Mark-Recapture Abundance Estimate of Fall-Run Chum Salmon in the Upper Tanana River, Alaska, 1995

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ABSTRACT: The primary objective of this study was to determine the feasibility of a mark-recapture program to estimate inseason and postseason abundance of fall-run chum salmon *Oncorhynchus keta* in the upper Tanana River. We used 2 fish wheels, each on opposite riverbanks, to capture fish for tagging and 2 additional fish wheels on opposite riverbanks to recover tagged fish approximately 76 km upstream. All chum salmon caught during a daily 6-h schedule were marked with spaghetti tags. From 16 August through 30 September 1995, a total of 3,993 fall-run chum salmon were released with orange tags from the right bank; 181 were released with yellow tags from the left bank. From 18 August to 1 October, the right-bank recovery wheel caught 6,773 chum salmon, of which 103 were recaptures (94 orange; 9 yellow). During the same period, the left-bank recovery wheel caught 3,902 chum salmon, of which 63 were recaptures (55 orange; 8 yellow). Catches from both recovery wheels were pooled because tagged fish were not bank-oriented and there was no statistically significant difference in the marked proportions between each wheel. However, information from yellow-tagged fish was not adequate for estimating abundance. Bailey's closed population model produced a total estimate of 268,173 (SE = 21,597) fall-run chum salmon that passed the tagging site after 16 August. No significant sources of bias from assumption violations were detected. The mean migration rate between tagging and recovery sites was 26 km/d. We concluded that a mark-recapture program using fish wheels for fish capture appears feasible but should continue in a developmental stage to allow further evaluation of its utility under a variety of circumstances. Tagging fish from only the right-bank tagging wheel and tagging more fish, while using 2 wheels for tag recovery, may be necessary to improve precision of the abundance estimate.

INTRODUCTION

Genetically distinct (Seeb et al. 1995) summer and fall runs of chum salmon *Oncorhynchus keta* return to the Yukon River drainage. During the spawning migration in the Tanana River, fall-run (fall) chum salmon are generally larger and have a higher oil content than summer-run (summer) chum salmon, and consequently are a more desirable food resource. Fall chum salmon are therefore an important component of the commercial, subsistence, personal use, and recreational fisheries in the Yukon River drainage. A substantial portion of this fall run originates from the Tanana River and its tributaries. From 1985 through 1994, the annual Tanana River harvest averaged approximately 74,000 fish, or about 22% of the entire Yukon River drainage harvest of fall chum salmon (Bergstrom et al. 1996). Contribution of Tanana River stocks to the lower Yukon River fisheries harvest is likely but unknown; hence the total contribution is probably higher.

The summer run arrives in the Tanana River in early July and ends 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, peak migration occurs in mid September, and continues into late fall, at which time freeze-up limits fishing activity on the river. Fall chum salmon spawn from mid October through November, primarily in areas where upwelling groundwater maintains an ice-free substrate during most years and allows spawning under frigid air temperatures. However, these limited spawning areas strongly influence population levels (Buklis and Barton 1984).

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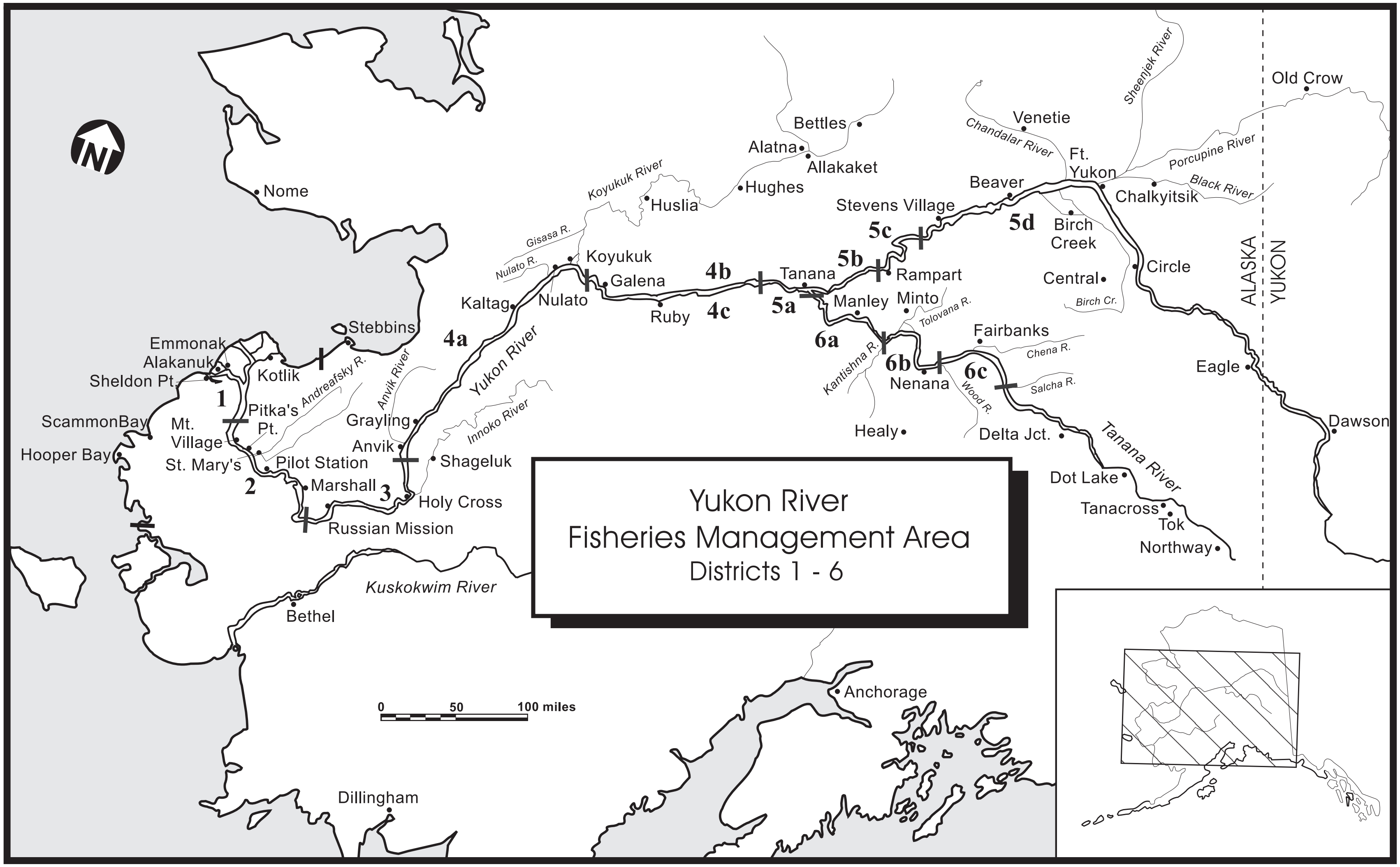

Figure 1. The Yukon River Fishery Management Area.

The Alaska Department of Fish and Game (ADF&G) manages the fisheries in the Alaska portion of the Yukon River drainage. The Tanana River drainage is 1 of 6 Yukon River drainage management districts and is further divided into 4 subdistricts (6-A through 6-D; Figure 1). Summer and fall chum salmon are managed separately by regulatory season. In District 6 the fall chum salmon season begins on 16 August, and despite some mixing of the 2 runs after this date all chum salmon are, for inseason management purposes, designated as the fall run. 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 operates test fish wheels and uses their catch per unit effort (CPUE) 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 2 tributary spawning areas, the Toklat and Delta Rivers, are estimated annually. Counts of spawners obtained during ground and aerial surveys in these 2 rivers are the primary indices used to assess the relative abundance of fall chum salmon in the Tanana River drainage. The Alaska Board of Fisheries 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 provide accurate 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 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 that 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 other Alaskan and Canadian stocks.

Buklis (1981) tagged fall chum salmon from right- and left-bank fish wheels located near Manley Hot Springs and used tag returns from the subsistence and commercial fisheries 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 limited-range, user-nonconfigurable 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 (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. Several years later, a dual-beam, user-configurable sonar system used in the Tanana River near Manley Hot Springs between 16 July and 3 August 1990 indicated possible feasibility (LaFlamme 1990); however, that project was not continued in subsequent years.

Barton (1992), using radiotelemetry in 1989 identified spawning areas in the upper Tanana River and estimated 121,556 ± 45,107 (95% CI) fall chum salmon upstream from Fairbanks, the Delta River component representing 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.

The primary objective of this study was to 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. We hoped this would lead to a mark-recapture program that would provide reliable escapement estimates facilitating quantitative predictions that would benefit management of fall chum salmon in the Tanana River. Secondary objectives were to estimate migration rate and determine the run timing of spawning stocks in the Delta River and proximal mainstem areas.

METHODS

Tagging

Two privately contracted fish wheels, positioned on opposite riverbanks (banks), were used to capture chum salmon for tagging. The right-bank wheel was located 9 km upstream from the mouth of the Kantishna River and approximately 2 km upstream from the left-bank wheel (Figure 2). Both wheels had an attached live box and were operated continuously, except when repairs were being made or debris was being removed. All fish caught were removed from the live box with a dip net and identified to species. The sex of all salmon species was determined by inspecting external characteristics. All chum salmon caught during a 6-h daily schedule were measured from mid eye to tail fork (MEF) to the nearest 5 mm and marked with individually numbered 30-mm spaghetti tags; also, the adipose fin was clipped to assess tag loss. To simplify assessment of possible bank orientation, yellow tags were applied to left-bank captures and orange tags were used for right-bank captures. Physical injuries and aberrations potentially detrimental to the survival or swimming ability of the fish were noted. The daily tagging schedule of fixed duration was intended to deploy tags in proportion to run abundance. From 7 to 14 August, tagging was conducted from 1000 to 1600 hours and thereafter from 1200 to 1800 hours. Tagging began on 7 August at the left-bank wheel, on 10 August at the right-bank wheel, and ceased at both wheels on 30 September. Tagging prior to 16 August, when all chum

