum salmon. Dates for weekly strata based on recovery site strata schedule, SE = standard error, CV = coefficients of variation.

		Abundance			**Capture probability**		
Stratum	**Date of stratum**	**Estimate**	**SE**	**CV**	**Estimate**	**SE**	**CV**
			Crew strata estimates				
1	Jul 30-Aug 5	10,082	3,523	0.35	0.023	0.008	0.35
2	Aug 6-12	7,739	2,769	0.36	0.033	0.012	0.36
3	Aug 13-19	41,673	12,641	0.30	0.010	0.003	0.30
4	Aug 20-26	15,703	6,372	0.41	0.059	0.024	0.41
5	Aug 27-Sep 2	27,846	3,991	0.14	0.046	0.007	0.15
6	Sep 3-9	62,888	5,626	0.09	0.024	0.002	0.08
7	Sep 10-18	30,254	3,350	0.11	0.028	0.003	0.11
			Crew strata (2-7) estimates				
2	Aug 6-12	9,722	2,893	0.30	0.030	0.008	0.27
3	Aug 13-19	41,056	12,526	0.31	0.010	0.003	0.30
4	Aug 20-26	15,866	6,310	0.40	0.059	0.023	0.39
5	Aug 27-Sep 2	27,811	3,967	0.14	0.046	0.006	0.13
6	Sep 3-9	62,889	5,626	0.09	0.024	0.002	0.08
7	Sep 10-18	30,254	3,350	0.11	0.028	0.003	0.11
			Video strata (2-7) estimates				
2	Aug 6-12	9,111	2,492	0.27	0.028	0.008	0.29
3	Aug 13-19	42,343	12,878	0.30	0.010	0.003	0.30
4	Aug 20-26	17,822	5,741	0.32	0.052	0.017	0.33
5	Aug 27-Sep 2	27,926	3,913	0.14	0.046	0.006	0.13
6	Sep 3-9	62,660	5,484	0.09	0.024	0.002	0.08
7	Sep 10-18	29,190	3,035	0.10	0.029	0.003	0.10
			Crew seasonal estimates				
1-7	Jul 30-Sep 18	196,186	12,546	0.06			
2-7	August 6-Sep 18	187,598	12,148	0.06			
			Video seasonal estimate				
2-7	August 6-Sep 18	189,052	12,505	0.07			

Table 9.—Comparison of unadjusted video and crew recapture data generated between strata 2 and 7 on the Yukon River, Alaska, 2002. The number of tags missed was calculated from a comparison of the weekly recapture results for each method.

	Crew data			**Video data**			
Stratum	**Number examined**	**Tagged fish**	**Tags missed**	**Number examined**	**Tagged fish**	**Tags missed**	**Number not determined**
2	457	13	1	472	15	0	2
3	1,123	13	0	1,158	13	0	5
4	1,170	46	1	1,205	46	1	8
5	2,988	133	6	3,053	132	7	15
6	5,754	147	4	5,852	151	0	11
7	3,368	83	13	3,751	96	2	14
Total	14,860	435	25	15,491	453	10	55

Table 10.—Comparison of the annual Darroch estimate of crew-generated data with measured components of the Yukon River fall chum salmon run (tributary escapement, harvest, and Canadian border passage) upstream of the tagging site from 1996 to 2002.

	Years						
Description	1996	1997	1998	1999	2000	2001	2002
				Escapement projects			
Chandalar River	208,170	199,874	75,811	88,662	65,894	110,971	89,847
Sheenjek River	246,889	80,423[a]	33,058	14,229	30,084[b]	53,932	31,856
Fishing Branch River	77,278	26,959	13,564	12,094	5,053	21,635	13,300
Sum of escapement	532,337	307,256	122,433	114,985	101,031	186,538	135,003
				Border Passage			
Mainstem border passage	143,758	94,725	48,047	75,541	59,598	38,908	91,808
				Harvest above the study area			
Rampart	896	646	100	4,324	0	183	0[c]
Steven's Village	991	1,585	1,076	20	10	20	0[c]
Beaver	9	243	409	16	0	21	1[c]
Fort Yukon	8,144	6,119	3,035	9,702	355	2,209	3,523[c]
Circle	5,308	3,707	37	2,722	0	2,588	74[c]
Central	132	0	0	0	0	0	0[c]
Eagle	14,916	14,488	543	11,292	32	2,714	339[c]
Chalkytsik	1,230	936	433	442	0	73	4[c]
Other	505	421	50	65	1	0	100[c]
Sum of harvest	32,131	28,145	5,683	28,583	398	7,808	4,041[c]
				Comparison of Rampart-Rapids estimate with the sum of escapement, harvest, and border passage			
Darroch estimate (this project)	654,296	369,547	194,963	189,741	[d]	201,766	196,186
Sum of escapement, harvest, and border passage	708,226	430,126	176,163	219,109	[d]	233,254	230,852[c]
Percent difference	-7.6	-14.1	10.7	-13.4	[d]	-13.5	-15.0[c]

