3A97-37

MARK-RECAPTURE ABUNDANCE ESTIMATE OF FALL-RUN CHUM SALMON IN THE UPPER TANANA RIVER, ALASKA, 1996

by

Thomas A. Cappiello

and

Dana L. Bruden

Regional Information Report[1] No. 3A97 - 37

Alaska Department of Fish and Game
Commercial Fisheries Management and Development Division, AYK Region
333 Raspberry Road
Anchorage, Alaska 99518

November 1997

[1] The Regional Information Report Series was established in 1987 to provide an information access system for all unpublished divisional reports. These reports frequently serve diverse ad hoc information purposes or archive basic uninterpreted data. To accommodate timely reporting of recently collected information, reports in this series undergo only limited internal review and may contain preliminary data; this information may be subsequently finalized and published in the formal literature. Consequently, these reports should not be cited without prior approval of the author or the Commercial Fisheries Management and Development Division.

AUTHORS

Thomas A. Cappiello is now an Assistant Area Management Biologist for the Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, P.O Box 1467, Bethel, AK 99559

Dana Bruden is a Biometrician for the Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, 333 Raspberry Road, Anchorage, AK 99518.

ACKNOWLEDGMENTS

We thank the following technicians who collected the tagging data: Bradley Russell, Tom McCutcheon, and Dennis Argall. We also thank the following individuals who provided and operated the project fish wheels: Charlie and Robin Boulding, Percy Duyck Jr., and Fran and Mike Turner. We thank Louis Barton for guidance and advice in carrying out this project and Jeff Bromaghin for Fortran program development and biometric support. Manuscript review was provided by Louis Barton, Jeff Bromaghin, and Larry Buklis.

PROJECT SPONSORSHIP

This study was partially funded by the Bering Sea Fisherman's Association.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

The primary objective of this study was to develop and determine the feasibility of a mark-recapture program to be used to estimate in- and postseason abundance of fall chum salmon *Oncorhynchus keta* in the upper Tanana River. This was the second year of this project. One fish wheel was used to capture chum salmon to be tagged and two additional fish wheels, each on opposite riverbanks, were used to recover tagged fish approximately 76 km upstream. All chum salmon caught during a daily 12-h schedule were marked with spaghetti tags. From 16 August through 30 September 1996, a total of 4,016 fall chum salmon were released with tags. From 18 August to 1 October, the right-bank recovery wheel caught 3,566 chum salmon, of which 74 were recaptures. During the same period, the left-bank recovery wheel caught 3,369 chum salmon, of which 113 were recaptures. Because recapture probability varied temporally, the Darroch model was used to estimate that a total of 134,563 ± 33,212 (95% C.I.) fall chum salmon passed the tagging site after 15 August. Although recapture probability was also related to length and a variable termed "condition", which indicated the presence or absence of observable physical abnormalities that might conceivably influence fish survival or susceptibility to fish wheels, insufficient data prevented further stratification. The mean migration rate between tagging and recovery sites was 31 km/d. We conclude that this mark-recapture program using fish wheels for fish capture still appears feasible, but should continue in a developmental stage to allow further evaluation of its utility under a variety of circumstances.

KEY WORDS: Yukon River, Tanana River, *Oncorhynchus keta,* chum salmon, mark-recapture, abundance, escapement, migration rate, run timing.

INTRODUCTION

Genetically distinct (Seeb et al. 1995) summer and fall runs of chum salmon *Oncorhynchus keta* return to the Yukon River drainage. Fall-run (fall) chum salmon are an important component of the commercial, subsistence, personal use, and recreational fisheries in the Yukon River drainage. A substantial portion of this run originates in the Tanana River and its tributaries. From 1985 through 1994, the annual total harvest of fall chum salmon in the Tanana River averaged approximately 74,000 fish, or about 22% of the entire Yukon River drainage harvest (Bergstrom et al. 1996). However, contribution of Tanana River stocks to the lower Yukon River fisheries harvest is unknown.

Summer-run (summer) chum salmon arrive in the Tanana River in early July and finish migrating in mid to late August. Spawning takes place in runoff tributaries during August. The fall run begins to enter the Tanana River by mid August, with peak migration generally occurring in mid-September. The fall run continues well into October when freezing temperatures and icing conditions limit fishing activity on the river. Tanana River fall chum stocks spawn from early October through November, primarily in areas where upwelling ground water keeps the spawning substrate relatively ice-free in most years. This specific site selection allows spawning under frigid air temperatures, but the limited spawning area available strongly influences population levels (Buklis and Barton 1984). Tanana River fall chum salmon are generally larger, have a higher oil content, and are a more desirable food resource than summer-run chum salmon.

Alaska Department of Fish and Game (ADF&G) manages the fisheries in the Alaska portion of the Yukon River drainage. The lower portion of the Tanana River drainage is one of six Yukon River drainage management districts and is further divided into four subdistricts (6-A through 6-D; Figure 1). Summer- and fall chum salmon are managed as separate stocks by regulatory season. In District 6 the fall chum salmon season begins on 16 August. Despite some mixing of the two runs, all chum salmon are considered fall after this date for inseason management purposes. Subsistence and personal use fisheries are normally open for two 48-h periods per week. The commercial fishery, which is opened by emergency order for no more than one 42-h period per week (24 h per week in subdistrict 6-A), has a guideline harvest range of 2,750 to 20,000 fish. This guideline may be exceeded if escapement goals and subsistence needs are not jeopardized. Management tends to be conservative because existing tools are insufficient to provide inseason assessments and projections of run strength and timing.

Currently, ADF&G uses catch per unit effort from "test" fish wheels and fishery performance data to assess inseason run strength in the Tanana River. Test fish wheels must have intra- and interannual fishing consistency to be reliable and useful management tools. This needed consistency, which depends on a number of factors including fish wheel location and structure, is often undermined by changes in water level and river topography, and damage to the fish wheel by drifting debris. Even under ideal conditions, management must be prudent when relying on run indicators that must be interpreted relative to an historical database of index information.

The magnitude and distribution of fall chum salmon spawning in the Tanana River are not well known, largely due to drainage size (115,250 km^2), glacial turbidity, and wintry conditions during spawning. Escapements in two known spawning areas, the Toklat and Delta Rivers, are estimated annually. Counts of spawners obtained during ground and aerial surveys in these rivers are the primary indices used to assess the relative abundance of fall chum salmon in the Tanana River drainage. ADF&G has established minimum escapement goals for fall chum salmon of 33,000 in the Toklat River and 11,000 in the Delta River. Spawning chum salmon are also counted during ground and aerial surveys in the upper Tanana River mainstem (upstream of the Kantishna River), and in a few other tributaries, but these data are not relied on as heavily for run indexing. A sonar project in the Toklat River, a tributary of the Kantishna, was started in 1994 to develop a more complete and timely escapement assessment for that spawning area. Although existing projects in the Toklat and Delta Rivers and various other sites provide useful escapement information for specific stocks, there are no programs that assess fall chum salmon abundance for the entire Tanana River drainage.

Accurate escapement estimates are needed for making run projections used for managing various fall chum salmon fisheries in the lower Yukon River. Since 1985, the United States and Canada have been negotiating to develop coordinated conservation and management of Yukon River chinook *O. tshawytscha* and fall chum salmon stocks which spawn in the Canadian portion of the Yukon River drainage. Tanana River harvest and escapement estimates are important for assessing the relative timing and abundance of Alaskan and Canadian stocks in the lower Yukon River.

Buklis (1981) reported on tagged fall chum salmon from right- and left-bank fish wheels located near Manley Hot Springs. Tag returns from the subsistence and commercial fisheries were used to estimate abundance. The Petersen abundance estimate, which included Kantishna River stocks, was 676,241 in 1979 and 383,770 in 1980. Buklis concluded that these estimates, although affected by some assumption violations, were positively biased because they were 253% and 125% higher than the observable population (total harvest plus escapement indices). A non-user-configurable sonar unit, typically used to assess salmon abundance in comparatively shallower and much smaller tributary streams, could not be used successfully in the Tanana River at Fairbanks in 1981 (Buklis 1982). Potential problems encountered were a paucity of sites suitable for the sonar gear, shifting silt, high amounts of debris, and unsuitable conditions for accurately assessing species composition. A dual-beam, user-configurable sonar system was used in the Tanana River near Manley Hot Springs between 16 July and 3 August of 1990. The initial indications were favorable for feasibility (LaFlamme 1990); however, that project was not continued in subsequent years. Barton (1992) used radiotelemetry in 1989 to identify spawning areas in the upper Tanana River and estimated 121,556 ± 45,107 (95% C.I.) fall chum salmon upstream from Fairbanks; the Delta River component represented between 11% and 24% of the total. He concluded that in at least some years mainstem spawning areas collectively represent a more substantial proportion of fall chum salmon spawning escapement than was previously thought.

This study began in 1995 with the intent to develop a mark-recapture program for providing in- and postseason abundance estimates of fall chum salmon in the Tanana River, upstream from the mouth of the Kantishna River. The objectives of this study were to: (1) develop and determine the feasibility of a mark-recapture program that can be used to estimate inseason and postseason abundance of fall chum salmon in the Tanana River upstream from the mouth of the Kantishna River, (2) estimate migration rates, and (3) determine the run timing of spawning stocks in the Delta River and proximal mainstem areas. A successful mark-recapture program would provide a reliable quantitative and predictive tool for making fishery management decisions that affect the status of fall chum salmon in the Tanana River.

In the 1995 field season, two tagging wheels and two recovery wheels were operated on the Tanana River (Cappiello and Bromaghin 1997). Fish from the right-bank tagging wheel were marked with orange tags and from the left bank with yellow tags. A series of statistical tests were used to test the assumptions of a non-stratified mark recapture estimate. No bank orientation was found and the proportion of marked fish in the recovery wheels remained relatively constant throughout the study period. Left bank tags had a higher recovery rate (8.8%, n = 181) than right bank tags (3.5%, n = 3,993) and they did not appear to be deployed in proportion to run abundance or catch. Because no cause could be determined for the higher recovery rate, they were treated as untagged fish in the analysis. Logistic regression was used to test if the probability of recapture was a function of sex, length and condition, and no relationship was found. Because all of the assumptions were met in 1995, the Bailey closed-population estimator (Seber 1982) was used with a resulting estimate of 268,173 ± 42,330 (95% C.I). With commercial and subsistence harvest estimates subtracted, the point estimate for potential escapement in the upper Tanana River in 1995 was 183,267 fall chum salmon.

Cappiello and Bromaghin (1997) recommended that the mark-recapture program be evaluated under different circumstances from 1995, particularly during lower run sizes. Evaluation of the program is expected to continue through the 1997 field season. In 1996, one tagging wheel and two recovery wheels were operated at approximately the same locations as in 1995. The Bailey estimator was again used to provide inseason abundance estimates of fall chum salmon in 1996. To increase the precision of the abundance estimate, the tagging schedule was increased from 6-h/d in 1995 to 12-h/d in 1996 in order to tag a larger proportion of the chum salmon run.

METHODS

Fish Capture

Tagging Phase

One tagging wheel, located on the right bank, was operated during the 1996 season (Figure 2). This location was the more productive of the two sites used in 1995 (Cappiello and Bromaghin 1997). A private contractor provided and maintained the fish wheel, which operated continuously from 16 August through 30 September except when repairs were being made or debris was being removed. Fish captured by the fish wheel were retained in an attached live box.

The tagging crew operated for a 12-h period, from 0800 to 2000 hours each day. Every day prior to the tagging schedule, all fish caught overnight were removed from the live box with a dip net, identified by species, and counted. The tagging crew then checked the live box at least three times per day during the tagging schedule. All chum salmon caught during the 12-h daily schedule were measured from mid eye to fork of tail (MEF) to the nearest 5 mm, and marked with individually numbered 30.5-mm spaghetti tags. The right pelvic fin was clipped to permit assessment of tag loss. Physical aberrations potentially detrimental to the survival or swimming ability of the fish were briefly described in a notebook. The sex of all salmon species was determined by inspection of external characteristics.