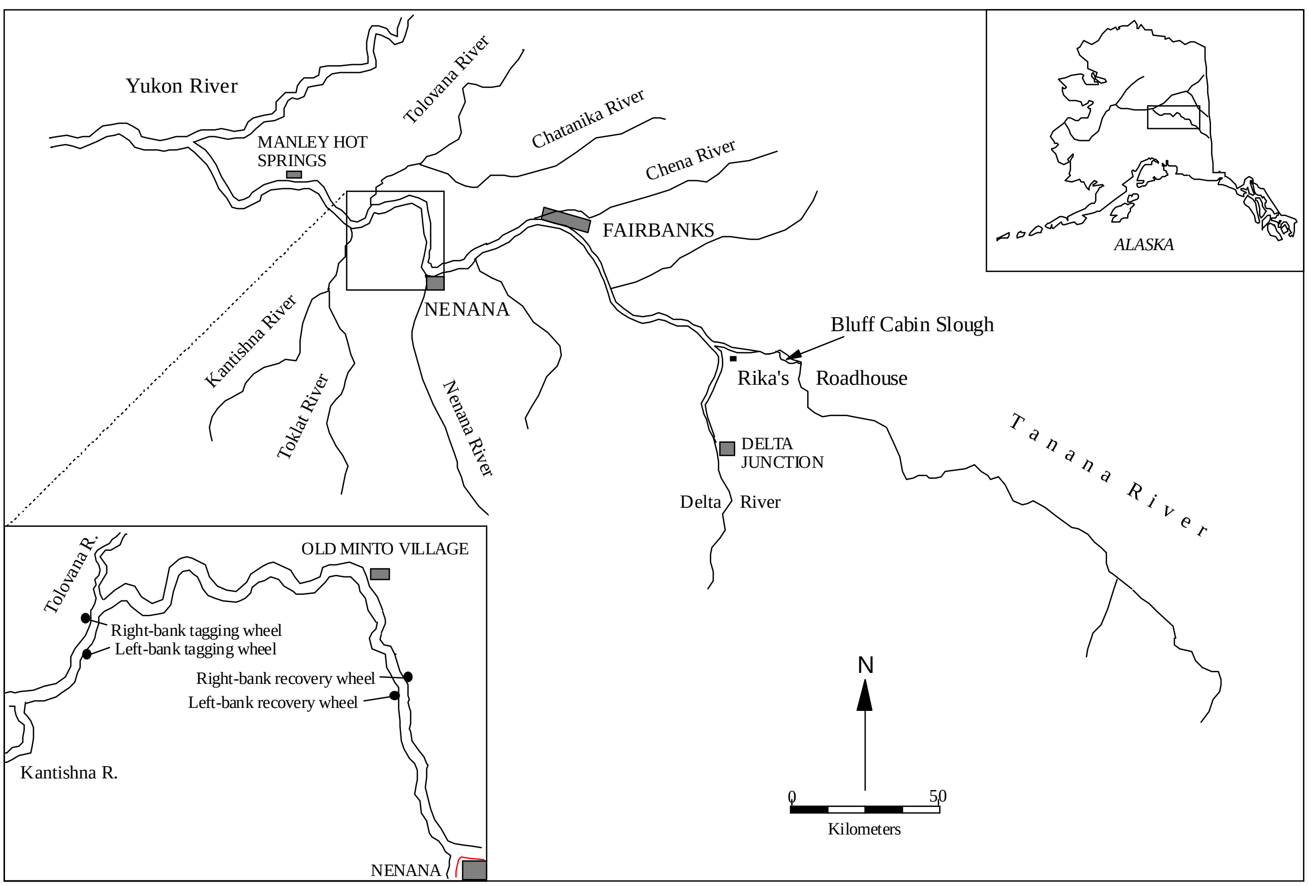

Figure 2. The Tanana River drainage and locations of fish wheels used for tagging and recovery of fall chum salmon, 1995.

salmon are considered to be summer-run stock, was primarily intended to solve any unexpected logistical or procedural problems.

Tag Recovery

Right- and left-bank fish wheels, located approximately 76 km upstream from the tagging wheels and 24 km downstream from Nenana, were used to sample chum salmon for tags. The recovery wheels were 1.6 km apart and were operated by private contractors. Since 1988, the right-bank wheel has been used as a *test* fish wheel for indicating inseason timing and relative run strength of summer and fall chum salmon. Recapture efforts began 7 August and ended 1 October on the right bank and ended 29 September on the left bank. Recovery-wheel operators removed and examined all fish in the live box at least once each day. Fish caught were identified to species; sex of all salmon was determined from external characteristics. Chum salmon were inspected for tags and a clipped adipose fin, and the tag number and color of all tagged fish was recorded. Neither length measurements nor presence of physical injuries were recorded from unmarked fish. Recovery-wheel operators released all fish except during commercial or subsistence fishing periods when they were allowed to retain fish as legally permitted.

By becoming eligible for a $200 drawing (one winner), fishermen were encouraged to turn in tags. Volunteer recoveries were only 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

Data Reduction

To estimate the abundance of chum salmon that satisfied the fall regulatory definition, data from fish tagged on and after 16 August were used. Similarly, the total number of chum salmon and the number of recaptures caught in both recovery wheels on or after the day of the first recapture were used. Fish tagged before 16 August (i.e., summer-run fish) but recaptured during the fall season were treated as unmarked fish for estimating abundance. Reducing the number of unmarked fish by the ratio of summer-to-fall run recaptures was considered; however, estimates of this ratio would be highly variable because of the low number of recaptures. In addition, we desired to provide results consistent with following years, at which time tagging would begin on 16 August.

Diagnostic Statistical Tests

A series of statistical tests were used to determine if the data from the 2 recovery wheels and the 2 tag colors could be pooled. Pooling was desirable for reducing variance and simplifying abundance estimation, which would have pragmatic importance for streamlining the tagging program. The significance level for all tests was $\alpha = 0.05$. A chi-square test of homogeneity (Johnson and Bhattacharyya 1996) was used to test a hypothesis that orange- and yellow-tagged fish had the same probabilities of being recaptured in the right-bank recovery wheel, recaptured in the left-bank recovery wheel, and of not being recaptured in either recovery wheel.

Most mark-recapture models assume that fish have equal probabilities of being captured in at least one capture event. Fish wheels are often believed to selectively capture fish based on physical characteristics, such as size or sex. The presence of unequal capture probabilities would require use of a stratified abundance estimator. As noted above, the sex and length of each tagged fish was recorded. Also fish "condition" (i.e., the presence or absence of observable physical abnormalities that might conceivably influence fish survival or susceptibility to fish wheels) was also recorded. A logistic regression (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 (SAS) LOGISTIC[1] procedure (SAS Institute 1988). All possible interaction terms among the 3 predictor variables were included in the model. The variables sex and condition were coded as indicator values having the value 0 or 1. Although not knowing length and condition of unmarked chum salmon caught in the recovery wheels prevented stratification by these variables, knowing if unequal recapture probabilities were a possible source of bias was useful for determining the feasibility of this project.

Abundance Estimate

An appropriate population abundance estimator was selected based on the results of the diagnostic statisti-

[1] Mentioned for scientific completeness; does not constitute endorsement.

Table 1. Combinations of run size, tagging effort, recovery effort, and fish wheels used to produce 24 different scenarios for estimating abundance and coefficient of variance of fall-run chum salmon in the Tanana River.

Run Size Factor[a]	Tagging Effort Factor[a]	Recovery Fish Wheel
1	1 (6 h/d)	Right bank only
0.75	1.3 (8 h/d)	Both
0.5	2 (12 h/d)	
	4 (24 h/d)	

[a] Multiplication factor, where 1 = 1995 levels.

cal tests. We assumed 5% mortality from tagging and decreased the daily number of tags deployed accordingly. True mortality caused by tagging and handling were unknown and inestimable under the circumstances of this study. To demonstrate various tag-induced mortalities for comparative purposes, the final abundance estimate was also calculated with assumed mortalities ranging from 0 to 20% in 2.5% increments.

Migration Rate

Time between tagging and recovery wheels was determined to the nearest day for all recaptures by subtracting the date a fish was tagged from the date of its first recapture, and this was assumed to be travel time for that fish. A Cramer Von Mises test (Conover 1980) was used to test whether the distribution of travel times was the same between yellow- and orange-tagged fish. The migration rate was calculated for each recaptured fish by dividing the distance between wheels tagged and recaptured (Appendix A) by travel time.

Stock Timing

Chum salmon spawning in the Delta River were counted weekly by ground survey. Spawning areas at Bluff Cabin Slough, Rika's Roadhouse, and the outlet to Clearwater Lake were surveyed from the ground at least once during the peak spawning period. Tags were retrieved to estimate the median date that tagged fish passed the tagging wheel site.

Project Scenarios

Because this was a feasibility study, several different run sizes were examined as related to threshold tagging and recovery efforts. The related assumptions were that (1) changes in run size have a direct linear effect on tagging and recovery catches (constant effort but changing CPUE), and (2) changes in tagging effort (fraction of total catch that is tagged) have a direct linear effect on the marked proportion observed in each recovery wheel. The scenarios were based on the cumulative number of tags deployed in the right-bank wheel and the cumulative catch of recaptures and total catch in each recovery wheel that were observed on 15 September 1995. This date was chosen because it is the historical average midpoint of the fall chum salmon run in the Tanana River near Nenana and a time when management decisions become most critical (Keith Schultz, ADF&G, Fairbanks, personal communication). Abundance and coefficient of variance (CV) was estimated for various combinations of 2 levels of recovery effort, 3 run sizes, and 4 levels of tagging effort (Table 1).

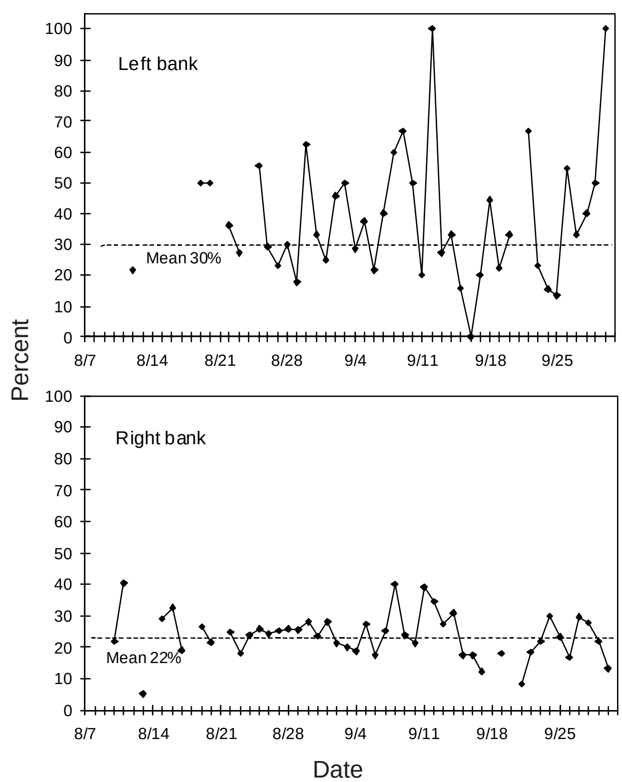

Figure 3. Daily percentage of total catch of fall chum salmon tagged at right- and left-bank fish wheels, Tanana River, 1995. Only days with 24 h of effort are plotted.