[a] High water from 29 August until 3 September prevented completion of this project in 1997.
[b] Project ended early due to low water.
[c] This number should be considered a preliminary estimate of harvest pending completion of final project reports (personal communication Bonnie Borba, Alaska Department of Fish and Game).
[d] An estimate is not available in 2000 due to an early closure of the project.

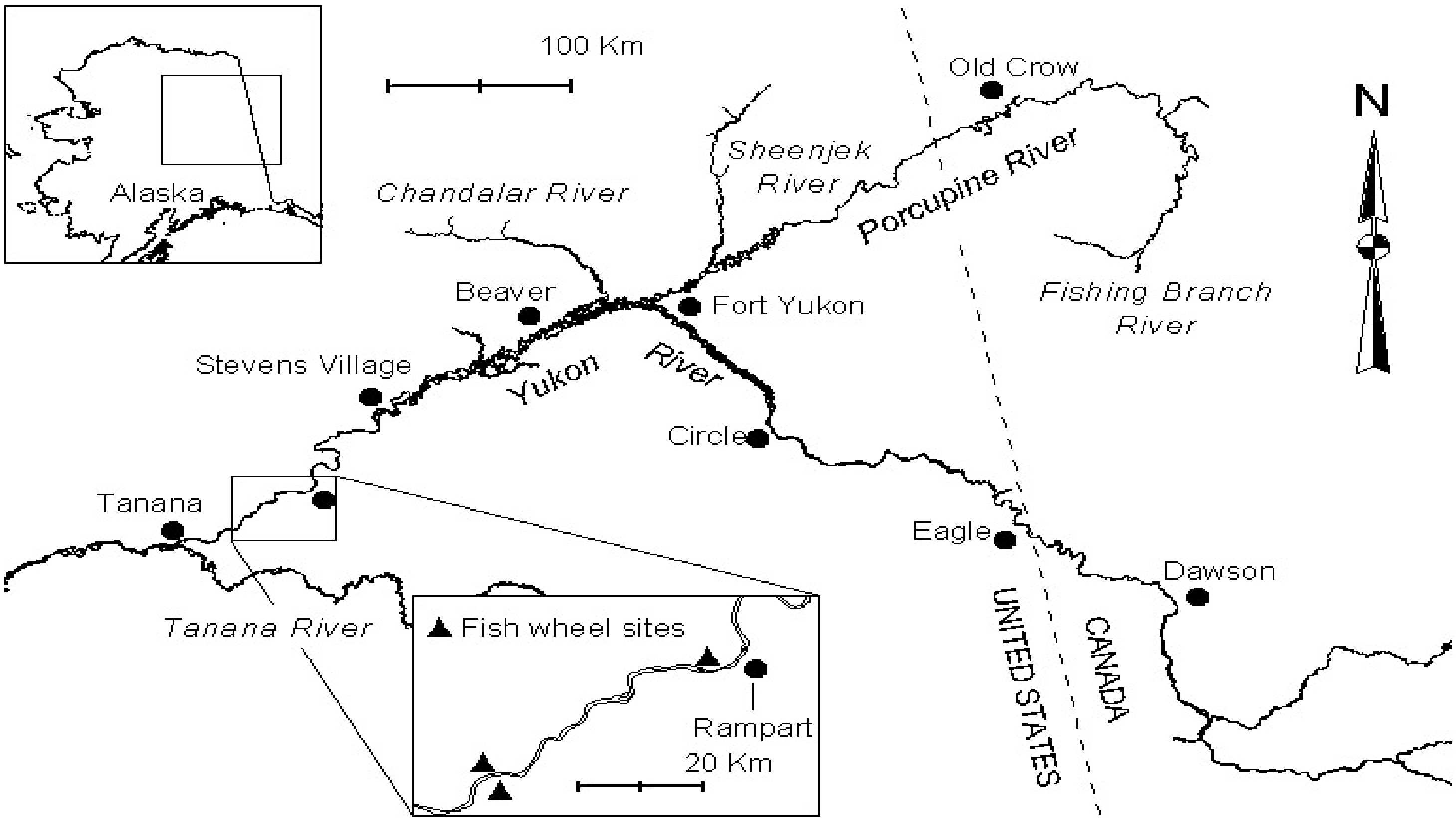

Figure 1.—Map of the Yukon River drainage with an inset of the study area. The marking and recapture fish wheels are indicated with triangles.