Recovery Phase

Right- and left-bank fish wheels, located approximately 76 km upstream from the tagging wheel and 24 km downstream from Nenana, were used to sample chum salmon for tags. Each wheel had an attached live box. The recovery wheels were 1.6 km apart and were operated by private contractors. Since 1988, the right-bank wheel has been used by ADF&G as a test fish wheel for indicating inseason timing and relative run strength of summer- and fall chum salmon. Recapture efforts for both wheels began 16 August and ended 2 October. Recovery wheel operators removed all fish from the live boxes at least twice daily. Fish were identified by species and counted, and the sex of all salmon was determined from external characteristics. All chum salmon were inspected for tags and a clipped pelvic fin, and the tag number of all tagged fish was recorded. Recovery wheel operators released all fish, except during commercial or subsistence fishing periods when they were allowed to retain fish with the proper permit.

Volunteer tag recoveries by fishermen were encouraged by their becoming eligible for a $200 drawing (one winner). Volunteer recoveries were primarily used for qualitative information about migration. Additional recoveries were made by ADF&G personnel conducting ground surveys of selected spawning areas. Tag recoveries from spawning grounds provided run timing information.

Data Analysis

Migration Rate

Travel time between tagging and recovery wheels was determined to the nearest day for all recaptures by subtracting the date the fish was tagged from the date of its first recapture. A Kolmogorov-Smirnov test (Conover 1980) was used to test the hypothesis that the distribution of travel time was the same between male and female fish. The migration rate was calculated for each recaptured fish by dividing the distance between the tagging wheel and the wheel of recapture (Appendix B) by travel time.

Diagnostic Statistical Tests

A series of statistical tests were used to test mark-recapture model assumptions. The significance level for all tests was $\alpha = 0.05$. Most mark-recapture models assume that fish have equal probabilities of being captured in at least one capture event. Fish wheels are often thought to selectively capture fish based on physical characteristics, such as size or sex. The presence of unequal capture probabilities would require the use of a stratified abundance estimator. A variable termed "condition", which indicated the presence or absence of observable physical abnormalities that might conceivably influence fish survival or susceptibility to fish wheels, was recorded at the tagging wheel. Logistic regression (Hosmer and Lemeshow, 1989) was used to model the probability of recapture as a function of the variables sex, length, and condition. Sex and condition were coded as indicator values having the value 0 or 1. Although the lack of information from all chum salmon caught in the recovery wheels would have hampered stratification, knowing if unequal recapture probabilities were a possible source of bias was useful for continuing to determine the feasibility of the tagging project.

The tagging schedule was designed to capture and tag fall chum salmon proportional to run size, which would satisfy an assumption of many mark-recapture models. The degree to which this objective was achieved is difficult to assess directly; however, if the objective was achieved, then the proportion of the recovery wheel catch bearing tags, termed marked proportion, should be constant over time. Although a chi-square test of homogeneity could be used to test the hypothesis that the daily marked proportion was constant over time, many of the observed proportions were quite small and the distribution of the test statistic may be poorly approximated by a chi-square distribution. For that reason, simulation techniques were used to estimate the distribution of the test statistic. A FORTRAN program (RANDTEST, Jeff Bromaghin, Alaska Department of Fish and Game, Anchorage) was developed for the simulation. Given the hypothesis that the marked proportion was constant over time, it was estimated as the ratio of the total number of marked fish captured in the recovery wheels during the entire study period to the total number of fish captured (both marked and unmarked) in the recovery wheels during the entire study period. The simulation consisted of randomly generating daily numbers of recaptured fish, as a binomial random variable, given the number of fish examined for tags each day and the assumed constant marked proportion. A total of 10,000 such data sets were randomly generated, and a chi-square test statistic was computed for each data set. The *P*-value of the test was estimated as the proportion of the randomly generated test statistics that exceeded the value of the test statistic computed from the observed data.

The daily proportion recaptured (proportion of tagged fish released at the tagging wheels that were subsequently recaptured in the recovery wheels) was used to test the assumption of a constant probability of recapture in the recovery wheels. Under the hypothesis that the proportion recaptured was constant over time, it was estimated as the ratio of the total number of recaptures in the recovery wheels during the entire study period to the total number of tagged fish released at the tagging wheel during the entire study period. The same test statistic described above, implemented in the program RANDTEST, was used to test if the proportion recaptured was constant over time.

Abundance Estimate

The Bailey closed-population model for sampling with replacement (Seber 1982) was used to provide inseason estimates. Because we were continuing to evaluate the validity of mark-recapture model assumptions in 1996, final model selection for the abundance estimate depended on post-season evaluation of the data and is presented in detail in the results. Inseason, the daily number of tags deployed was decreased by 5% to allow for a tagging-induced mortality. True mortality caused by tagging and handling are unknown and inestimable under the circumstances of this study. By assuming a 5% decrease in the number of fish tagged, we attempted to compensate for closure violations that affected only the tagged fish. Milligan et al. (1984) assumed a 10% mortality, based on radiotelemetry results, for estimating abundance of fall chum salmon tagged with spaghetti tags in the upper Yukon River. We thought 10% was too high for our situation. Barton (1992) reported that 5.2% of radio-tagged fall chum salmon in the Tanana River near Fairbanks did not proceed upstream.

Stock Timing

Chum salmon spawning in the Delta River were counted during weekly ground surveys. Spawning areas in the Tanana River, Bluff Cabin Slough and Rika's Roadhouse, were surveyed from the ground at least once during peak of spawning. Tags were retrieved to estimate the median date these tagged fish passed the tagging wheel site.

RESULTS

Fish Capture

Tagging Phase

The tagging wheel caught 6,669 chum salmon of which 4,016 were released with tags (Appendix A.1). Wheel effort was interrupted during the tagging schedule for 2 h each on 25 and 26 August. The wheel was moved away from the bank on 6, 22 and 26 September in response to declining water levels. The daily percent of the total catch that was tagged ranged from 33 to 80% with a mean for days with 24 h of effort of 61% (Figure 3). Catch per hour of effort (CPUE) dropped steadily from 16 to 24 August reaching a minimum on 24 August (Figure 4). CPUE began to increase markedly on 4 September, and reached a peak on 20 September. Tagging wheel CPUE closely reflected the recovery wheels CPUE until 3 September. From 4 September through the end of the study the tagging wheel CPUE was higher than the CPUE in either recovery wheel CPUE.

Recovery Phase

The right-bank recovery wheel caught a total of 3,566 chum salmon of which 74 were recaptures (Appendix A.2). Of these recaptures, two were fish that had been previously recaptured in the right-bank recovery wheel. Wheel effort was interrupted for 12 h on 23 September due to low water levels. Catch trends of the right-bank recovery wheel were similar to the left-bank recovery wheel (Figure 4).

The left-bank recovery wheel caught a total of 3,369 chum salmon of which 113 were recaptures (Appendix A.3). Of these recaptures, five were fish previously caught in a recovery wheel; three in the right-bank wheel and two in the left-bank wheel. Fishing effort was continuous throughout most of the recovery period. The wheel was moved away from the bank on 11 September because of declining water levels. CPUE began relatively high, dropped during the latter part of August and the beginning of September and then reached a peak again on 18 September (Figure 4).

A total of 327 tags were returned by various fisheries participants, ADF&G personnel, and other entities (Table 1). Of all the tag returns, 183 were from spawning fish in the Delta River. Some of the tags were found in various locations downstream from the tagging site; six from the Kantishna River, eight from the Toklat River, and three from the Yukon River.

Data Analysis

Migration Rate

Travel time was computed as the number of days between marking and subsequent first recapture. Travel time for all first-time recaptures ranged from 1 to 15 d (Figure 5) with a median of 2 d (n = 176). Some slower fish marked during the final stages of the study did not have an opportunity to reach the recovery wheels while they were operational. Inclusion of the fish that were marked in the final week of capture that did reach the recovery wheels would negatively bias travel times estimates. Consequently, fish that were marked after 24 September were not considered for estimation of travel time. Because the recovery wheels operated two days later in the season than the tagging wheel, all fish remaining in the data set had at least eight days to reach the recovery wheels. The 15-d travel time for one fish indicates that not all bias was eliminated, but removing fish marked in the last 13 days of tagging operations would have substantially reduced the sample size.

The final distribution of travel times had a range from 1 to 15 days (mean = 2.8 d; median = 2 d, n = 158). There was no significant difference in the frequency distribution of travel time between male and female tagged fish (Kolmogorov-Smirnov, $P \approx 0.2800$). Therefore, data for both sexes were pooled (Table 2). There were no visually discernible trends in travel time during this study (Figure 5). The mean migration rate, calculated for fish tagged prior to 25 September that were subsequently recaptured, was 31.4 km/d.

Diagnostic Statistical Tests

The following tests examined whether the probability of recapture was constant through time or whether it was a function of fish length, sex, and condition. The probability of recapture for a fish marked in the last days of the tagging operations was affected by the number of days that it had to reach the recovery wheels while they were operational. A fish marked on 30 September that took three days to travel upstream had zero probability of recapture because it passed the recovery wheels on 3 October, after operations had ceased. Analysis was restricted to fish that were marked on days that all fish had a high probability of reaching the recapture site before operations ceased. Consequently, fish marked after 24 September were removed from the analysis of the probability of recapture.

A binomial test (Snedecor and Cochran 1989) was used to test the hypothesis that the marked proportion (including multiple recaptures) was equal between the two recovery wheels. This test was significant ($z = 3.5265$, $P \approx 0.0004$) with the left-bank recovery wheel having a higher proportion (3.8%) than the right-bank recovery wheel (2.3%). Although the test was significant, sample sizes were relatively large (n = 3,262 for right wheel, n = 2,980 for left wheel), and the proportions were judged to be equivalent from a practical point of view.

However, the significance of this test will be considered in the continuing evaluation of the feasibility of this project.

A logistic regression model (Hosmer and Lemeshow 1989) was used to model the probability of recapture as a function of the predictor variables sex, length, and condition using the Statistical Analysis System LOGISTIC procedure (SAS Institute 1988). A total of 3,434 fall chum salmon were tagged at the right-bank tagging wheel and 158 of these were subsequently recaptured (not including multiple recaptures and those marked in the last six days of the tagging operations) with complete information of the predictor variables. All possible interaction terms among the three predictor variables were included in the model. Terms remained in the model if the Wald test statistic was significant. A likelihood-ratio test of the hypothesis that none of the remaining variables or interaction terms influenced the probability of recapture was significant ($P \approx 0.0001$). Sex ($P \approx 0.0444$), condition ($P \approx 0.0033$), length ($P \approx 0.1895$) and a sex by length interaction ($P \approx 0.0314$) remained in the final model. Length remained in the model because of the significant sex by length interaction. The logistic model and observed data for good and bad condition males and females are shown in Figures 6 and 7. The probability of recapture tends to increase as length decreases. The sample sizes (n) and number of recaptures (r) were small for bad condition males ($n = 147$, $r = 13$) and females ($n = 143$, $r = 11$). Although the model slope for good condition males was near zero, the probability of recapture of good condition females increased as length decreased (Figure 7).

Under the hypothesis that the marked proportion (proportion of recovery wheel catch bearing tags) was constant over time, it was estimated as the ratio of the total number of marked fish to the total number captured, 187/6,242 = 0.02996. Because many of the observed marked proportions (Figure 8) were at or close to zero, simulation techniques described previously were used to estimate the distribution of the test statistic. A chi-square test statistic was computed using the observed data and the estimated marked proportion, resulting in a test statistic of 110.47 (45 df). The proportion of the randomly generated test statistics that exceeded the value of the test statistic computed with the observed data was 0.0001, which is an estimate of the *P*-value associated with the test statistic. Given the high significance of the test, the marked proportion could not be assumed constant through time.