RESULTS

Fish Capture

Tagging Phase

The left-bank tagging wheel caught 304 summer and 522 fall chum salmon (826 total), of which 37 and 181, respectively (218 total), were released with tags (Appendix B.1). Wheel effort was interrupted during the tagging schedule for 6 h on 14 and 17 August, and for 1 h on 15 August. The percentage of the daily total catch tagged ranged from 0 to 100% and averaged 30% for days with 24 h of effort (Figure 3). On 17 August the left-bank wheel was moved 2 km downstream because daily catches had decreased relative to the right-bank wheel. Low catches continued, but the wheel remained at this location absent a potentially better site. Catches of chum salmon were sporadic, and trends were not readily discernible throughout the operating period. Catch per hour of effort (CPUE) was low and variable during the fall run (Figure 4). Peak CPUE occurred on 14 August when all chum salmon were still considered to be summer-run fish. Damage to one of the chutes that deliver fish from the wheel baskets to the live box lowered catch rates on 21 August and on 2, 3, and 19 September.

The right-bank tagging wheel caught 471 summer and 17,111 fall chum salmon (17,582 total) of which 137 and 3,993, respectively (4,130 total), were tagged (Appendix B.2). Wheel effort was interrupted 6 times to make repairs and clear debris; however, none of the interruptions occurred during the tagging schedule. The daily percentage of the total catch that was tagged ranged from 5 to 40% and averaged 22% for days with 24 h of effort (Figure 3). This proportion decreased during the mid-September peak because of greater nocturnal catches. Peak CPUE occurred from 15 to 17 September (Figure 4), and minor peaks of less magnitude occurred around 5 and 26 September.

Recovery Phase

The left-bank recovery wheel caught a total of 4,521 chum salmon (348 summer and 4,173 fall), of which 74 (65 orange tags; 9 yellow tags) were recaptures (Appendix B.3). Of 4 orange-tagged fish recaptured more than once, 2 were previously recaptured in the left-bank recovery wheel and 2 were previously recaptured on the right bank. Fishing effort was continuous through most of the recovery period; the few interruptions that occurred were minor. Peaks in CPUE occurred on 17 August and for several days encompassing 12 September (Figure 5).

The right-bank recovery wheel caught a total of 8,274 chum salmon (1,266 summer; 7,008 fall; Appendix B.4) of which 112 were recaptures (100 orange tags; 11 yellow tags; 1 tag loss). Of 3 tagged fish recaptured more than once, 1 orange-tagged fish had been recaptured twice in the left-bank wheel, and 1 yellow-tagged fish was recaptured previously on the right bank. Catch trends of the right-bank recovery

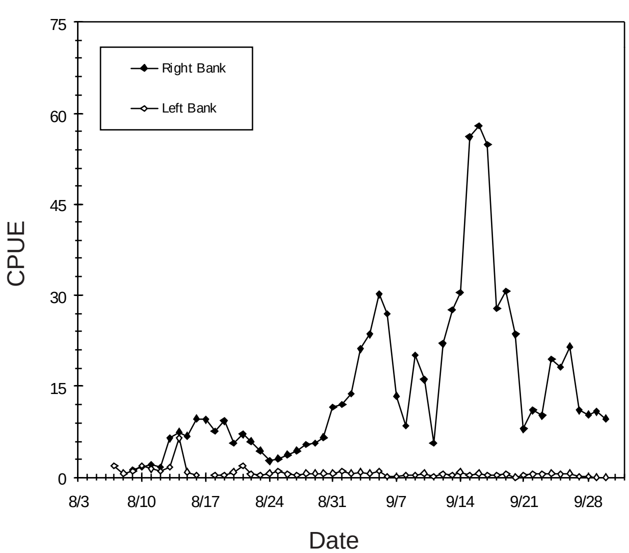

Figure 4. Daily number of chum salmon caught per hour (CPUE) in right- and left-bank tagging fish wheels, Tanana River 1995.

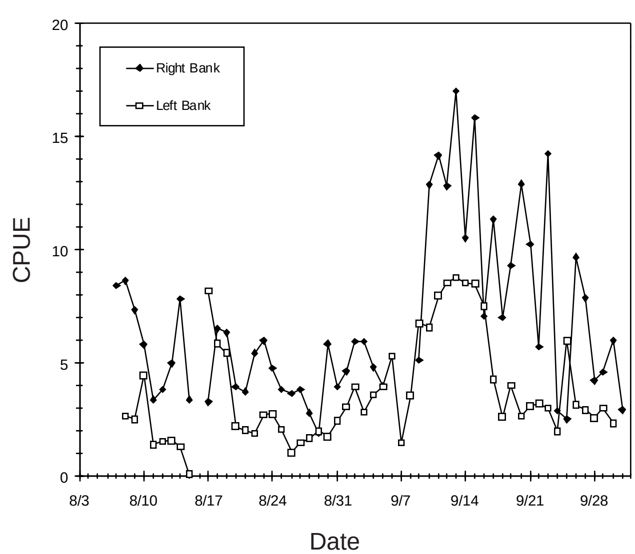

Figure 5. Daily number of chum salmon caught per hour (CPUE) in right- and left-bank recovery fish wheels, Tanana, River 1995.

Table 2. Number of tag recaptures by location and tag color from fall-run chum salmon tagged in the Tanana River, 1995, that were returned by various fisheries participants and others.

Recapture Location	Orange Tags	Yellow Tags	Total
Tanana River, Fairbanks	37	2	39
Tanana River, Nenana	196	11	207
Tanana River, Old Minto	4	2	6
Tanana River, Delta Junction	19	0	19
Moody Cr. (Nenana River)	5	0	5
Chena River	2	0	2
Delta Clearwater	1	0	1
Delta River	39	0	39
Chatanika River	3	0	3
Tolovana River	3	0	3
Sushana River (Toklat River)	3	0	3
Kantishna River	5	0	5
Yukon River, Nulato	2	0	2
Yukon River, Marshall	2	0	2
Yukon River, Ruby	1	0	1
Yukon River, Tanana	2	0	2
Grand Total	324	15	339

wheel were similar to, but more erratic than, the left-bank recovery wheel. Peaks in CPUE occurred from 9 to 14 September (Figure 5).

Recoveries from sources other than the fish wheels used in this project included 324 orange and 15 yellow tags (Table 2). Most of the recoveries (207) came from the commercial and subsistence fisheries in the Nenana area. Of 15 tags returned from locations downstream of the tagging sites, 7 were from the Yukon River, 5 from the Kantishna River, and 3 from the Sushana River, a tributary of the Toklat River. Some tags were found under unusual circumstances: 2 tagged chum salmon were caught by Sport Fish Division personnel using hoop nets for burbot *Lota lota* in the Chena River, and a hunter returned 5 tags from Moody Creek, a tributary of the Nenana River that has previously not been documented as a chum salmon spawning area.

Data Analysis

Data Reduction

From 16 August through 30 September, 3,993 orange and 181 yellow tags were deployed. After adjusting for a 5% mortality, these totals were reduced to 3,793 orange and 172 yellow tags. The first recapture of a fall chum salmon occurred on 18 August on the right bank. After the recaptures that were tagged prior to 16 August were removed, the number of recaptures caught in the right-bank wheel was reduced to 94 orange tags (including 4 recaptured more than once), 9 with yellow tags (1 more than once), and 1 tag loss. For some statistical testing and abundance calculations, the tag loss was treated as an orange tag because it was caught late in September and well after 10 September, the last day a yellow tag was recaptured. After recaptures tagged prior to 16 August were removed from the left-

Table 3. Chi-square test results showing that the probabilities a tagged fall-run chum salmon was recaptured in the right-bank fish wheel, recaptured in the left-bank fish wheel, or not recaptured were dependent on the location tagged in the Tanana River. Only first-time recaptures were used.

	Recapture Location			
Location Tagged	Right Bank	Left Bank	Not Recaptured	Total
Right bank (orange tags)	91	52	3,850	3,993
Left bank (yellow tags)	8	8	165	181

$\chi^2 = 15.55$, $P \approx 0.0004$, df = 2

Table 4. Summary of binomial tests for fall-run chum salmon in the Tanana River, 1995, for bank orientation for equal recapture rates between tag colors, and for equal marked proportions (orange-tagged fish only) between recovery fish wheels.

Hypothesis Tested	Ratio-1	PM-1	Ratio-2	P-2	P-1,2 pooled	z	P value
Bank orientation (chi-square component 1)	91/143	0.636	8/16	0.5	0.623	1.067	0.286
Recapture rates equal between tag color (chi-square component 2)	143/3,993	0.358	16/181	0.088	0.038	-3.615	0.0003
Proportions of recaptures equal between recovery fish wheels	95/6,773	0.01403	55/3,902	0.01410	0.01405	-0.029	0.977

bank catch, the number of fall chum recaptures was reduced to 55 orange tags (including 3 caught more than once) and 8 yellow tags. The total catch (number of chum salmon examined for tags) in the recovery wheels from 18 August through 1 October was 10,675 (6,773 in the right bank and 3,902 in the left-bank wheel), and the total number of recaptures was 150 orange tags (95 right bank; 55 left bank) and 17 yellow tags (9 right bank; 8 left bank).