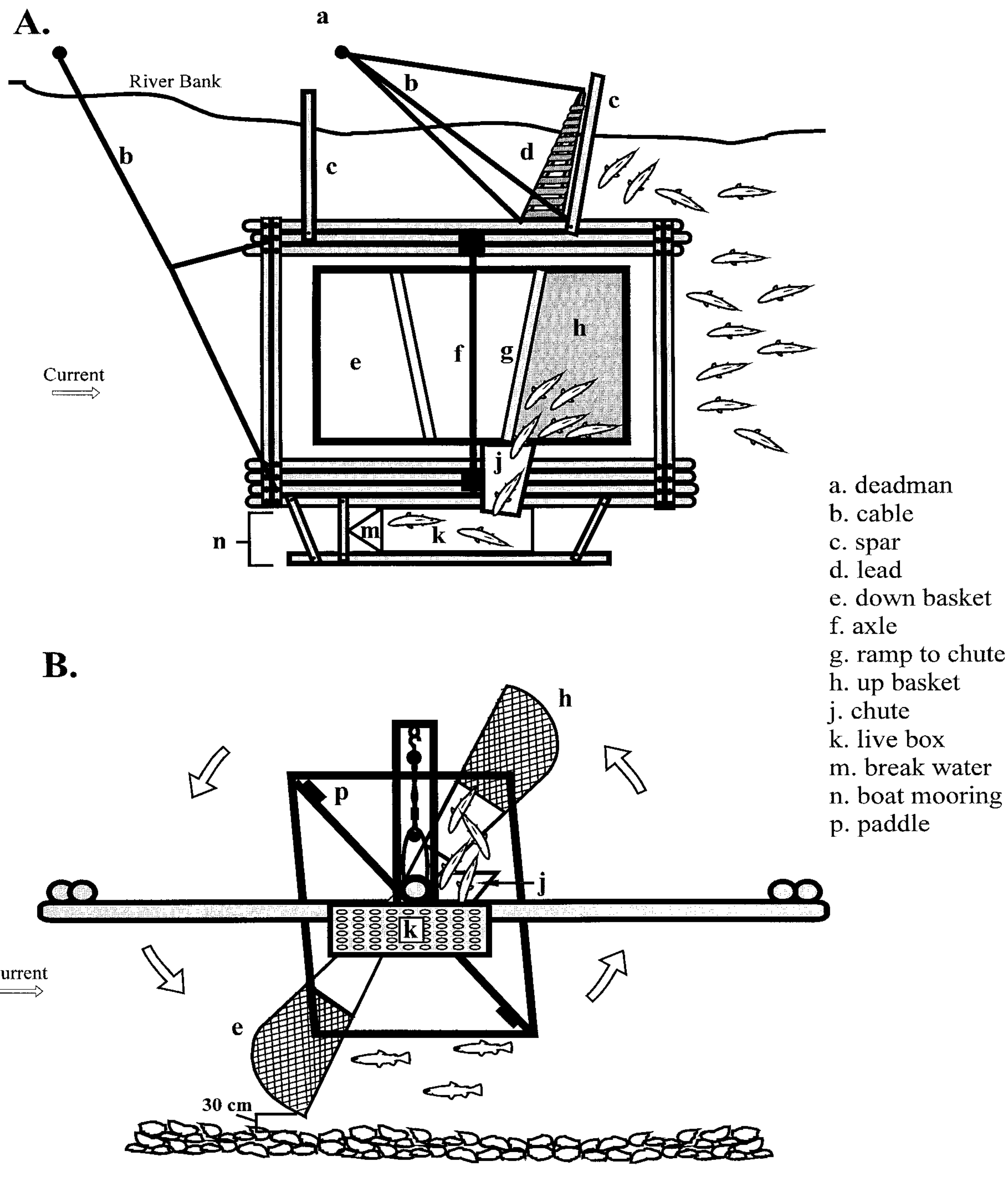

Figure 2.— Two-basket fish wheel equipped with padded chute and live-box. A. Aerial view. B. Side view with arrows indicating the direction of wheel movement in response to the current.