Under the hypothesis that the proportion recaptured (proportion of tagged fish released at the tagging wheel that were subsequently recaptured) was constant over time, it was estimated as the total number of recaptures to the total number of marked fish released, 158/3,442 = 0.0459. Multiple recaptures and fish marked after 24 September were excluded from the data set for this test. Again, because many of the observed proportions are at or close to zero (Figure 9), the same simulation technique was used to estimate the distribution of the test statistic. A chi-square test statistic was computed using the observed data and the estimated proportion recaptured, resulting in a test statistic of 47.46 (39 df). The proportion of the randomly generated test statistics that exceeded the value of the test statistic computed with the observed data was 0.1715, which is an estimate of the *P*-value associated with the test statistic. This result indicates that the probability of recapture was relatively constant through time.

Abundance Estimate

The series of statistical tests above showed that there was a need for stratification for an unbiased abundance estimate. Although the logistic regression pointed to a need to stratify by condition, sex and length of fish, the data are insufficient to do so. Failure to meet the assumption of equal proportions of marked fish in the recovery wheels through time suggested a need for a stratification through time, particularly when the cause of the change could not be identified. For this reason, the Darroch estimator for stratified populations (Darroch 1961) was used with strata defined in time. The Darroch estimator conditions on the number of tags released in each stratum, so the assumption of tagging in proportion to abundance of the run is not needed.

The notation used here follows Darroch (1961). Subscript i refers to the tagging sample stratum and subscript j refers to the recovery stratum. Let a_i = the number of tagged fish released in stratum i, c_{ij} = the number of tagged fish released in stratum i that are recaptured in the recovery stratum j, and let b_j = the number of untagged fish captured in recovery stratum j. The stratified estimate of the number of unmarked fish in the population ($\hat{n}$) was

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

where b is a vector with elements b_j, C is a matrix of the c_{ij}, and a is a vector with elements a_i.

The Darroch estimator is not designed to accommodate multiple recaptures of individual fish. Therefore, only unique recaptures were considered in this analysis (n = 176). The proportion of marked fish that had multiple recaptures was 7/183 = 0.038. Because marking all fish in the recovery wheel was not practicable, no data are available to estimate the probability that an unmarked fish would have multiple recaptures. Based on the assumption that the same proportion of the unmarked and marked captures in the recovery wheels are multiple recaptures, the daily number of unmarked fish at the recovery wheel ($\mathbf{b}_j$), was reduced 3.8%. We felt the assumption was reasonable, given that obtaining the tag number from recaptures requires a small amount of additional handling.

Tagging began on 16 August and we used data from the recovery wheels beginning on August 18, the day of the first recapture. Based on the distribution of travel times (Table 2), we assumed that some of the unmarked fish captured in the recovery wheels between 18 and 23 August passed the tagging wheel before it was operational. The capture of unmarked fish in the recovery wheels that did not pass the tagging wheel while operational is a violation of the closure assumption, and would positively bias the abundance estimator. For that reason, a method to subset the data was adopted.

We used the distribution of travel times to remove a proportion of the unmarked fish between 18 and 23 August. For each day, the number of unmarked fish was multiplied by the appropriate cumulative frequency, which resulted in a final vector of the daily number of unmarked fish captured in the recovery wheels ($\mathbf{b}_j$s; Table 3). We assumed that the distribution of travel times of marked fish was an accurate representation of the distribution of travel times of unmarked fish. This assumption is not testable and it could be that marked fish have longer travel times than unmarked fish because of a need to "recover" from the tagging process. However, the travel times of marked fish are the only information available to estimate the proportion of unmarked fish early on in the recovery wheel catches that passed the tagging wheel location while it was operational.

Tagging ended on 30 September and recovery efforts ended on 2 October. Similar to the unmarked fish at the beginning of the study, a proportion of the fish tagged between 25 and 30 September did not pass the recovery wheels before the study ended. Using the distribution of travel times again, the number of tagged fish released between 25 and 30 September was reduced ($\mathbf{a}_i$s; Table 3). Additionally, the number of fish released with tags was reduced by an assumed mortality rate of 5%.

The length of the time strata was determined by the requirement that the **C** matrix be nonsingular and our desire that strata be of approximately equal length. The tagging and recovery strata are defined in Table 4. The data used in the final Darroch estimate are shown in Table 5.

The final estimate of the number of unmarked fish ($\hat{n}$) was 130,794 which when added to the mortality-adjusted number of marked fish, 3,769, resulted in a final abundance estimate of 134,563 ± 33,212 (95% C.I.). Beginning on 15 September, daily estimates, using the Bailey estimator for populations with replacement, were provided to managers. The commercial fall chum harvest in the Tanana River subdistricts 6-B and 6-C was 16,640 (Busher 1997) and the preliminary subsistence and personal use harvest in the same subdistricts was 34,476 (K. Schultz, personal communication, ADF&G, Fairbanks). With these harvest estimates subtracted from the abundance estimate, the point estimate of the potential escapement in the upper Tanana River was approximately 83,447 chum salmon.

Stock Timing

A total of 183 tags were recovered from spawning chum salmon in the Delta River during October and November. Nine tags were recovered from spawning fish in Bluff Cabin Slough and nine tags were recovered from fish in the Tanana River near Rika's Roadhouse. The tag deployment dates from the Delta River recoveries ranged from 23 August to 29 September (median = 14 September; Figure 10). The median dates of passage for the mainstem spawning stocks near Rika's Roadhouse and Bluff Cabin Slough were not calculated due to the low sample sizes.

DISCUSSION

The logistic regression analysis indicated the recovery wheels may have been selective for smaller fish. These data pointed to a possible need for stratification by sex and size which could not be incorporated into the analysis because the length of fish was not recorded at the recovery wheels. However, the results of the logistic regression may have been confounded by temporal trends in probability of recapture. For example, smaller fish may have had a tendency to pass by the recapture wheels during a time when the probability of recapture was larger due to other factors, i.e., water level or changing abundance of fish in the river. Logistic regression results from the 1995 study did not indicate a need for stratification (sex, length and condition were not significant in the model). We will continue to test data for gear selectivity, and if subsequent data indicate a need for stratification, options for collecting sex-length data at the recovery wheels or modeling the capture probability as a function of sex and length will be explored.

The marked proportion of recovery-wheel catches was higher in the latter half of the study period (12 September to 2 October) than the first half (18 August to 11 September). This increase in the marked proportion was likely caused by a change in the efficiency of the tagging wheel. The tagging wheel appeared to have gained in efficiency in comparison to the recovery wheels in early September. Possible causes of efficiency changes include repositioning of the wheels, changing water levels and changing abundance of fish in the river. Because several possible causes were present, direct effects could not be ascertained.

We used the Darroch model for a final abundance estimate primarily because of temporal differences in the proportion of marked fish at the recovery wheels. Temporal stratification can accommodate variation in capture probabilities due to wheel efficiency, movement of the wheel or water level. The number of fish recaptured is conditioned on the number released so the assumption of marking in proportion to run abundance is not needed. Although the model accounts for differential capture probabilities through time, the differential capture probabilities by sex, condition, and length are not specifically accounted for in the model.

An assumption of the Darroch model is that all animals released within each tagging strata have the same probability distribution of moving to the different recovery strata. This assumption was not met in our study. A fish released towards the end of a tagging strata would have a much higher probability of moving into the next recovery strata than a fish released at the beginning of that tagging strata. This effect is reduced as strata lengths decrease, and , for that reason, we used the shortest possible strata that produced a nonsingular recapture matrix. Also implicit in the model is that fish within a tagging strata move and are caught independently from one another. Darroch (1961) showed that violations in the assumption of independent movement do not affect the consistency of the estimator.

Another assumption of all mark-recapture models is that there is no tag loss. In this study, the right pelvic fin was clipped as a secondary mark to examine this assumption. Because all recaptures had both a spaghetti tag and a fin clip, tag loss does not appear to be a problem in this study. In 1995 only one fish was recognized as having lost a tag.

The abundance estimate in this study represents the number of chum salmon that passed the tagging site between 16 August and 30 September, 1995. An inestimable number of fall chum salmon migrated up the Tanana River after 30 September. As indicated by tag returns, the abundance estimate may have included some fish that migrated to the Kantishna and Toklat Rivers or migrated to downstream areas such as the Yukon River. In addition, some fish were harvested between the tagging and recovery sites. Although these events violate the assumption of closed-population models, closure violations that occur with equal rates among marked and unmarked fish do not bias the abundance estimate (Seber 1982). We feel that it is reasonable to assume there will inevitably be marked and unmarked fish that alter their migration route once they pass the tagging wheel site. This should not be confused with the 5% mortality rate we used to account for fish that died or ceased migration due to the capture and handling process at the tagging wheel. Also, in our estimation procedure the probability of survival was assumed constant for all strata. The total abundance estimate refers to the population size at the time of the first sample, in this case at the tagging wheel site.

Although a midseason abundance estimate was obtained and provided to managers, its utility to predict overall run strength still relied on run timing information, which is a variable that should be considered if and when the midseason estimate is used for future management decisions.

The mean migration rate obtained in our study (31.4 km/d) was similar to the 30.5 - 35.7 km/d that was reported by Milligan et al. (1984) for fall chum salmon in the upper Yukon drainage, Canada. Buklis and Barton (1984) estimated a slightly higher rate, 37 km/d, by using mean date of passage at various locations on the lower Yukon River. Brock (1976, as cited by Buklis and Barton 1984) estimated a migration rate of 28.4 km/d for fall chum salmon in the Yukon River near Dawson. The migration rate between tagging and recovery wheels in 1995 was 26 km/d (Cappiello and Bromaghin 1997). Because of a number of factors that may affect migration rates, i.e. water levels, distance from spawning grounds, handling techniques, sample size, the difference in migration rates between the two years of our study is probably not biologically significant.

Tag recoveries from spawning chum salmon in the Delta River suggested that the run timing midpoint of this stock at the tagging site was 14 September, the same as in 1995. This midpoint of the Delta River stock appeared to be earlier relative to tag deployment than in 1995; however, the number of tags returned from the Delta River in 1995 (n = 39) was much lower than in 1996 (n = 183). Run timing for the Rika's Roadhouse and Bluff Cabin Slough spawning stocks was not adequately assessed due to the low number of tags recovered and the limited number of ground surveys.

RECOMMENDATIONS

Sex, length and condition influenced the probability of recapture in 1996, unlike in 1995. If the 1997 data continue to indicate that there are differential recapture probabilities, collection of additional data at the recovery wheels may be necessary for an unbiased abundance estimate. If collection of additional data is not possible, simulations could be conducted to determine the extent of the bias of the Bailey and/or Darroch estimate when differential capture probabilities exist. Also, more investigation into modeling the recapture probability as a function of covariates is warranted if this aspect of the data continues to appear.

Although the Bailey closed-population estimator is the most practical for midseason abundance estimates, it may be biased to an unknown degree if the marked proportion and/or probability of recapture is changing through time. As an example, the final estimate for 1996 using the Bailey estimate was 127,256; approximately 7,000 fish lower than the Darroch estimate. The utility of this project as management tool to provide inseason abundance estimates will depend on a timely analysis if and when stratification is required. The program SPAS (Stratified Population Analysis System) developed by Arnason et al. (*In Press*) can be utilized by project personnel to analyze data when there is a need for stratification.

The recommendation after the 1995 season was to increase the tagging effort to increase the proportion of marked fish in the sampling design. In 1995, with a 6-h tagging schedule each day, 4,174 fish were tagged, with 3,993 of those being marked at the right bank. In 1996, with only the right-bank wheel operating on a 12-h tagging schedule, 4,016 fish were tagged. Twice the tagging effort at the right bank in 1996 resulted in approximately the same number of tags as 1995 probably because of the decreased abundance of the run, an estimated 268,173 in 1995 and 134,563 in 1996. The overall proportion marked in 1996 (3.0%) was approximately double that of 1995. The expanded tagging schedule in 1996 helped to keep the CV of the estimate low (0.12), despite the smaller run size. We recommend that the tagging schedule be maintained at the maximum possible number of hours.