Diagnostic Statistical Tests

The chi-square test of homogeneity for equality of recapture probabilities between orange- and yellow-tagged fish (based on the location of first recapture and including one fish missing an assumed orange tag) was significant ($\chi^2 = 15.55$, $P \approx 0.0004$, df = 2; Table 3). To identify the source of the significant test result, 2 additional tests were conducted on subsets of the data considered in the chi-square test. The first test focused on the subset of data involving tag color and recapture location; fish tagged but not recaptured were not considered. A binomial test (Johnson and Bhattacharyya 1996) was used to test whether both orange- and yellow-tagged fish had the same probability of recapture in a given recovery wheel, a test for the presence of bank orientation. This test was not significant (z = 1.067, $P \approx 0.286$; Table 4). For the second test, left- and right-bank recaptures were pooled, and the same binomial test was used to test another hypothesis: that the recapture probabilities were equal for both orange and yellow tags. This test was significant (z = -3.615, $P \approx 0.0003$; Table 4), yellow tags having a greater recapture probability (8.8%) than orange tags (3.5%). This prompted evaluation of the yellow tag data. Yellow tags did not appear to be deployed in relation to catch or run magnitude, were poorly represented in daily and cumulative recaptures, and had a significantly greater recovery rate. No obvious cause for these observations was apparent. Because of these observations, the low number of yellow tags deployed, and a desire to avoid compromising the quality of the abundance estimate, a decision was made to treat recaptures of yellow tags as unmarked fish. Subsequent analyses were then based only on orange-tag data germane to abundance estimation. The marked proportions (including multiple recaptures and the lost tag) of orange tags between right- (0.01403) and left-bank (0.01410) recovery wheels were not significantly different (z = -0.029, $P \approx 0.977$; Table 4); therefore, the data from both recovery wheels were pooled.

Of 3,993 fall chum salmon tagged at the right-bank wheel, excluding 2 lacking complete sex, length, and condition information, 142 were subsequently recaptured. With the logistic regression model, a likelihood ratio test upheld the hypothesis that none of the variables or interaction terms influenced the probability of recapture ($P \approx 0.434$). This test result suggested that recapture probabilities were equal for all fish and that stratification by sex, length, or condition was unnecessary.

The tagging schedule was designed to capture and tag fall chum salmon in proportion 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 marked proportion should be constant over time. A chi-square test of homogeneity could have been used to test the hypothesis that the daily marked proportion was constant over time. Unfortunately, many of the observed daily proportions were quite small (Figure 6), which would have resulted in the distribution of the test statistic being poorly approximated by a chi-square distribution. For that reason, simulation techniques were used to estimate the distribution of the test statistic.

Under the hypothesis that the marked proportion was constant over time, the overall proportion was estimated as the ratio of the total number recaptured to the total number captured by both recovery wheels,

Table 5. Chi-square test results on daily recapture proportions of combined recovery fish wheel catches of fall-run chum salmon in the Tanana River, 1995.

	Observed Data			Expected Data			Chi-square Components			
Date	Tagged	Untagged	Total	Tagged	Untagged	Total	Tagged	Untagged	Total	Percent
8/18	2	281	283	3.98	279.02	283	0.982	0.014	0.996	1.44
8/19	0	148	148	2.08	145.92	148	2.080	0.030	2.109	3.05
8/20	2	137	139	1.95	137.05	139	0.001	0.000	0.001	0.00
8/21	5	171	176	2.47	173.53	176	2.582	0.037	2.619	3.79
8/22	2	206	208	2.92	205.08	208	0.291	0.004	0.295	0.43
8/23	5	175	180	2.53	177.47	180	2.414	0.034	2.448	3.54
8/24	4	138	142	2.00	140.00	142	2.014	0.029	2.043	2.95
8/25	2	110	112	1.57	110.43	112	0.115	0.002	0.117	0.17
8/26	1	92	93	1.31	91.69	93	0.072	0.001	0.073	0.11
8/27	1	99	100	1.41	98.59	100	0.117	0.002	0.118	0.17
8/28	2	63	65	0.91	64.09	65	1.293	0.018	1.311	1.90
8/29	0	182	182	2.56	179.44	182	2.557	0.036	2.594	3.75
8/30	1	152	153	2.15	150.85	153	0.615	0.009	0.624	0.90
8/31	2	182	184	2.59	181.41	184	0.133	0.002	0.134	0.19
9/1	1	236	237	3.33	233.67	237	1.630	0.023	1.654	2.39
9/2	3	207	210	2.95	207.05	210	0.001	0.000	0.001	0.00
9/3	1	200	201	2.82	198.18	201	1.178	0.017	1.195	1.73
9/4	0	99	99	1.39	97.61	99	1.391	0.020	1.411	2.04
9/5	1	126	127	1.78	125.22	127	0.345	0.005	0.350	0.51
9/6	0	36	36	0.51	35.49	36	0.506	0.007	0.513	0.74
9/7	1	31	32	0.45	31.55	32	0.674	0.010	0.683	0.99
9/8	2	283	285	4.00	281.00	285	1.004	0.014	1.018	1.47
9/9	3	463	466	6.55	459.45	466	1.922	0.027	1.950	2.82
9/10	10	521	531	7.46	523.54	531	0.864	0.012	0.876	1.27
9/11	10	502	512	7.19	504.81	512	1.094	0.016	1.110	1.60
9/12	4	614	618	8.68	609.32	618	2.526	0.036	2.562	3.70
9/13	1	456	457	6.42	450.58	457	4.577	0.065	4.643	6.71
9/14	4	580	584	8.21	575.79	584	2.156	0.031	2.187	3.16
9/15	3	346	349	4.90	344.10	349	0.739	0.011	0.750	1.08
9/16	14	361	375	5.27	369.73	375	14.466	0.206	14.672	21.21
9/17	5	226	231	3.25	227.75	231	0.948	0.014	0.961	1.39
9/18	6	313	319	4.48	314.52	319	0.514	0.007	0.521	0.75
9/19	4	318	322	4.52	317.48	322	0.061	0.001	0.062	0.09
9/20	6	302	308	4.33	303.67	308	0.646	0.009	0.655	0.95
9/21	5	209	214	3.01	210.99	214	1.321	0.019	1.340	1.94
9/22	7	407	414	5.82	408.18	414	0.240	0.003	0.244	0.35
9/23	1	116	117	1.64	115.36	117	0.252	0.004	0.256	0.37
9/24	5	198	203	2.85	200.15	203	1.617	0.023	1.640	2.37
9/25	5	328	333	4.68	328.32	333	0.022	0.000	0.022	0.03
9/26	8	240	248	3.48	244.52	248	5.850	0.083	5.934	8.58
9/27	1	162	163	2.29	160.71	163	0.727	0.010	0.737	1.07
9/28	1	181	182	2.56	179.44	182	0.948	0.014	0.962	1.39
9/29	6	193	199	2.80	196.20	199	3.671	0.052	3.723	5.38
9/30	2	68	70	0.98	69.02	70	1.050	0.015	1.065	1.54
10/1	1	67	68	0.96	67.04	68	0.002	0.000	0.002	0.00
Totals	150	10,525	10,675	150	10,525	10,675	68.210	0.972	69.182	100.00

(i.e., 150/10,675 = 0.01405). A chi-square test statistic was computed using the observed data and the overall proportion tagged, resulting in a test statistic of 69.18 (Table 5). The simulation randomly generated daily numbers of tagged fish, as a binomial random variable, given the number of fish examined for tags each day and an assumed constant proportion tagged of 0.01405. A total of 10,000 such data sets were randomly generated, and a chi-square test statistic was computed for each data set. A frequency histogram (Figure 7) of these randomly generated test statistics provides an estimate of the distribution of the test statistic. As expected, the distribution of the test statistic appears to be somewhat more skewed than a chi-square distribution. The proportion (0.0260) of the randomly generated test statistics that exceeded the value of the test statistic computed with the observed data, 69.18, is an estimate of the *P* value associated with the test statistic. Although the test was significant, an examination of the daily components of the test statistic revealed that approximately 21% of the value of the test statistic was attributed to a single day, 16 September. This outlier was eliminated from the data set and the simulation test was repeated. This new simulation resulted in an estimated *P* value of 0.105. As before, the distribution is slightly more skewed than the comparable chi-square distribution (Figure 7). Based on this simulated *P* value, the proportion of tagged fish recaptured in the recovery wheels was considered to be sufficiently constant over time; hence, fish had been tagged approximately in proportion to abundance.

Abundance Estimate

The series of diagnostic tests determined that stratification was not required for an unbiased abundance estimate. Because the recovery wheels caught some tagged fish more than once, we reasonably assumed some untagged fish were also caught more than once. For that reason, the Bailey closed population model for sampling with replacement (Seber 1982) was used to estimate abundance. Based on the cumulative number of fish tagged from 16 August through 30 September, the cumulative recovery data from 18 August through 1 October, and a 5% tag-induced mortality, the final abundance estimate was 268,173 ± 42,330 (95% CI; Table 6). The CV for the daily estimates decreased from 0.5 on 18 August to 0.08 on 1 October and reached 0.11 on 15 September. The abundance estimate decreased linearly from 282,313 to 225,822 as the assumed tag-induced mortality increased from 0 to 20% (Figure 8). The commercial fall chum harvest in the Tanana River Subdistricts 6-B through 6-D was 60,466 (Busher and Borba 1996) and the preliminary subsistence and personal use harvest was 24,440 (B. Borba, ADF&G, Fairbanks, personal communication). With these harvest estimates subtracted from the abundance estimate, the point estimate of the spawning escapement in the upper Tanana River was approximately 183,267 fall chum salmon.

Migration Rate

Travel time to either recovery wheel for orange-tagged fish ranged from 1 to 22 d (mean 3.6 d; median 3 d, $n = 157$) and from 2 to 8 d (mean 3.5 d; median 3 d, $n = 19$) for yellow-tagged fish. Lacking a significant difference in the frequency distribution of travel time between orange- and yellow-tagged fish (Cramer Von Mises *T.S.* = 0.177, $0.6 < P < 0.7$), data for both tag colors were pooled. Although the mean travel time for females (4.0 d, $n = 100$) was slightly slower (nonstatistical comparison) than for males (3.3 d, $n = 76$), the medians (3 d) between the sexes were equal. The mean migration rate for all recaptures was 26 km/d (median 25 km/d). There were no visually discernible trends in travel time over the course of this study (Figure 9).