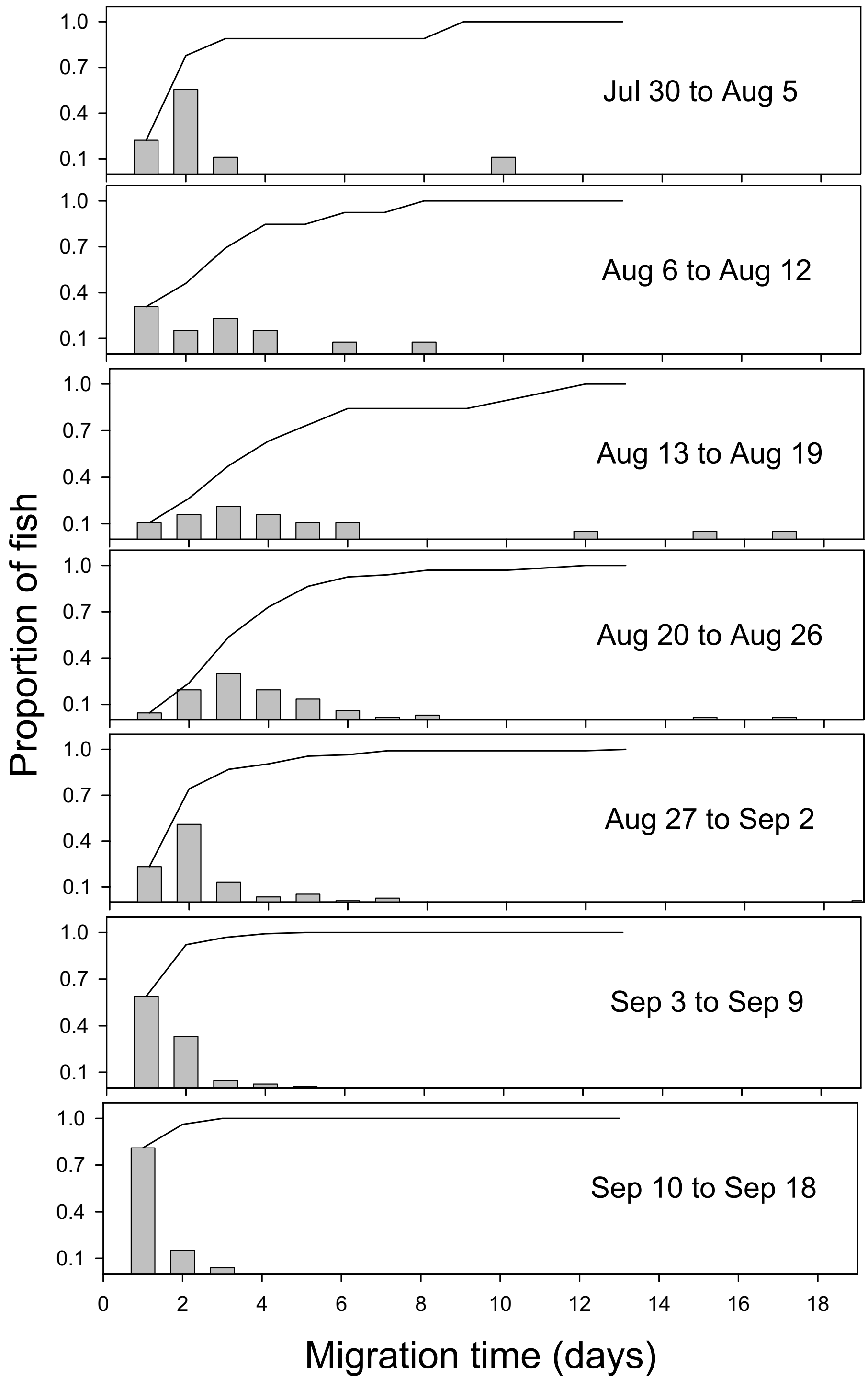

Figure 3.— Estimated migration time (days) for tagged fall chum salmon between the marking and recapture sites, by recovery stratum, on the Yukon River, Alaska, July 30 to September 18, 2002. Histograms represent proportion of recaptured fish, and the line represents the cumulative proportion.