Increases in the marked proportion in the recovery wheels might be due to declining water level or changing abundance of fish in the river. Changes in wheel location, even minor, could also change catch efficiency. Once a good location is found for the tagging wheel, attempts should be made to maintain its position and catch efficiency as much as possible. This is particularly important to maintain the accuracy of the inseason abundance estimates if the Bailey model is to be used.

As was recommended from the 1995 study, this project should continue to use two fish wheels for tag recovery. The left-bank recovery wheel will probably be less productive than the right bank wheel, but it will increase sample size and help reduce variance. Use of two wheels will also help maintain recovery effort if one of the wheels becomes disabled.

The results of this study in 1995 and 1996 indicated that a mark-recapture program, using fish wheels for fish capture, is feasible for a reasonably precise abundance estimate of chum salmon in the upper Tanana River. However, before this program is fully accepted as a reliable annual management tool, its performance as a function of run size, water levels and other factors should continue to be evaluated. The 1996 season provided an opportunity to evaluate the program at a very different run size and water conditions than observed in 1995. The CV of the estimate (0.12) was reasonable in 1996 despite the need for temporal stratification, although the effect of potential size, sex, and condition selectivity of the fish wheels was not evaluated. Lower run size situations are critical because they provide less margin of error for fishery decisions relative to meeting minimum escapement goals. Additionally, any changes in fish wheel operation, could affect the results. Continued operation of this project in a developmental capacity will also allow further exploration of abundance estimation procedures that may be adaptable to a broader range of circumstances.

LITERATURE CITED

Arnason, A. N., C. W. Kirby, C.J. Schwarz, and J. R. Irvine. *In press*. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report Fisheries and Aquatic Sciences.

Barton, L.H. 1992. Tanana River, Alaska, fall chum salmon radio telemetry study. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin 92-01, Juneau.

Bergstrom, D.J., and six co-authors. 1996. Annual management report for subsistence, personal use, and commercial fisheries of the Yukon area, 1994. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 3A96-18, Anchorage.

Buklis, L.S. 1981. Yukon and Tanana River fall chum salmon tagging study, 1976-1980. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 194, Juneau.

Buklis, L.S. 1982. Anvik, Andreafsky, and Tanana River salmon escapement studies. Alaska Department of Fish and Game, Commercial Fisheries Division, Yukon Salmon Escapement Report 15, Anchorage.

Buklis, L.S., and L.H. Barton. 1984. Yukon River fall chum salmon biology and stock status. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 239, Juneau.

Cappiello, T.A. and J.F. Bromaghin.1997. Mark-recapture abundance estimate of fall-run chum salmon in the upper Tanana River, Alaska, 1995. Alaska Fishery Research Bulletin 4(1), 12-35.

Conover, W.J. 1980. Practical nonparametric statistics. Second edition, John Wiley and Sons, New York.

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

Hosmer, D. W. and Lemeshow, S. 1989. Applied Logistic Regression. John Wiley & Sons Inc., New York.

LaFlamme, T.R. 1990. Tanana river sonar progress report. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 3A90-27, Anchorage.

Milligan, P.A., W.O. Rublee, D.D. Cornett, and R.A.C. Johnston. 1984. The distribution and abundance of chum salmon (*Oncorhynchus keta*) in the upper Yukon River basin as determined by a radio-tagging and spaghetti tagging program: 1982-1983. Department of Fisheries and Oceans, Whitehorse, Yukon.

SAS Institute. 1988. User's Guide: Version 6. SAS Institute, Cary, North Carolina.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin and Company Limited, London.

Seeb, L.W., P.A. Crane, and R.B. Gates. 1995. Progress report of genetic studies of Pacific Rim chum salmon and preliminary analysis of the 1993 and 1994 south Unimak June fisheries. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 5J95-07, Anchorage.

Snedecor, G.W. and W.G. Cochran. 1989. Statistical Methods, Eighth edition. Iowa State University Press, Ames, IA.

Table 1. Number of tags by location from fall chum salmon tagged in the Tanana River, 1996, that were returned by various fisheries participants and other entities.

Recapture Location	Number of Tags
Bluff Cabin Slough	9
Delta Clearwater	1
Delta River	183
Kantishna River	6
Salcha River	2
Tanana River, Delta Juction	1
Tanana River, Fairbanks	47
Tanana River, Nenana	12
Tanana River, Old Minto	45
Tanana River, Rika's	9
Toklat River	8
Yukon River, Rampart	2
Yukon River, Tanana	1
Unknown	1
Grand Total	327

Table 2. Counts, frequencies, and cumulative frequencies of travel times between the tagging and recovery wheels on the Tanana River, 1996.

Travel Time (d)	Count	Frequency	Cumulative Frequency
1	4	0.025	0.025
2	93	0.592	0.618
3	31	0.197	0.815
4	14	0.089	0.904
5	7	0.045	0.949
6	3	0.019	0.968
7	1	0.006	0.975
8	4	0.025	1.000

Table 3. Observed and adjusted number of releases at the tagging wheel and observed and adjusted number of unmarked catches at the recovery wheels used in the Darroch model to estimate abundance of fall chum salmon in the Tanana River, 1996.

	Releases at Tagging Wheel (ai)			Unmarked Catches at Both Recovery Wheels (bj)		
Date	Tags Released	Estimated Proportion Passing Recovery Wheels	Adjusted Tags Released	Unmarked Catch	Estimated Proportion Passing Tagging Wheel	Adjusted Unmarked Catch
16-Aug	88	1.00	84			
17-Aug	63	1.00	60			
18-Aug	80	1.00	76	306	0.62	189
19-Aug	49	1.00	47	242	0.82	198
20-Aug	58	1.00	55	197	0.90	178
21-Aug	45	1.00	43	157	0.95	149
22-Aug	45	1.00	43	193	0.97	187
23-Aug	24	1.00	23	133	0.98	129
24-Aug	8	1.00	8	189	1.00	189
25-Aug	9	1.00	9	200	1.00	200
26-Aug	13	1.00	12	171	1.00	171
27-Aug	27	1.00	26	103	1.00	103
28-Aug	21	1.00	20	73	1.00	73
29-Aug	18	1.00	17	61	1.00	61
30-Aug	31	1.00	29	86	1.00	86
31-Aug	32	1.00	30	90	1.00	90
1-Sep	41	1.00	39	111	1.00	111
2-Sep	39	1.00	37	138	1.00	138
3-Sep	38	1.00	36	84	1.00	84
4-Sep	22	1.00	21	65	1.00	65
5-Sep	52	1.00	49	37	1.00	37
6-Sep	75	1.00	71	51	1.00	51
7-Sep	67	1.00	64	29	1.00	29
8-Sep	73	1.00	69	55	1.00	55
9-Sep	128	1.00	122	39	1.00	39
10-Sep	157	1.00	149	87	1.00	87
11-Sep	115	1.00	109	103	1.00	103
12-Sep	159	1.00	151	125	1.00	125
13-Sep	148	1.00	141	150	1.00	150
14-Sep	158	1.00	150	138	1.00	138
15-Sep	189	1.00	180	137	1.00	137
16-Sep	104	1.00	99	188	1.00	188
17-Sep	137	1.00	130	188	1.00	188
18-Sep	137	1.00	130	263	1.00	263
19-Sep	143	1.00	136	244	1.00	244
20-Sep	258	1.00	245	241	1.00	241
21-Sep	130	1.00	124	250	1.00	250
22-Sep	176	1.00	167	212	1.00	212
23-Sep	122	1.00	116	108	1.00	108
24-Sep	163	1.00	155	108	1.00	108
25-Sep	154	0.98	143	110	1.00	110
26-Sep	125	0.97	115	75	1.00	75
27-Sep	114	0.95	103	69	1.00	69
28-Sep	74	0.90	64	119	1.00	119
29-Sep	64	0.82	50	66	1.00	66
30-Sep	43	0.62	25	56	1.00	56
1-Oct				45	1.00	45
2-Oct				21	1.00	21

Table 4. Definition of the tagging and recovery strata used in the application of the Darroch estimator on the Tanana River mark-recapture project, 1996.

Date	Tagging Strata	Recovery Strata
16-Aug	1	
17-Aug	1	
18-Aug	1	1
19-Aug	1	1
20-Aug	1	1
21-Aug	1	1
22-Aug	1	1
23-Aug	2	1
24-Aug	2	1
25-Aug	2	2
26-Aug	2	2
27-Aug	2	2
28-Aug	2	2
29-Aug	3	2
30-Aug	3	2
31-Aug	3	3
1-Sep	3	3
2-Sep	3	3
3-Sep	3	3
4-Sep	3	3
5-Sep	4	3
6-Sep	4	3
7-Sep	4	4
8-Sep	4	4
9-Sep	4	4
10-Sep	4	4
11-Sep	5	4
12-Sep	5	4
13-Sep	5	5
14-Sep	5	5
15-Sep	5	5
16-Sep	5	5
17-Sep	5	5
18-Sep	6	5
19-Sep	6	5
20-Sep	6	6
21-Sep	6	6
22-Sep	6	6
23-Sep	6	6
24-Sep	7	6
25-Sep	7	6
26-Sep	7	7
27-Sep	7	7
28-Sep	7	7
29-Sep	7	7
30-Sep	7	7
1-Oct		7
2-Oct		7

Table 5. The number of tagged fish recaptured by tagging and recovery strata (c_{ij}), the number of tagged fish released in each tagging strata (a_i), and the number of unmarked fish caught in the recovery wheels by recovery strata (b_j) on the Tanana River, 1996.

Tagging Strata[a]	Recovery Strata[b]								
	c_{i1}	c_{i2}	c_{i3}	c_{i4}	c_{i5}	c_{i6}	c_{i7}	$c_{i.}$	a_i
c_{1j}	20	6	0	0	0	0	0	26	407
c_{2j}	0	3	0	0	0	0	0	3	97
c_{3j}	0	0	4	1	0	0	0	5	210
c_{4j}	0	0	0	10	4	0	0	14	524
c_{5j}	0	0	0	0	49	2	1	52	960
c_{6j}	0	0	0	0	2	41	10	53	918
c_{7j}	0	0	0	0	0	0	23	23	654
$c_{.j}$	20	9	4	11	55	53	34	176	
b_j	1,219	694	576	438	1,308	1,029	451		

[a] definition of tagging strata 1=8/16-22, 2=8/23-28, 3=8/29-9/04, 4=9/05-10, 5=9/11-17, 6=9/18-23, 7=9/24-9/30

[b] definition of recovery strata 1=8/18-24, 2=8/25-30, 3=8/31-9/06, 4=9/07-12, 5=9/13-19, 6=9/20-25, 7=9/26-10/02