Stock Timing

In the Delta River, 39 orange tags were recovered from spawning fish during October and November (Table 7). A total of 14 orange tags were recovered from spawning fish at Bluff Cabin Slough, and 5 orange tags were recovered from the Tanana River at Rika's Roadhouse. Yellow tags were not found at any of the surveyed

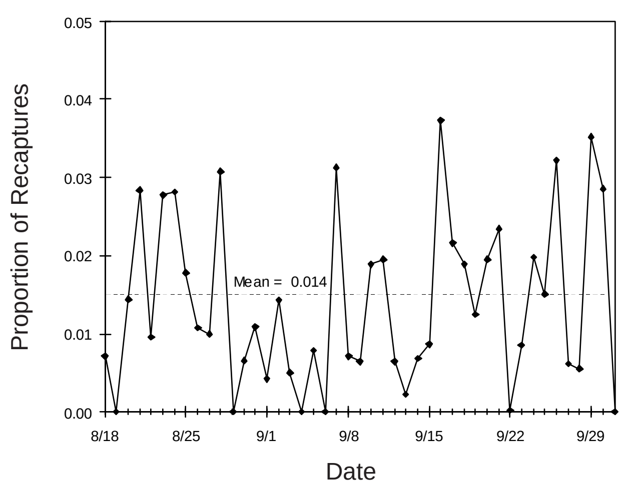

Figure 6. Daily proportion of recaptures in the pooled (right and left bank) recovery fish wheel catch of fall chum salmon in the Tanana River, 1995.

Table 6. Daily cumulative catch statistics and Bailey abundance estimates of fall-run chum salmon in the Tanana River, 1995. The number of tags deployed was adjusted for a 5% mortality.

Date	Tagged (Adjusted)	Examined For Tags	Recaptures	Abundance	95% Confidence Bounds Lower	Upper	SE	CV
8/16	71							
8/17	112							
8/18	156	283	2	14,768	372	29,164	7,345	0.50
8/19	212	431	2	30,528	715	60,341	15,211	0.50
8/20	239	570	4	27,294	5,550	49,038	11,094	0.41
8/21	279	746	9	20,841	8,608	33,075	6,242	0.30
8/22	314	954	11	24,989	11,491	38,488	6,887	0.28
8/23	332	1,134	16	22,166	12,003	32,329	5,185	0.23
8/24	346	1,276	20	21,040	12,321	29,760	4,449	0.21
8/25	364	1,388	22	21,982	13,261	30,704	4,450	0.20
8/26	385	1,481	23	23,774	14,530	33,017	4,716	0.20
8/27	410	1,581	24	25,945	16,051	35,839	5,048	0.19
8/28	443	1,646	26	27,023	17,096	36,950	5,065	0.19
8/29	475	1,828	26	32,177	20,347	44,007	6,036	0.19
8/30	517	1,981	27	36,596	23,371	49,821	6,748	0.18
8/31	579	2,165	29	41,804	27,190	56,418	7,456	0.18
9/1	656	2,402	30	50,851	33,346	68,355	8,931	0.18
9/2	723	2,612	33	55,565	37,276	73,853	9,331	0.17
9/3	819	2,813	34	65,848	44,472	87,224	10,906	0.17
9/4	919	2,912	34	76,487	51,652	101,322	12,671	0.17
9/5	1,107	3,039	35	93,480	63,538	123,422	15,277	0.16
9/6	1,213	3,075	35	103,644	70,444	136,845	16,939	0.16
9/7	1,290	3,107	36	108,360	74,112	142,608	17,473	0.16
9/8	1,368	3,392	38	119,016	82,345	155,687	18,710	0.16
9/9	1,478	3,858	41	135,800	95,431	176,169	20,596	0.15
9/10	1,557	4,389	51	131,447	96,268	166,625	17,948	0.14
9/11	1,606	4,901	61	126,978	95,821	158,134	15,896	0.13
9/12	1,780	5,519	65	148,873	113,439	184,307	18,079	0.12
9/13	1,953	5,976	66	174,225	133,047	215,403	21,009	0.12
9/14	2,168	6,560	70	200,342	154,316	246,367	23,482	0.12
9/15	2,391	6,909	73	223,268	173,009	273,527	25,642	0.11
9/16	2,619	7,284	87	216,812	172,040	261,583	22,843	0.11
9/17	2,772	7,515	92	224,025	179,018	269,033	22,963	0.10
9/18	2,914	7,834	98	230,618	185,703	275,533	22,916	0.10
9/19	3,039	8,156	102	240,671	194,709	286,634	23,450	0.10
9/20	3,145	8,464	108	244,242	198,894	289,591	23,137	0.09
9/21	3,160	8,678	113	240,576	196,895	284,256	22,286	0.09
9/22	3,206	9,092	120	240,927	198,460	283,394	21,667	0.09
9/23	3,258	9,209	121	245,952	202,775	289,130	22,029	0.09
9/24	3,391	9,412	126	251,335	208,088	294,581	22,065	0.09
9/25	3,487	9,745	131	257,457	213,998	300,915	22,173	0.09
9/26	3,569	9,993	139	254,776	213,017	296,534	21,305	0.08
9/27	3,644	10,156	140	262,497	219,623	305,372	21,875	0.08
9/28	3,710	10,338	141	270,125	226,155	314,094	22,433	0.08
9/29	3,763	10,537	147	267,936	225,217	310,655	21,795	0.08
9/30	3,793	10,607	149	268,241	225,759	310,723	21,674	0.08
10/1	3,793	10,675	150	268,173	225,842	310,503	21,597	0.08

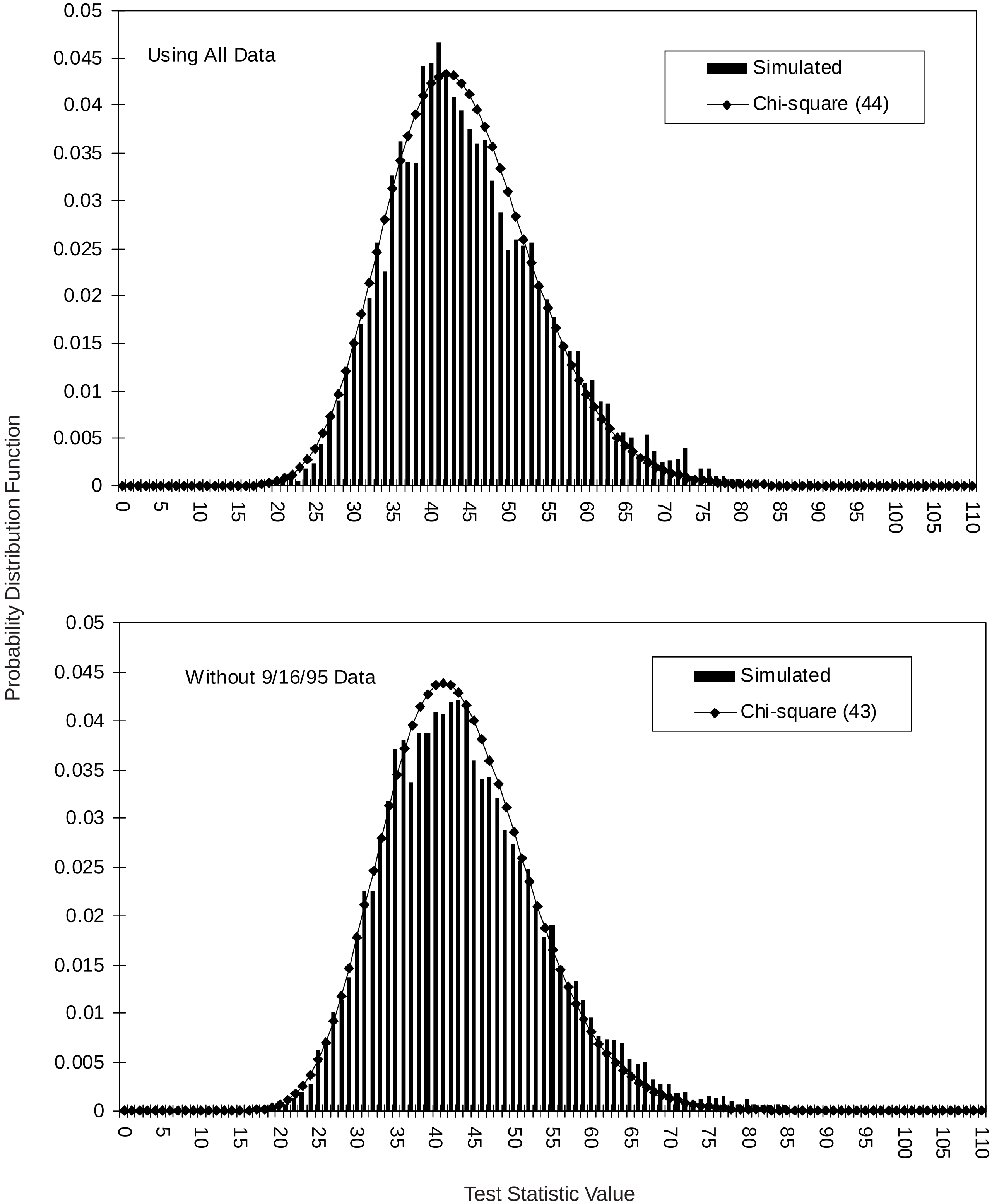

Figure 7. Distributions of chi-square test statistics from simulated data sets based on the mean percent of recaptures in the combined recovery fish wheel catch of fall chum salmon in the Tanana River from 18 August through 1 October 1995.

Table 7. Numbers and dates of tag recoveries for fall-run chum salmon tagged in the Tanana River and recaptured at selected spawning areas in 1995.

Date Found	Bluff Cabin Slough	Spawning Area Delta River	Rika's Roadhouse
20-Oct	no survey	16	no survey
26-Oct	no survey	6[a]	no survey
27-Oct	7	8	5
3-Nov	7	6	no survey
9-Nov	no survey	1	no survey
22-Nov	no survey	2	0
Grand Total	14	39	5

[a] Tag returns were from local residents.

spawning areas. Tag deployment dates from all spawning-ground recoveries were concentrated around mid September (Figure 10). The tag-deployment dates from the Delta River recoveries ranged from 28 August to 30 September (median = 14 September). 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 size and lack of temporal representation.

Project Scenarios

Based on the performance of the right-bank tagging wheel and the 2 recovery wheels used in 1995, a coefficient of variance for an abundance estimate on 15 September was $\leq$0.10 in most run-size cases if the tagging effort was $\geq$012 h/d and both recovery wheels were used (Table 8). At 75% of the 1995 run, a CV $\leq$0.10 was predicted for either 12 h/d tagging effort using both recovery wheels or 24 h/d tagging effort using only the right-bank recovery wheel. At 50% of the 1995 run, a CV$\leq$ 0.10 was predicted for 24 h/d tagging effort using both recovery wheels or only the right recovery wheel. Because fishery harvests and escapement counts indicated the 1995 Tanana River fall chum salmon run was larger than average, no cases of larger runs were considered.