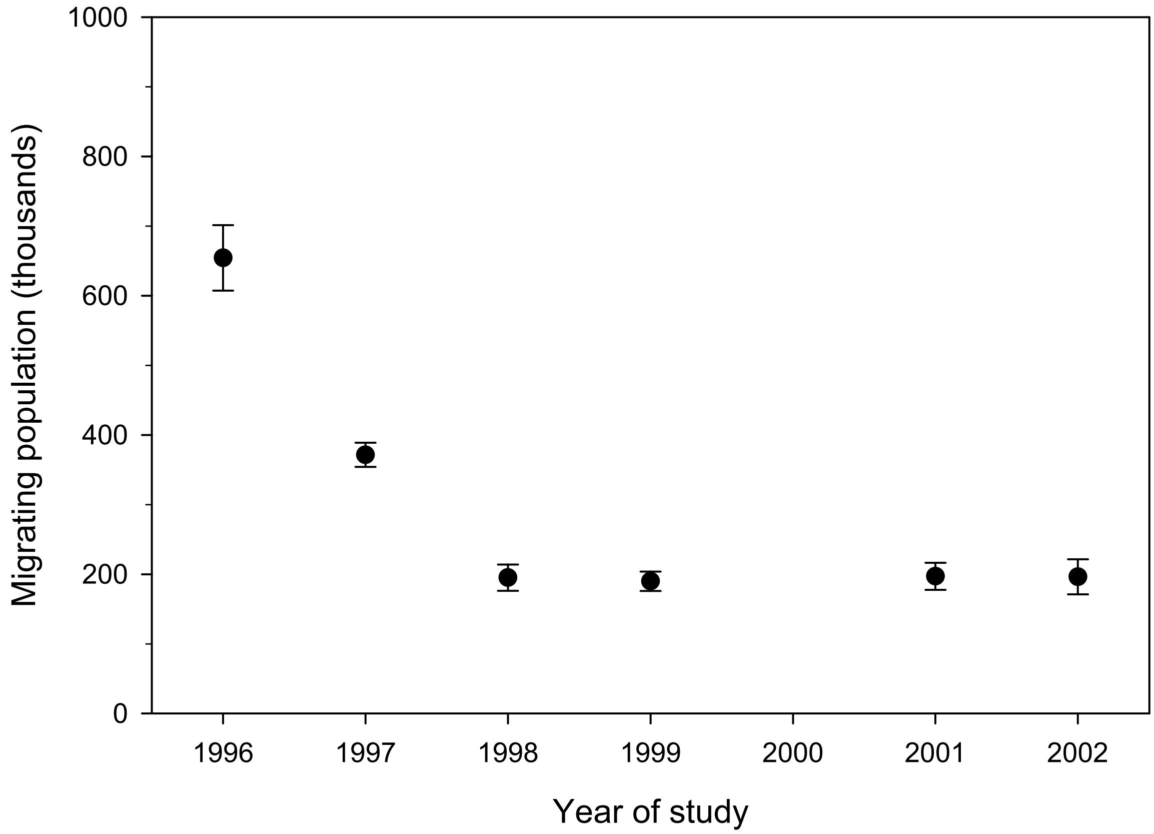

Figure 4.— Population estimates and bound confidence intervals (2 × SE) at the study site from 1996 to 2002 excluding 2000. In the year 2000 a seasonal estimate was not generated because the project ran only through August 19.