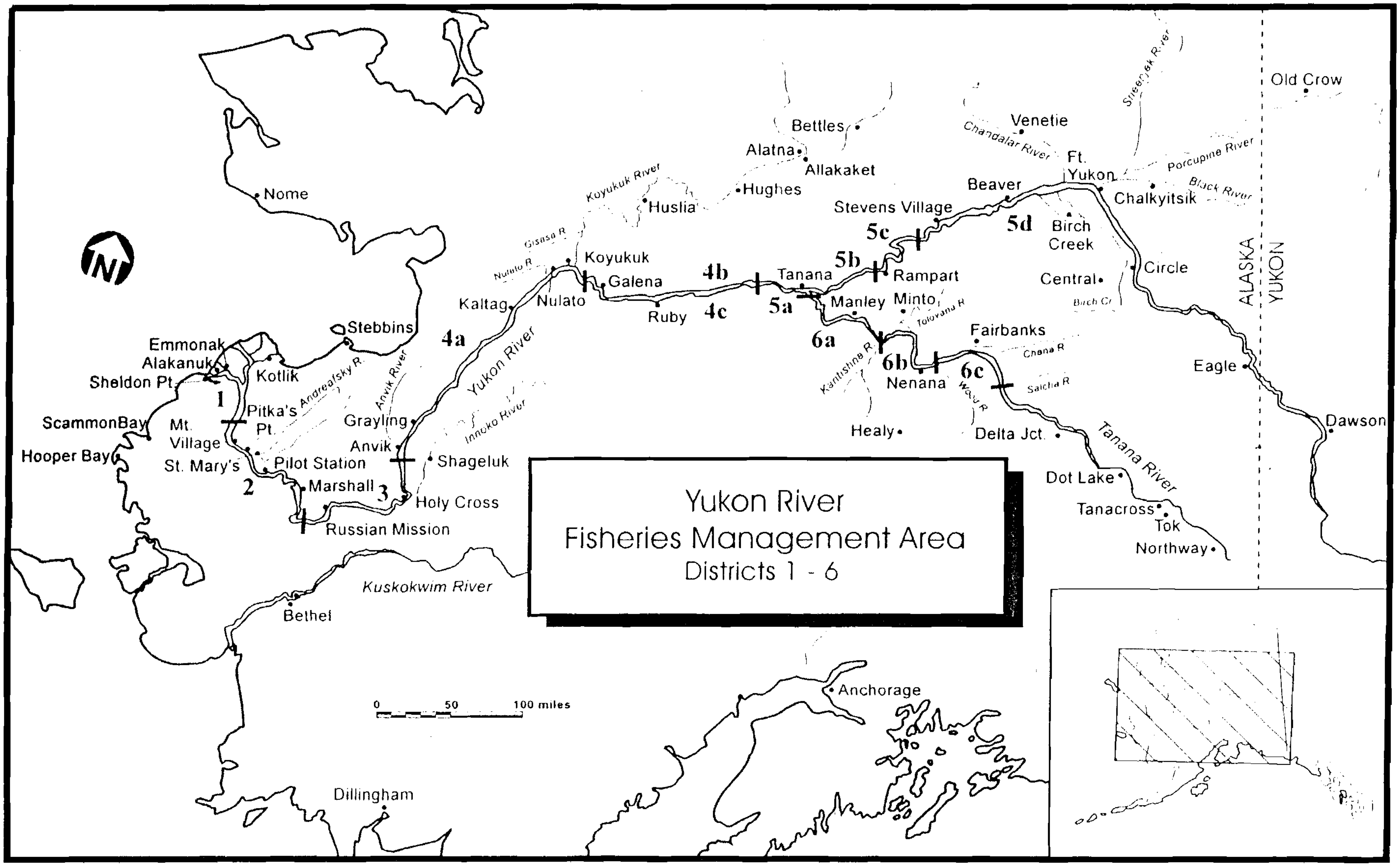

Figure 1. Fisheries management districts and subdistricts in the Yukon and Tanana River drainages.

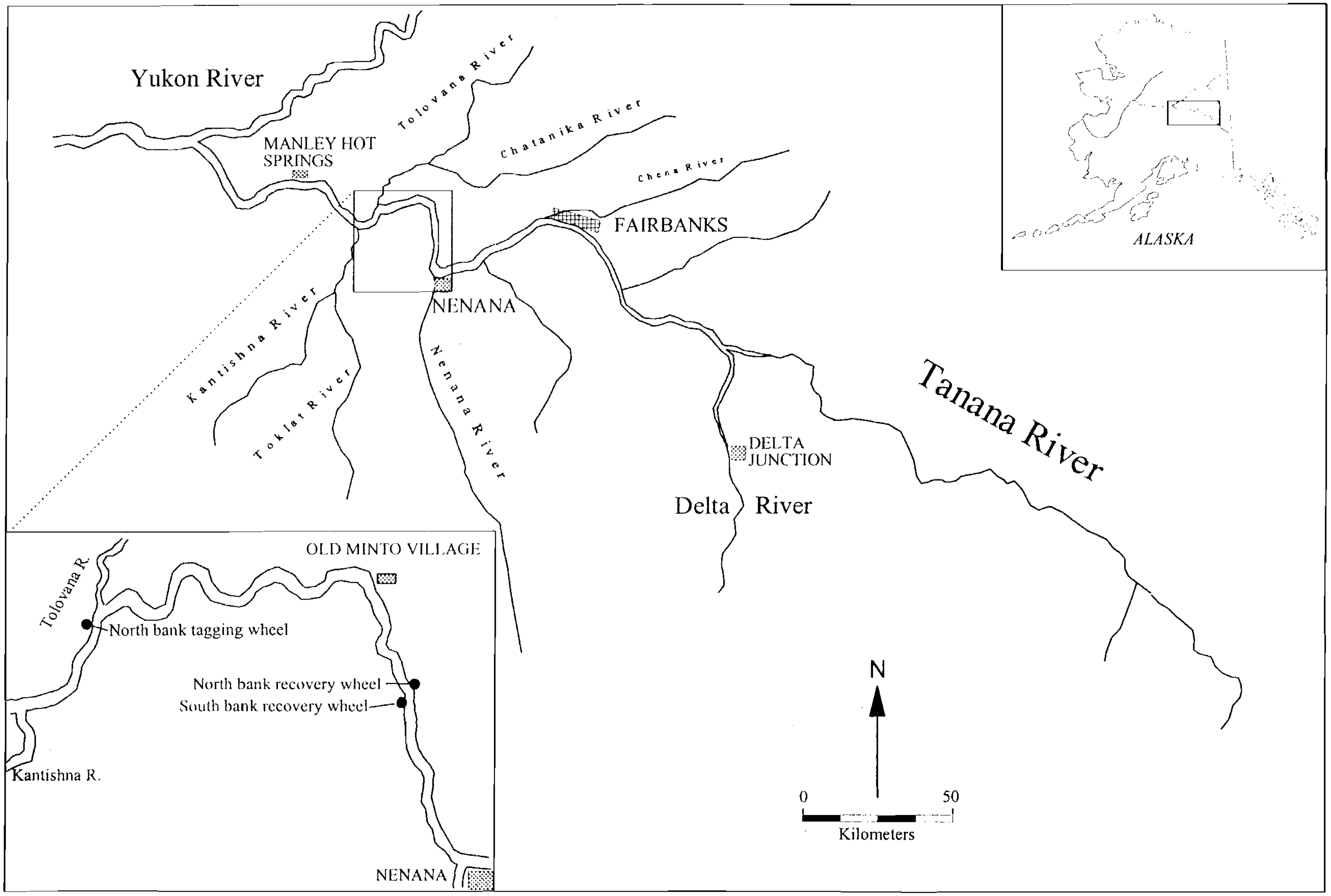

Figure 2. The Tanana River drainage and location of fish wheels used for tagging and recovery of fall chum salmon, 1996.

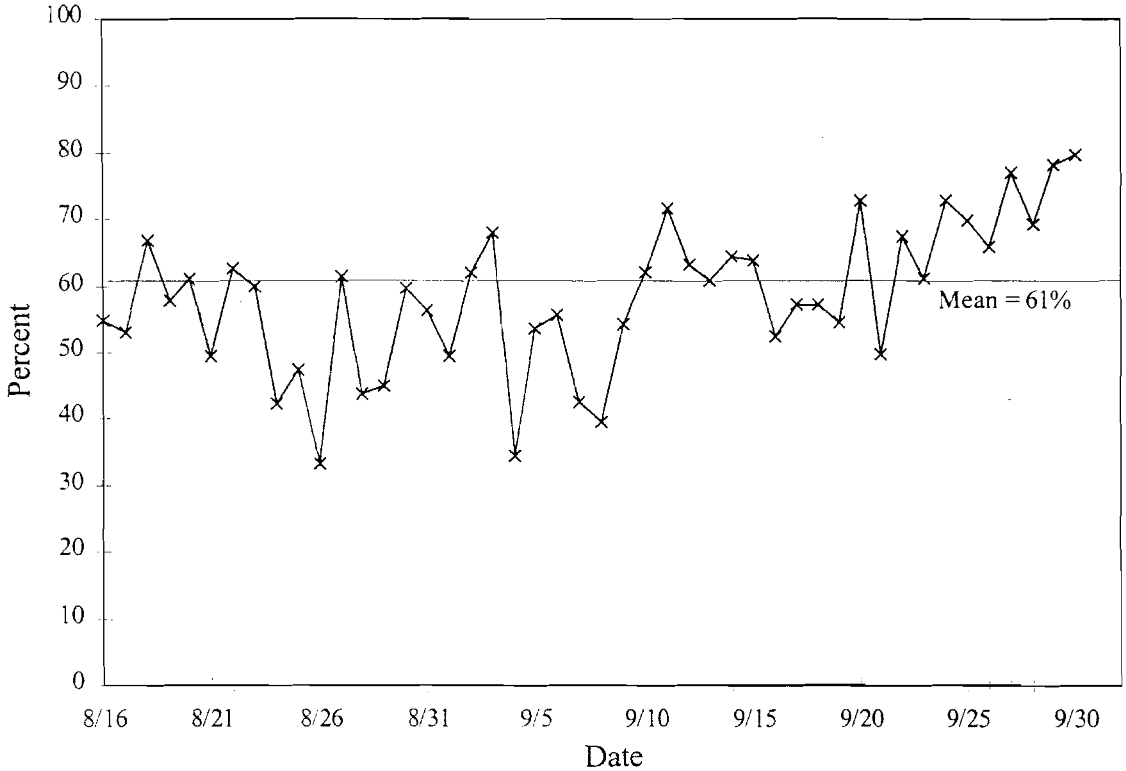

Figure 3. The percent of the total daily catch of fall chum salmon marked at the tagging wheel, Tanana River, 1996.