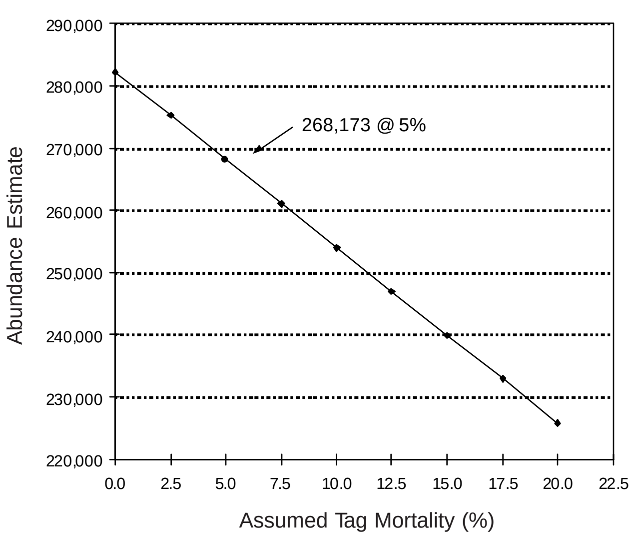

Figure 8. Effect of varying the assumed tag-induced mortality on the final abundance estimate of fall chum salmon in the Tanana River, 1995.

DISCUSSION

The abundance estimate in this study represents the number of chum salmon that passed the tagging site after 16 August. The estimate does not include an unknown but probably low number of fall chum salmon that migrated up the Tanana River after the project was terminated. As indicated by tag returns, the abundance estimate included an unknown number of fish that migrated up the Tolovana or Kantishna Rivers, as well as those that migrated to downstream areas, such as the Yukon River. In addition, a low number of fish were harvested between the tagging and recovery sites.

According to Seber (1982) closure violations that occur with equal rates among marked and unmarked fish do not bias the abundance estimate but the abundance estimated is before the violations occurred. 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, which was 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.

Pahlke and Bernard (1996) reported high tag loss and concluded spaghetti tags were unsuitable as a primary mark to estimate abundance of chinook salmon in the Taku River. We experienced low tag loss, which was probably due to a short hiatus between marking and recapture. Also, fish were migrating with little threat of predation or other events that could cause tag loss.

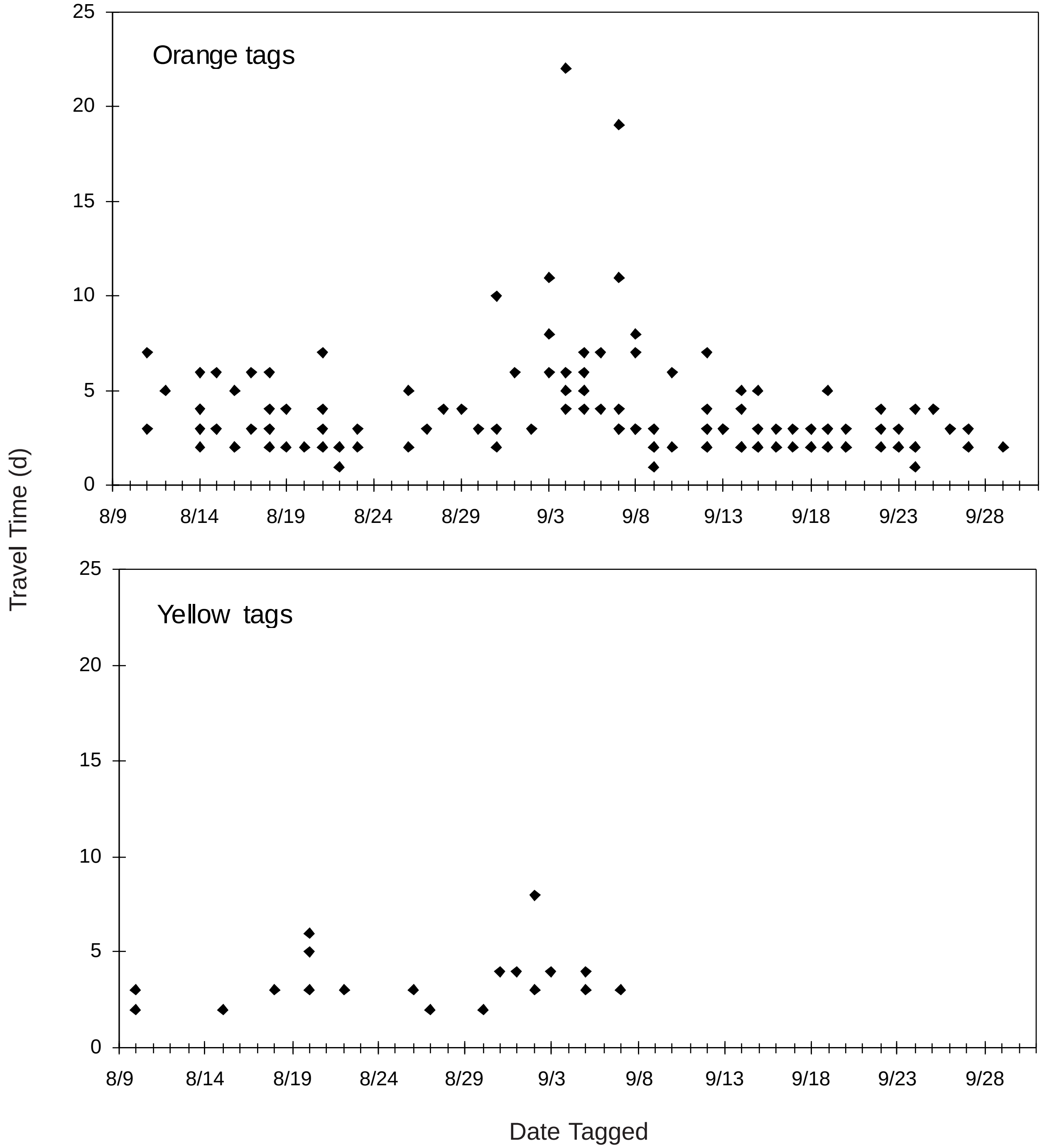

Figure 9. Frequencies of days travel time by date tagged for orange- and yellow-tagged chum salmon recaptured in either the right- or left-bank recovery fish wheels in the Tanana River, 1995.

Table 8. Hypothetical summary statistics, abundance estimates, and coefficients of variance of fall-run chum salmon in the Tanana River expected on 15 September under different factors of tagging effort and run size relative to the 1995 tag deployment at the right-bank fish wheel and catches of marked and unmarked chum salmon in the right- and left-bank recovery fish wheels.

Tagging Effort Factor	Run Size Factor	Tags Deployed	Recovery Catch: Recaptures	Recovery Catch: Total	Abundance Estimate	CV on 15 Sept.
			Using right-bank recovery fish wheel only			
1 (6 h/d)	1	2,391	46	3,922	199,572	0.14
1 "	0.75	1,793	35	2,942	148,638	0.16
1 "	0.5	1,196	23	1,961	97,732	0.20
1.3 (8 h/d)	1	3,188	61	3,922	200,639	0.12
1.3 "	0.75	2,391	46	2,942	149,692	0.14
1.3 "	0.5	1,594	31	1,961	98,761	0.17
2 (12 h/d)	1	4,782	92	3,922	201,718	0.10
2 "	0.75	3,587	69	2,942	150,761	0.12
2 "	0.5	2,391	46	1,961	99,812	0.14
4 (24 h/d)	1	9,564	184	3,922	202,808	0.07
4 "	0.75	7,173	138	2,942	151,846	0.08
4 "	0.5	4,782	92	1,961	100,885	0.10
			Using both recovery fish wheels			
1 (6 h/d)	1	2,391	73	6,909	223,268	0.11
1 "	0.75	1,793	55	5,182	166,708	0.13
1 "	0.5	1,196	37	3,455	110,161	0.16
1.3 (8 h/d)	1	3,188	97	6,909	224,025	0.10
1.3 "	0.75	2,391	73	5,182	167,459	0.11
1.3 "	0.5	1,594	49	3,455	110,901	0.14
2 (12 h/d)	1	4,782	146	6,909	224,787	0.08
2 "	0.75	3,587	110	5,182	168,217	0.09
2 "	0.5	2,391	73	3,455	111,650	0.11
4 (24 h/d)	1	9,564	292	6,909	225,554	0.06
4 "	0.75	7,173	219	5,182	168,981	0.07
4 "	0.5	4,782	146	3,455	112,410	0.08

Multiple recaptures were a source of concern in the abundance calculation. If unmarked fish were also recaptured more than once with the same probability as marked fish, then multiple recaptures were not a source of bias in the abundance estimate. By the time tagged fish were recaptured, handling stress from tagging was probably diminished and inconsequential. Marking some or all fish in the recovery wheels, which would enable this assumption to be tested, was not practicable.

Although a midseason abundance estimate was achievable, a prediction of overall run strength relies on run timing. This variable should be considered if and when a midseason estimate is used for management decisions. However, harvest regulation based on this abundance estimate will still depend on policy guidelines established by the Alaska Board of Fisheries. For example, long-term comparisons between spawner counts in the Delta River and the mark-recapture abundance estimate will be required if fall chum salmon are managed to achieve escapement goals in the Delta River.

Migration rates were positively biased because not all tagged fish, particularly the slower ones, had an opportunity to reach the recovery wheels when the project was terminated. This bias was presumably small, due to the potentially low number of recaptures from fewer numbers of tags deployed in the final days. The mean migration rate obtained in this study (26 km/d) is lower than the 30.5–35.7 km/d reported by Milligan et al. (1984) for fall chum salmon in the upper Yukon drainage, Canada. It is also lower than the 37 km/d that Buklis and Barton (1984) estimated from mean date of passage at various locations on the lower Yukon River. Similar to the migration rate in this study, Brock (1976, as cited by Buklis and Barton 1984) reported a rate of 28.4 km/d for fall chum salmon in the Yukon River near Dawson.

Tag recoveries from spawning chum salmon in the Delta River indicate that peak migration of this stock at the right-bank tagging site was around 15 September, which coincided with peak tag deployment. Run timing for the Rika's Roadhouse and Bluff Cabin Slough spawning stocks was not adequately obtained due to the low number of tags recovered and the limited number of ground surveys.

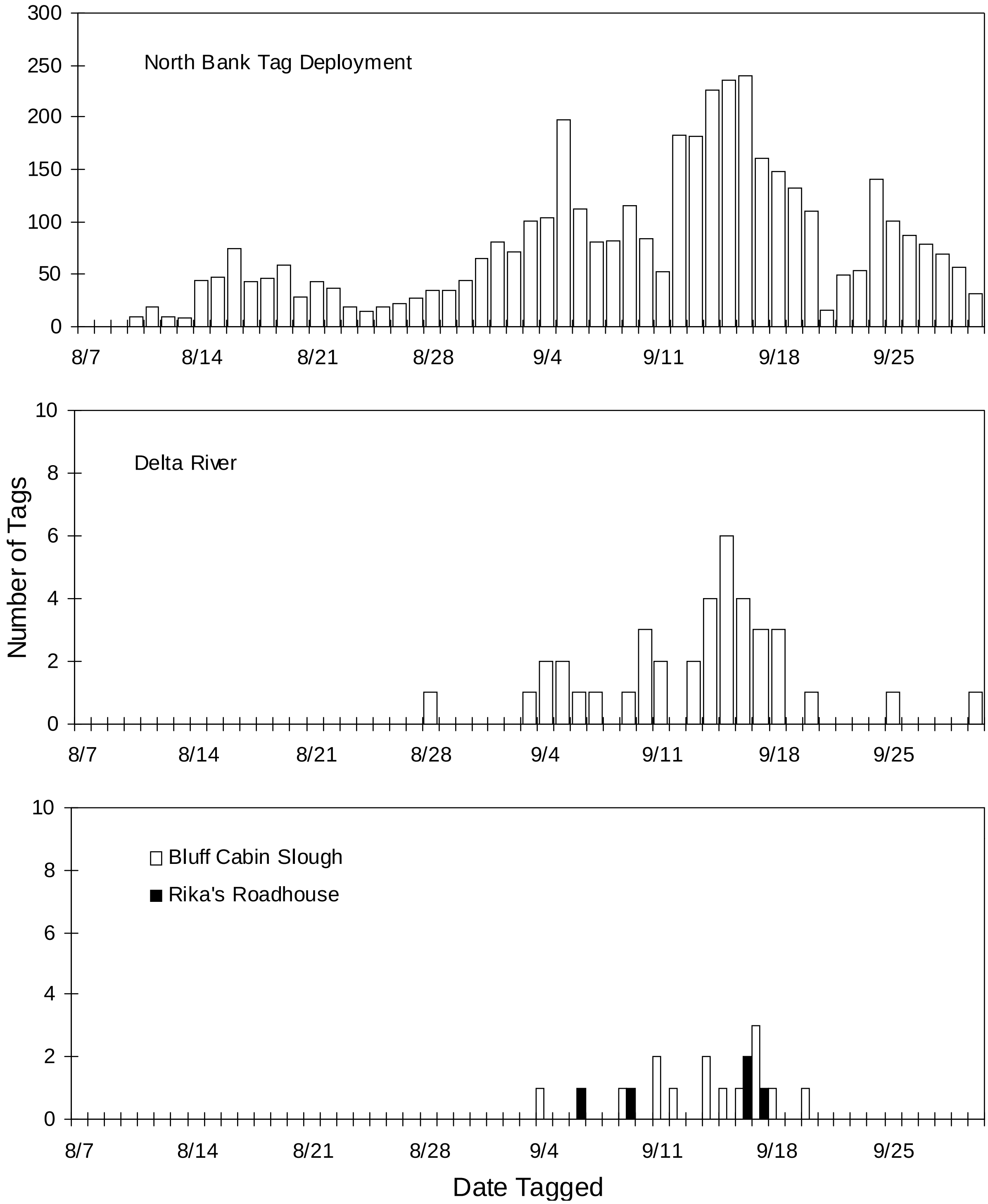

Figure 10. Number of orange tags recovered from fall chum salmon at various spawning grounds by date tagged in the Tanana River, 1995. The number of tags deployed by day (top graph) is shown for comparison.

CONCLUSIONS

1. The results of this study indicated that a mark-recapture program, using fish wheels for fish capture, may be feasible for estimating abundance of fall chum salmon in the upper Tanana River.

2. Before this program is fully adopted as a reliable annual management tool, its performance with relatively lower run sizes (e.g., 50% of 1995 levels) and various other factors, such as water levels, should be evaluated. Lower run sizes provide less margin of error for fishery decisions relative to meeting minimum escapement goals, and unless tag deployment and recovery efforts are substantially increased, low runs could increase the confidence bounds of the abundance estimate. Additionally, fish wheel malfunctions, river conditions, or changes in wheel operators, 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.

3. The left-bank tagging wheel is unnecessary for future mark-recapture abundance estimates of fall chum salmon. Bank-side predisposition was not apparent, and the low number of tags deployed from this site was not cost effective. Considering the performance of the left-bank wheel at the 2 locations and information provided by the fish-wheel contractor, finding a wheel site on the left bank that would result in adequate chum catches is doubtful.

4. Tagging a greater portion of the fall chum salmon population, particularly with small run sizes, may be necessary if improved precision of a mid or postseason abundance estimate is desired. Although tagging the entire catch at the right-bank tagging wheel may be desirable for improving precision, some problems could be encountered: (1) fish tagged after remaining in the live box overnight may be stressed and react differently causing a difference in recapture probabilities, (2) high mortalities may occur in the live box from overcrowding during peak catches, and (3) tagging in constant proportion to the run may not be possible during days when the catch exceeds the number that can be tagged in a work day. To address problem 1, fish held overnight could receive different tags or be specially noted in the data to test for differences in recapture probability. A time-stratified abundance model may help correct potential bias from problem 3. Stratified abundance estimates, however, may be difficult to generate inseason and the variance is often larger than estimates from unstratified models.

5. This project should continue to use 2 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 2 wheels will also help maintain recovery effort if one of the wheels becomes disabled.

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Appendix A. Distances from mouth of Tanana River to tagging and recovery fish wheel sites, and the distances between sites used for calculating migration rates of recaptured fall-run chum salmon in 1995.

	Distance From Mouth	
Location	Miles	Kilometers
Kantishna River mouth	793	1,276
Left-bank tagging site 2	796	1,281
Left-bank tagging site 1	798	1,283
Right-bank tagging site	799	1,285
Right-bank recovery site	844	1,358
Left-bank recovery site	845	1,360
Nenana	860	1,384

Distance between sites (km)	
Right tag to right recovery	73.21
Right tag to left recovery	74.82
Left tag to right recovery	74.82
Left tag to left recovery	76.43
Left tag site 2 to right recovery	76.83
Left tag site 2 to left recovery	78.44

Appendix B.1. Daily fishing effort and catches of summer- and fall-run chum salmon in the left-bank tagging wheel in the Tanana River, 1995.

Date	Effort (h/d)	Tagged			Recaptures		Mortalities		Catch Not Tagged			Total Catch		
		Male	Fem.	Total	Male	Fem.	Male	Fem.	Male	Fem.	Total	Male	Fem.	Total
Summer Run														
8/3	14	0	0	0	0	0	0	0	5	6	11	5	6	11
8/4	24	0	0	0	0	0	0	0	5	4	9	5	4	9
8/5	24	0	0	0	0	0	0	0	7	6	13	7	6	13
8/6	24	0	0	0	0	0	0	0	21	17	38	21	17	38
8/7	16	0	2	2	0	0	0	0	13	15	28	13	17	30
8/8	24	0	0	0	0	0	0	0	3	12	15	3	12	15
8/9	24	0	0	0	0	0	0	0	10	13	23	10	13	23
8/10	20	7	5	12	0	0	0	0	12	13	25	19	18	37
8/11	18	5	4	9	0	0	0	0	4	11	15	9	15	24
8/12	24	4	1	5	0	0	0	0	8	10	18	12	11	23
8/13	18	0	2	2	0	0	0	0	8	21	29	8	23	31
8/14	4[a]	0	0	0	0	0	0	1	7	18	25	7	19	26
8/15	26	3	4	7	0	0	0	0	7	10	17	10	14	24
Subtotal		19	18	37	0	0	0	1	110	156	266	129	175	304
Fall Run														
8/16	23	0	1	1	0	0	0	0	3	5	8	3	6	9
8/17	0[b]	0	0	0	0	0	0	0	0	0	0	0	0	0
8/18	20	2	2	4	0	0	0	0	2	2	4	4	4	8
8/19	24	2	3	5	0	0	0	0	2	3	5	4	6	10
8/20	24	6	8	14	0	0	0	0	2	4	6	8	12	20
8/21	6	2	2	4	0	0	0	0	3	4	7	5	6	11[c]
8/22	24	3	0	3	0	0	0	0	2	6	8	5	6	11
8/23	24	0	1	1	0	0	0	0	2	4	6	2	5	7
8/24	12	2	3	5	0	0	0	0	1	3	4	3	6	9
8/25	24	6	1	7	1	0	0	0	9	7	16	16	8	24
8/26	24	2	1	3	0	0	0	0	5	5	10	7	6	13
8/27	24	3	0	3	0	0	0	0	5	2	7	8	2	10
8/28	24	1	2	3	0	0	1	0	5	8	13	7	10	17
8/29	24	6	4	10	0	0	0	0	2	4	6	8	8	16
8/30	24	4	1	5	0	0	0	0	5	5	10	9	6	15
8/31	24	2	2	4	0	0	0	0	8	4	12	10	6	16
9/1	24	9	2	11	0	0	1	0	8	4	12	18	6	24
9/2	24	6	3	9	0	0	0	0	5	4	9	11	7	18[c]
9/3	24	3	3	6	0	0	0	0	9	6	15	12	9	21[c]
9/4	24	3	3	6	0	0	0	0	6	4	10	9	7	16
9/5	24	4	1	5	0	0	0	0	7	11	18	11	12	23
9/6	24	1	1	2	0	0	0	0	3	0	3	4	1	5
9/7	24	1	2	3	0	0	0	0	1	1	2	2	3	5
9/8	24	2	4	6	0	0	1	0	1	1	2	4	5	9
9/9	24	3	1	4	0	0	0	0	2	2	4	5	3	8
9/10	24	3	0	3	0	0	0	0	6	6	12	9	6	15
9/11	24	2	1	3	0	0	0	0	0	0	0	2	1	3
9/12	24	2	1	3	0	0	0	0	5	3	8	7	4	11
9/13	24	2	1	3	0	0	0	0	3	3	6	5	4	9
9/14	24	2	1	3	0	0	0	0	11	5	16	13	6	19
9/15	24	0	0	0	0	0	0	0	1	6	7	1	6	7
9/16	24	0	3	3	0	0	0	0	3	9	12	3	12	15
9/17	24	3	1	4	0	0	0	0	2	3	5	5	4	9
9/18	24	1	1	2	0	0	0	0	2	5	7	3	6	9
9/19	24	1	3	4	0	0	1	0	1	6	7	3	9	12[c]
9/20	24	0	0	0	0	0	0	0	2	0	2	2	0	2
9/21	24	4	2	6	0	0	0	0	1	2	3	5	4	9
9/22	24	1	2	3	0	0	1	1	4	4	8	6	7	13
9/23	24	1	1	2	0	0	1	1	4	5	9	6	7	13
9/24	24	0	2	2	0	0	0	0	4	9	13	4	11	15
9/25	24	0	6	6	0	0	0	0	3	2	5	3	8	11
9/26	24	3	2	5	0	0	0	0	3	7	10	6	9	15
9/27	24	1	1	2	0	0	0	0	3	0	3	4	1	5
9/28	24	0	2	2	0	0	0	0	0	2	2	0	4	4
9/29	24	0	1	1	0	0	0	0	0	0	0	0	1	1
9/30	24	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal		99	82	181	1	0	6	2	156	176	332	262	260	522
Grand Total		118	100	218	1	0	6	3	266	332	598	391	435	826