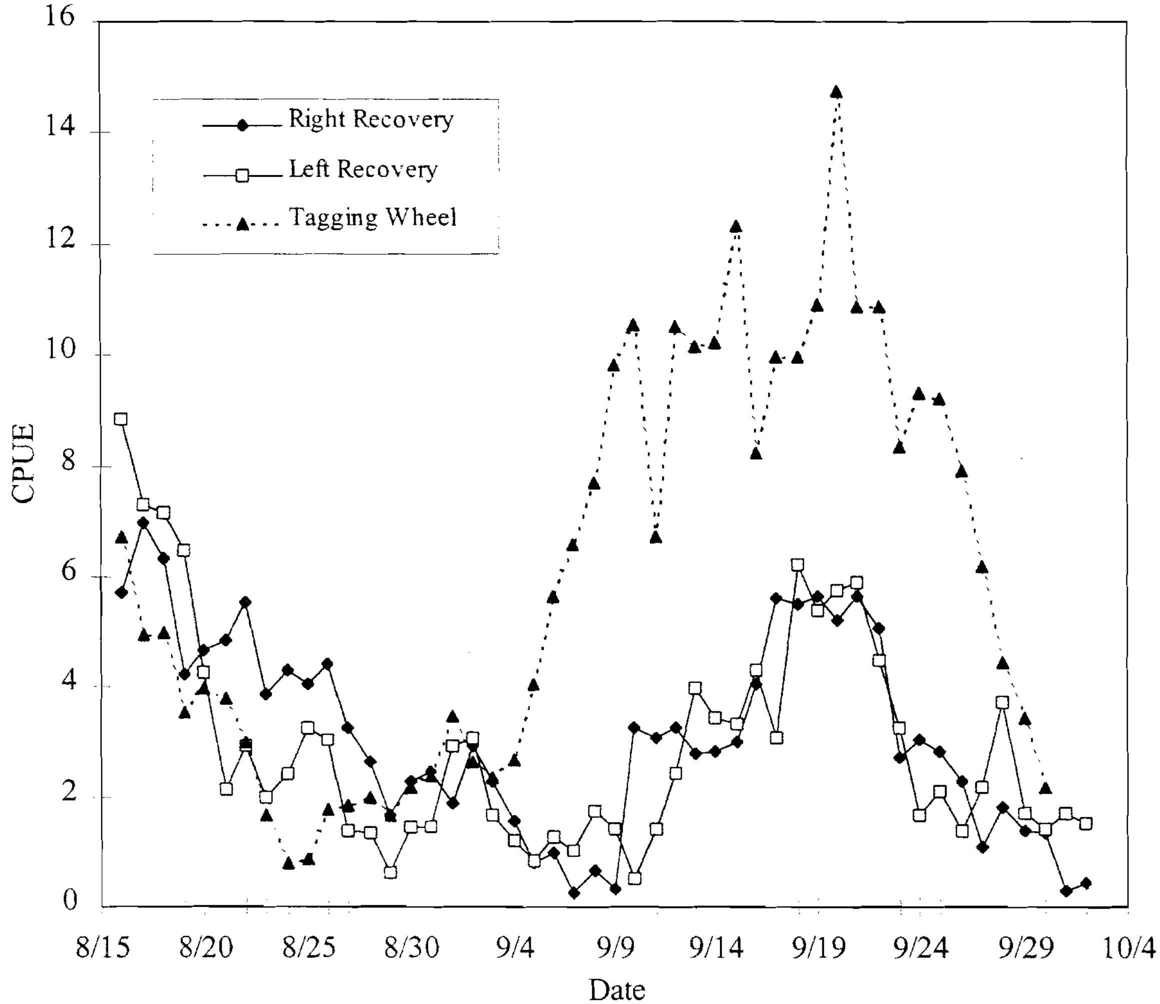

Figure 4. Daily catch per hour effort (CPUE) of fall chum salmon at the tagging and recovery fish wheels on the Tanana River, 1996.

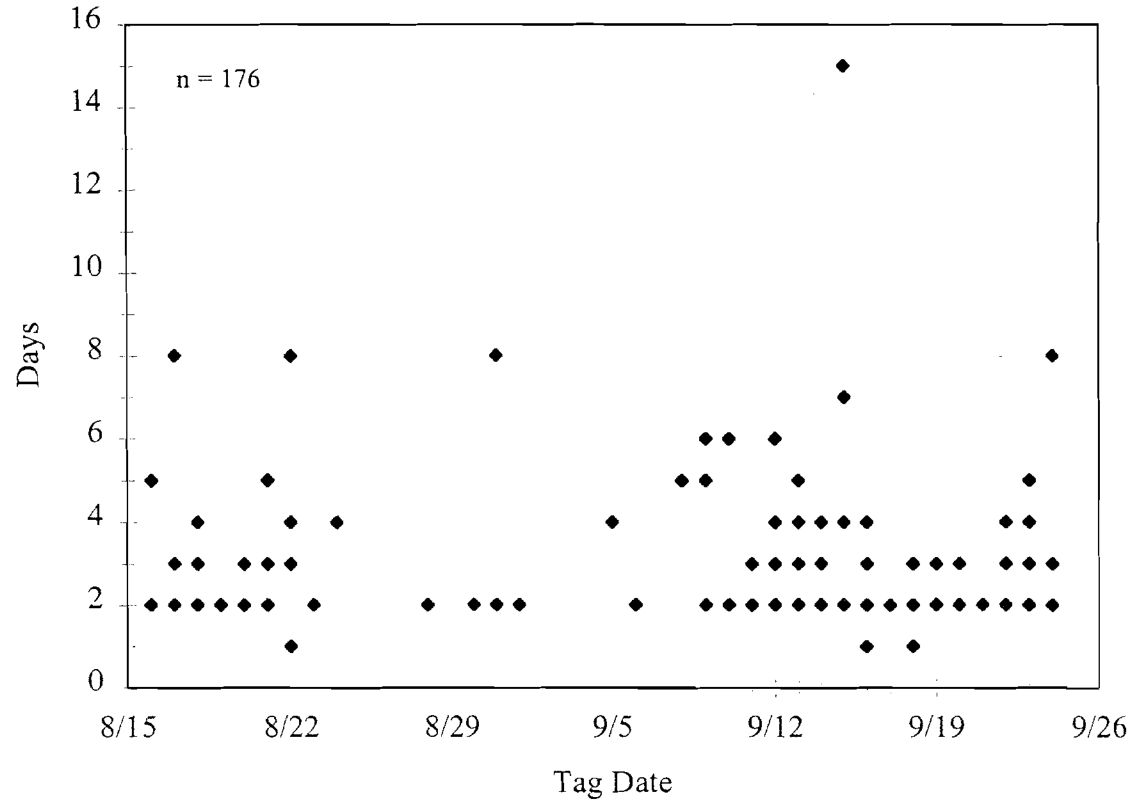

Figure 5. Travel time by date tagged of fall chum salmon between the tagging and recovery wheels on the Tanana River, 1996.

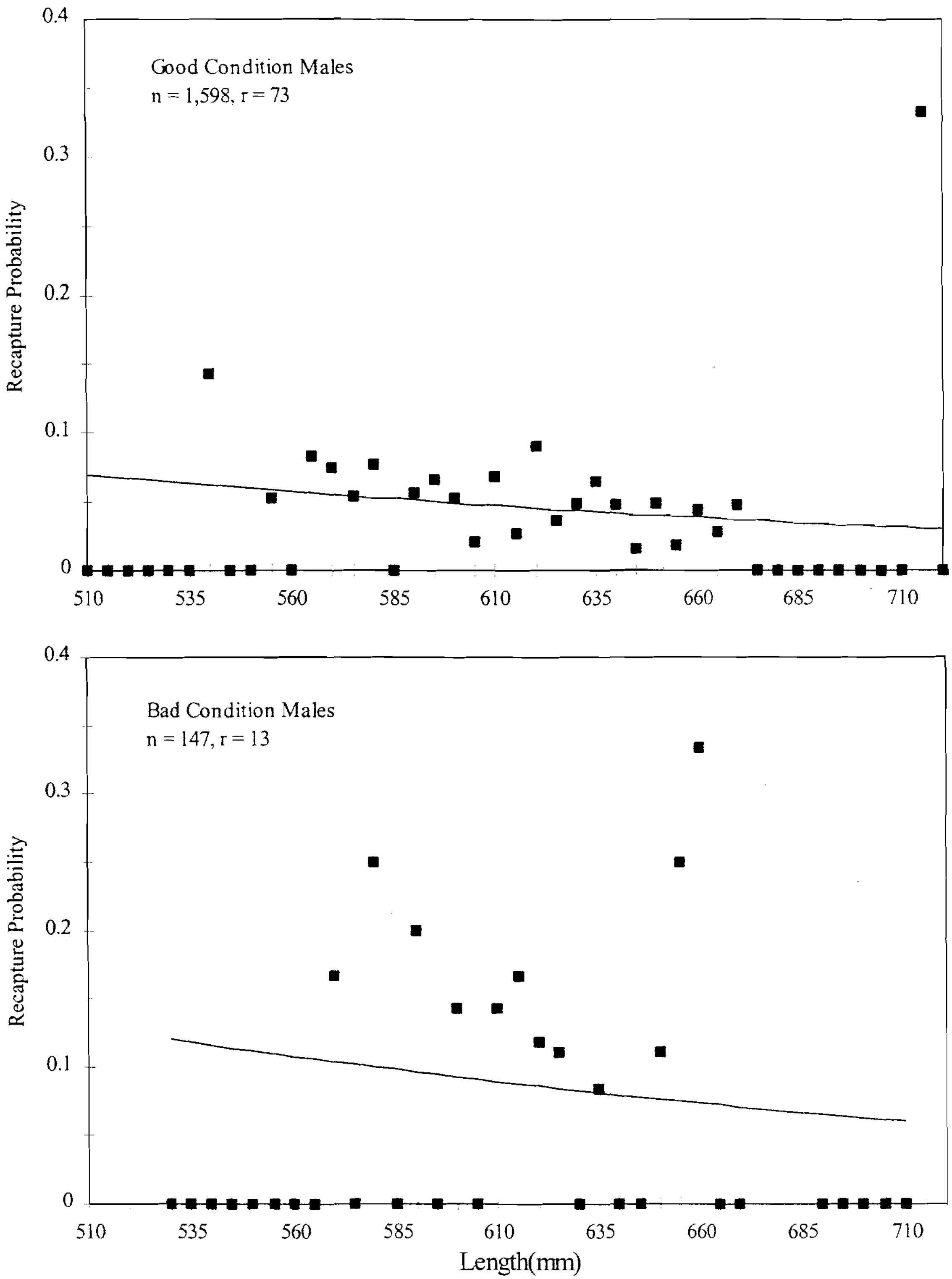

Figure 6. Logistic model and observed data for male fall chum salmon captured in the tagging wheel on the Tanana River, 1996 (n = number of fish tagged, r = number of fish recaptured).

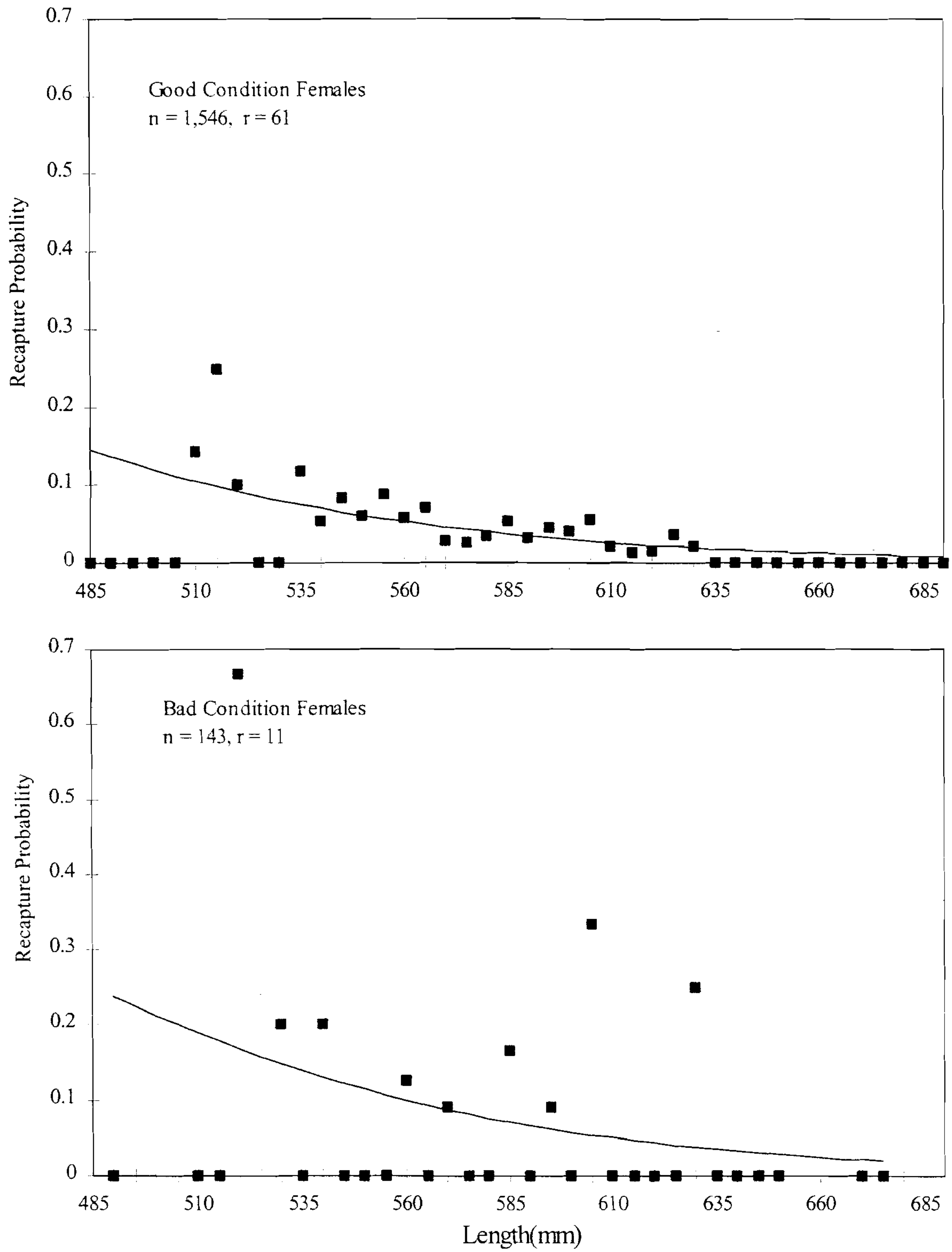

Figure 7. Logistic model and observed data for female fall chum salmon captured in the tagging wheel on the Tanana River, 1996 (n = number of fish tagged, r = number of fish recaptured).

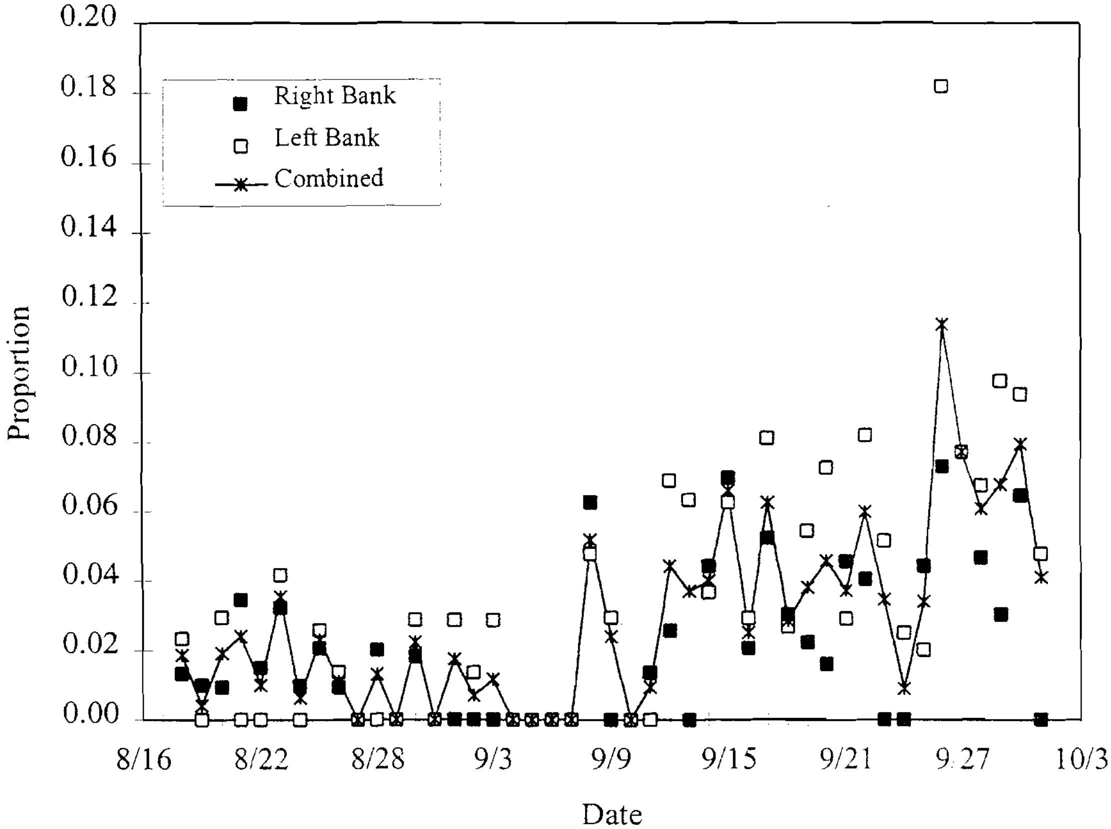

Figure 8. Daily proportion of marked fall chum salmon at the recovery wheels, Tanana River, 1996.

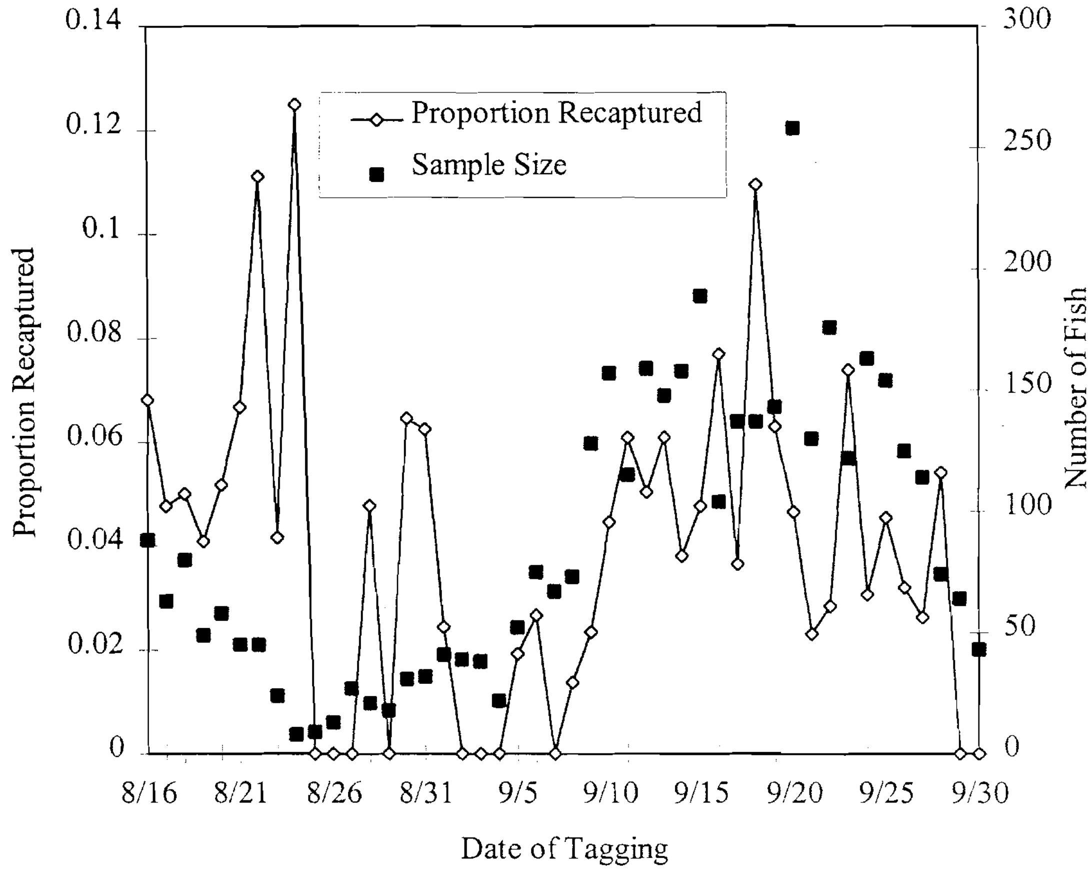

Figure 9. Estimated probability of tagged fall chum salmon being recaptured in the recovery wheels, Tanana River, 1996.

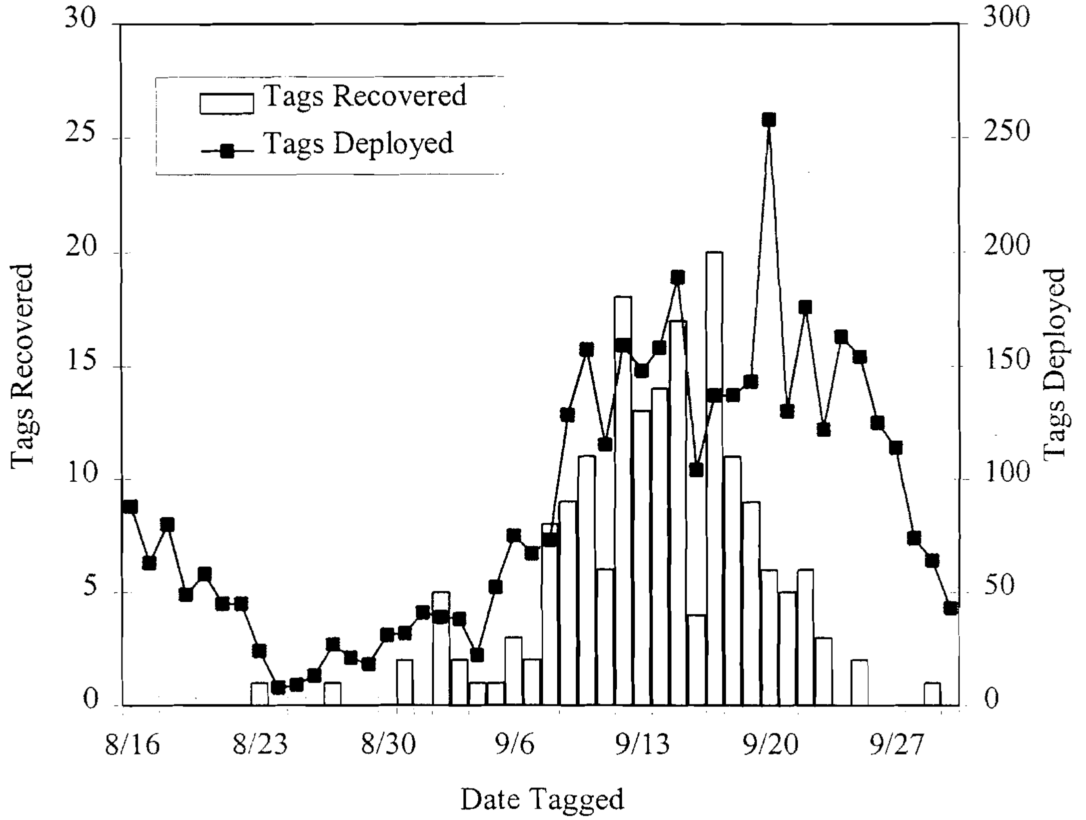

Figure 10. Number of tags recovered from fall chum salmon at the Delta River spawning grounds by date tagged in the Tanana River, 1996. The daily number of tags deployed is shown for comparison.

Appendix A.1. Daily effort and catches of fall chum salmon in the tagging wheel, Tanana River, 1996.

Date	Hours Fished	Tagged			Tagging Wheel Recaptures			Not Marked			Mortalities			Total		
		Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Femal	Total	Male	Female	Total
16-Aug	24	42	46	88	1	0	1	42	27	69	1	2	3	86	75	161
17-Aug	24	28	35	63	2	1	3	24	28	52	0	1	1	54	65	119
18-Aug	24	39	41	80	0	0	0	21	18	39	1	0	1	61	59	120
19-Aug	24	25	24	49	0	1	1	18	16	34	0	1	1	43	42	85
20-Aug	24	35	23	58	1	0	1	18	14	32	2	2	4	56	39	95
21-Aug	24	23	22	45	1	0	1	22	23	45	0	0	0	46	45	91
22-Aug	24	20	25	45	0	1	1	14	12	26	0	0	0	34	38	72
23-Aug	24	13	11	24	0	0	0	6	10	16	0	0	0	19	21	40
24-Aug	24	6	2	8	0	0	0	7	4	11	0	0	0	13	6	19
25-Aug [a]	22	4	5	9	0	0	0	5	5	10	0	0	0	9	10	19
26-Aug [a]	22	9	4	13	0	0	0	14	12	26	0	0	0	23	16	39
27-Aug [b]	24	20	7	27	0	0	0	12	5	17	0	0	0	32	12	44
28-Aug	24	13	8	21	2	0	2	13	12	25	0	0	0	28	20	48
29-Aug	24	9	9	18	0	0	0	11	11	22	0	0	0	20	20	40
30-Aug	24	16	15	31	0	0	0	10	11	21	0	0	0	26	26	52
31-Aug	24	14	18	32	0	0	0	15	10	25	0	0	0	29	28	57
1-Sep	24	20	21	41	0	0	0	20	22	42	0	0	0	40	43	83
2-Sep	24	23	16	39	0	0	0	5	19	24	0	0	0	28	35	63
3-Sep [c]	24	18	20	38	0	0	0	8	10	18	0	0	0	26	30	56
4-Sep	24	14	8	22	0	0	0	22	20	42	0	0	0	36	28	64
5-Sep	24	23	29	52	0	0	0	18	27	45	0	0	0	41	56	97
6-Sep [d]	24	44	31	75	0	0	0	26	33	59	1	0	1	71	64	135
7-Sep	24	37	30	67	0	1	1	52	38	90	0	0	0	89	69	158
8-Sep	24	46	27	73	0	0	0	76	36	112	0	0	0	122	63	185
9-Sep	24	75	53	128	0	0	0	67	40	107	1	0	1	143	93	236
10-Sep [e]	24	84	73	157	3	2	5	50	41	91	0	0	0	137	116	253
11-Sep [f]	24	68	47	115	1	1	2	29	15	44	0	0	0	98	63	161
12-Sep	24	91	68	159	0	1	1	48	41	89	3	0	3	142	110	252
13-Sep	24	86	62	148	1	1	2	54	40	94	0	0	0	141	103	244
14-Sep	24	86	72	158	3	0	3	38	46	84	0	0	0	127	118	245
15-Sep	24	107	82	189	3	0	3	48	56	104	0	0	0	158	138	296
16-Sep	24	55	49	104	1	4	5	30	58	88	1	0	1	87	111	198
17-Sep	24	70	67	137	2	1	3	44	54	98	0	1	1	116	123	239
18-Sep	24	60	77	137	1	0	1	37	64	101	0	0	0	98	141	239
19-Sep	24	62	81	143	3	2	5	53	60	113	0	1	1	118	144	262
20-Sep	24	117	141	258	2	2	4	39	53	92	0	0	0	158	196	354
21-Sep	24	53	77	130	3	1	4	57	70	127	0	0	0	113	148	261
22-Sep [g]	24	73	103	176	5	4	9	21	54	75	1	0	1	100	161	261
23-Sep	24	50	72	122	2	3	5	38	35	73	0	0	0	90	110	200
24-Sep	24	71	92	163	2	4	6	14	40	54	1	0	1	88	136	224
25-Sep	24	61	93	154	5	5	10	23	34	57	0	0	0	89	132	221
26-Sep [h]	24	45	80	125	9	6	15	17	31	48	1	1	2	72	118	190
27-Sep	24	44	70	114	1	3	4	12	18	30	0	0	0	57	91	148
28-Sep	24	28	46	74	0	3	3	10	20	30	0	0	0	38	69	107
29-Sep	24	25	39	64	1	1	2	8	8	16	0	0	0	34	48	82
30-Sep	24	14	29	43	1	0	1	5	5	10	0	0	0	20	34	54
Grand Total		1,966	2,050	4,016	56	48	104	1,221	1,306	2,527	13	9	22	3,256	3,413	6,669

[a] Wheel shutdown 2 h for repositioning.
[b] Added 15 ft of inshore lead.
[c] Removed 15 ft of inshore lead.
[d] Moved wheel out 4 ft.
[e] Log in basket shute may have decreased catch rate.
[f] Debris caught in basket may have reduced overnight catch.
[g] Moved wheel downstream about 6 ft.
[h] Moved wheel out about 6 ft.

Appendix A.2. Daily effort and catches of tagged and unmarked fall chum salmon in the right-bank recovery wheel, Tanana River, 1996.

	Hours	Marked			Not Marked			Total		
Date	Fished	Male	Female	Total	Male	Female	Total	Males	Females	Total
16-Aug	24	0	0	0	43	94	137	43	94	137
17-Aug	24	0	0	0	66	101	167	66	101	167
18-Aug	24	1	1	2	68	82	150	69	83	152
19-Aug	24	0	1	1	46	54	100	46	55	101
20-Aug	23 [a]	0	1	1	51	55	106	51	56	107
21-Aug	24	1	3	4	45	67	112	46	70	116
22-Aug	24	2	0	2	65	66	131	67	66	133
23-Aug	24	1	2	3	51	39	90	52	41	93
24-Aug	24	0	1	1	43	59	102	43	60	103
25-Aug	24	1	1	2	52	43	95	53	44	97
26-Aug	24	1	0	1	63	42	105	64	42	106
27-Aug	24	0	0	0	40	38	78	40	38	78
28-Aug	19	0	1	1	27	22	49	27	23	50
29-Aug	24	0	0	0	19	21	40	19	21	40
30-Aug	24	1	0	1	31	23	54	32	23	55
31-Aug	24	0	0	0	32	27	59	32	27	59
1-Sep	24	0	0	0	25	20	45	25	20	45
2-Sep	24	0	0	0	39	31	70	39	31	70
3-Sep	23	0	0	0	36	16	52	36	16	52
4-Sep	25	0	0	0	28	11	39	28	11	39
5-Sep	23 [a]	0	0	0	11	7	18	11	7	18
6-Sep	24 [a]	0	0	0	17	6	23	17	6	23
7-Sep	24 [a]	0	0	0	4	2	6	4	2	6
8-Sep	24 [a]	1	0	1	12	3	15	13	3	16
9-Sep	24 [a]	0	0	0	7	1	8	7	1	8
10-Sep	24 [b]	0	0	0	39	39	78	39	39	78
11-Sep	24	0	1	1	43	30	73	43	31	74
12-Sep	24	2	0	2	43	33	76	45	33	78
13-Sep	24	0	0	0	34	33	67	34	33	67
14-Sep	24	3	0	3	29	36	65	32	36	68
15-Sep	24	5	0	5	31	36	67	36	36	72
16-Sep	24	2	0	2	47	48	95	49	48	97
17-Sep	24	4	3	7	66	61	127	70	64	134
18-Sep	24	3	1	4	63	65	128	66	66	132
19-Sep	24	2	1	3	55	77	132	57	78	135
20-Sep	24	2	0	2	58	65	123	60	65	125
21-Sep	24	2	4	6	59	67	126	61	71	132
22-Sep	25	3	2	5	67	52	119	70	54	124
23-Sep	14 [c]	0	0	0	19	19	38	19	19	38
24-Sep	24	0	0	0	18	55	73	18	55	73
25-Sep	24	1	2	3	18	47	65	19	49	68
26-Sep	24	2	2	4	6	45	51	8	47	55
27-Sep	24	1	1	2	4	20	24	5	21	26
28-Sep	24	1	1	2	7	34	41	8	35	43
29-Sep	24	0	1	1	8	24	32	8	25	33
30-Sep	23	0	2	2	8	21	29	8	23	31
1-Oct	25	0	0	0	2	5	7	2	5	7
2-Oct	12	0	0	0	3	2	5	3	2	5
Grand Total		42	32	74	1,648	1,844	3,492	1,690	1,876	3,566

[a] Hole in live box.

[b] Low water, wheel spinning slow.

[c] Wheel stopped due to low water.

Appendix A.3. Daily effort and catches of tagged and unmarked fall chum salmon in the left-bank recovery wheel, Tanana River, 1996.

	Hours	Tagged			Not Marked			Total		
Date	Fished	Male	Female	Total	Male	Female	Total	Males	Females	Total
16-Aug	25	0	0	0	82	139	221	82	139	221
17-Aug	23	0	0	0	68	100	168	68	100	168
18-Aug	24	0	4	4	67	101	168	67	105	172
19-Aug	24	0	0	0	75	77	152	75	77	152
20-Aug	24	2	1	3	47	52	99	49	53	102
21-Aug	24	0	0	0	21	30	51	21	30	51
22-Aug	24	0	0	0	34	36	70	34	36	70
23-Aug	24	2	0	2	22	26	48	22	26	48
24-Aug	24	0	0	0	37	58	95	21	37	58
25-Aug	24	2	0	2	35	78	113	43	35	78
26-Aug	24	0	1	1	37	36	73	37	36	73
27-Aug	21	0	0	0	17	12	29	17	12	29
28-Aug	20	0	0	0	7	20	27	7	20	27
29-Aug	24	0	0	0	8	15	23	7	8	15
30-Aug	24	1	0	1	17	18	35	17	18	35
31-Aug	24	0	0	0	21	14	35	21	14	35
1-Sep	24	0	2	2	31	39	70	31	39	70
2-Sep	24	1	0	1	37	37	74	37	37	74
3-Sep	21	1	0	1	14	21	35	14	21	35
4-Sep	24	0	0	0	16	13	29	16	13	29
5-Sep	24	0	0	0	10	10	20	10	10	20
6-Sep	24	0	0	0	16	14	30	16	14	30
7-Sep	24	0	0	0	13	11	24	13	11	24
8-Sep	24	0	2	2	24	18	42	24	18	42
9-Sep	24	0	1	1	17	16	33	17	17	34
10-Sep	24	0	0	0	8	4	12	8	4	12
11-Sep	24 [a]	0	0	0	15	19	34	15	19	34
12-Sep	24	2	2	4	32	22	54	34	24	58
13-Sep	24	3	3	6	41	48	89	44	51	95
14-Sep	24	1	2	3	37	42	79	38	44	82
15-Sep	24	2	3	5	39	36	75	41	39	80
16-Sep	24	2	1	3	40	60	100	42	61	103
17-Sep	24	4	2	6	31	37	68	35	39	74
18-Sep	24	0	4	4	68	77	145	68	81	149
19-Sep	24	4	3	7	63	59	122	67	62	129
20-Sep	24	4	6	10	65	63	128	69	69	138
21-Sep	24	1	3	4	59	75	134	60	78	138
22-Sep	25	6	3	9	51	50	101	57	53	110
23-Sep	24	3	1	4	28	46	74	31	47	78
24-Sep	24	1	0	1	12	27	39	13	27	40
25-Sep	24	1	0	1	22	27	49	23	27	50
26-Sep	24	3	3	6	1	26	27	4	29	33
27-Sep	24	4	0	4	6	42	48	10	42	52
28-Sep	24	1	5	6	22	61	83	23	66	89
29-Sep	24	0	4	4	13	24	37	13	28	41
30-Sep	23	0	3	3	7	22	29	7	25	32
1-Oct	25	0	2	2	13	27	40	13	29	42
2-Oct	12	0	1	1	6	11	17	6	12	18
Grand Total		51	62	113	1,452	1,896	3,348	1,487	1,882	3,369

[a] Pushed wheel out 20 ft.

Appendix B. Distances from the mouth of the Yukon River to the tagging and recovery wheel sites on the Tanana River, and the distances between sites used for calculating migration rates of recaptured fall chum salmon in 1996.

Location	Distance From Mouth	
	Mile	Kilometer
Kantishna River mouth	793	1,276
Left-bank tagging wheel (site 2)	796	1,281
Left-bank tagging wheel (site 1)	798	1,283
Right-bank tagging wheel	799	1,285
Right-bank recovery wheel	844	1,358
Left-bank recovery wheel	845	1,360
Nenana	860	1,384
Between Sites		Distance (km)
Right-bank tagging wheel to right-bank recovery wheel		73.2
Right-bank tagging wheel to left-bank recovery wheel		74.8
Left-bank tagging wheel to right-bank recovery wheel		74.8
Left-bank tagging wheel to left-bank recovery wheel		76.4
Left-bank tagging wheel (site 2) to right recovery		76.8
Left-bank tagging wheel (site 2) to left-bank recovery wheel		78.4