[a] wheel down during day
[b] wheel was being moved
[c] chute damage, fish missing live box

Appendix B.2. Daily fishing effort and catches of summer- and fall-run chum salmon in the right-bank tagging wheel in the Tanana River, 1995.

Date	Effort (h/d)	Tagged			Recaptures		Mortalities		Catch Not Tagged			Total Catch		
		Male	Fem.	Total	Male	Fem.	Male	Fem.	Male	Fem.	Total	Male	Fem.	Total
Summer Run														
8/3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/9	10	0	0	0	0	0	0	0	7	5	12	7	5	12
8/10	24	2	7	9	1	0	0	0	20	11	31	23	18	41
8/11	24	9	10	19	0	0	0	0	12	16	28	21	26	47
8/12	6[a]	3	7	10	0	0	0	0	0	0	0	3	7	10
8/13	24	3	5	8	0	0	0	0	60	86	146	63	91	154
8/14	6[b]	17	27	441	0	0	0		0	0	0	18	27	45
8/15	24	27	20	47	0	0	1	0	40	74	114	68	94	162
Subtotal		61	76	137	2	0	1	0	139	192	331	203	268	471
Fall Run														
8/16	24	38	37	75	0	0	1	2	74	79	153	113	118	231
8/17	24	18	25	43	0	0	1	4	83	95	178	102	124	226
8/18	6[b]	18	28	46	0	0	0	0	0	0	0	18	28	46
8/19	24	25	34	59	1	0	3	1	91	69	160	120	104	224
8/20	24	24	5	29	0	0	0	0	58	47	105	82	52	134
8/21	6[b]	28	14	42	0	0	1	0	0	0	0	29	14	43
8/22	24	21	15	36	0	0	0	0	58	50	108	79	65	144
8/23	24	9	10	19	0	0	0	0	45	41	86	54	51	105
8/24	24	10	5	15	0	1	0	1	26	20	46	36	27	63
8/25	24	9	10	19	0	1	0	0	25	29	54	34	40	74
8/26	24	10	12	22	1	0	0	1	41	26	67	52	39	91
8/27	24	10	17	27	0	0	0	1	40	39	79	50	57	107
8/28	24	20	14	34	0	1	0	0	60	37	97	80	52	132
8/29	24	24	10	34	0	0	0	0	60	40	100	84	50	134
8/30	24	28	16	44	0	1	1	0	62	49	111	91	66	157
8/31	24	40	25	65	1	0	0	0	122	87	209	163	112	275
9/1	24	56	25	81	0	0	0	0	113	96	209	169	121	290
9/2	24	40	31	71	0	0	0	0	158	102	260	198	133	331
9/3	24	61	40	101	1	0	2	3	270	132	402	334	175	509
9/4	24	64	41	105	0	0	1	7	257	193	450[c]	322	241	563
9/5	24	115	83	198	2	1	0	0	319	205	524	436	289	725
9/6	24	68	44	112	1	0	0	0	306	229	535	375	273	648
9/7	24	40	41	81	0	3	2	5	129	101	230	171	150	321
9/8	24	48	34	82	0	1	0	0	65	57	122	113	92	205
9/9	24	64	52	116	0	0	0	0	223	145	368	287	197	484
9/10	24	46	37	83	0	0	0	0	184	121	305	230	158	388
9/11	24	30	22	52	0	0	0	0	40	41	81	70	63	133[d]
9/12	24	106	77	183	1	1	0	0	161	184	345	268	262	530
9/13	24	104	78	182	1	0	0	0	229	249	478	334	327	661
9/14	24	121	105	226	1	1	12	22	255	214	469	389	342	731
9/15	24	129	106	235	6	2	0	0	550	550	1,100	685	658	1,343
9/16	24	144	96	240	1	3	0	0	559	585	1,144	704	684	1,388
9/17	24	90	71	161	2	4	1	2	573	574	1,147	666	651	1,317
9/18	10[e]	90	59	149	2	0	0	0	60	67	127	152	126	278
9/19	24	64	68	132	1	0	0	0	313	291	604	378	359	737
9/20	9[f]	55	56	111	0	2	1	4	48	46	94	104	108	212
9/21	24	9	7	16	0	0	34	32	71	40	111	114	79	193[d]
9/22	24	22	27	49	0	2	7	4	98	105	203	127	138	265
9/23	24	20	34	54	0	1	0	0	87	103	190	107	138	245
9/24	24	63	77	140	1	1	0	0	137	188	325	201	266	467
9/25	24	47	54	101	3	2	0	0	140	190	330[g]	190	246	436
9/26	24	35	52	87	0	1	0	0	185	245	430	220	298	518
9/27	24	30	49	79	0	0	0	0	85	101	186	115	150	265
9/28	24	29	40	69	2	1	0	0	55	122	177	86	163	249
9/29	24	19	38	57	0	0	0	1	72	131	203	91	170	261
9/30	24	11	20	31	1	0	0	0	50	150	200[g]	62	170	232
Subtotal		2,152	1,841	3,9930	29	30	67	90	6,637	6,265	12,902	8,885	8,226	17,111
Grand Total		2,213	1,917	4,130	31	30	68	90	6,776	6,457	13,233	9,088	8,494	17,582

[a] hole in live box overnight, effective effort only 6 h
[b] 6-h day during tagging schedule only, wheel shut off remainder of day
[c] sex ratios estimated
[d] hole in live box
[e] wheel shut off at 2200 hours
[f] wheel shut off at 2100 hours
[g] unmarked catch estimated

Appendix B.3. Daily fishing effort and catches of summer and fall chum salmon in the left-bank recovery fish wheel in the Tanana River, 1995.

	Effort	Recaptures					Unmarked Catch			Total Catch		
Date	(h/d)	Male	Fem.	Org.	Yel.	Total	Male	Fem.	Total	Male	Fem.	Total
Summer Run												
8/7	0	0	0	0	0	0	0	0	0	0	0	0
8/8	15	0	0	0	0	0	17	23	40	17	23	40
8/9	24	0	0	0	0	0	27	33	60	27	33	60
8/10	24	0	0	0	0	0	52	55	107	52	55	107
8/11	24	0	0	0	0	0	18	15	33	18	15	33
8/12	24	0	0	0	0	0	18	19	37	18	19	37
8/13	24	0	0	0	0	0	16	22	38	16	22	38
8/14	24	0	0	0	0	0	22	9	31	22	9	31
8/15	24	0	0	0	0	0	2	0	2	2	0	2
Subtotal		0	0	0	0	0	172	176	348	172	176	348
Fall Run												
8/16	16	0	1	1	0	1[b,c]	41	89	130	41	90	131
8/17	24	1	3	3	1	4[d,e,f]	62	74	136	63	77	140
8/18	24	5	2	7	0	7[d,g]	54	70	124	59	72	131
8/19	24	0	0	0	0	0	23	30	53	23	30	53
8/20	24	0	2	2	0	2[b]	20	27	47	20	29	49
8/21	24	4	0	4	0	4	22	19	41	26	19	45
8/22	24	2	0	2	0	2	19	44	63	21	44	65
8/23	24	0	1	1	0	1	32	33	65	32	34	66
8/24	24	0	0	0	0	0	20	30	50	20	30	50
8/25	24	0	0	0	0	0	15	10	25	15	10	25
8/26	24	1	1	1	1	2	22	12	34	23	13	36
8/27	24	0	0	0	0	0	23	17	40	23	17	40
8/28	24	0	2	2	0	2	24	22	46	24	24	48
8/29	24	0	0	0	0	0	23	19	42	23	19	42
8/30	24	0	1	1	0	1	35	22	57	35	23	58
8/31	24	0	0	0	0	0	44	29	73	44	29	73
9/1	24	1	0	1	0	1	54	40	94	55	40	95
9/2	24	0	0	0	0	0	41	27	68	41	27	68
9/3	24	0	0	0	0	0	50	36	86	50	36	86
9/4	24	0	1	0	1	1	54	40	94	54	41	95
9/5	24	3	0	1	2	3	78	46	124	81	46	127
9/6	24	0	0	0	0	0	20	16	36	20	16	36
9/7	9	2	0	1	1	2	15	15	30	17	15	32
9/8	24	1	0	1	0	1[h]	92	69	161	93	69	162
9/9	24	2	0	1	1	2	93	63	156	95	63	158
9/10	24	2	3	3	2	5	114	72	186	116	75	191
9/11	24	2	1	3	0	3	124	78	202	126	79	205
9/12	24	0	0	0	0	0	134	76	210	134	76	210
9/13	24	0	0	0	0	0	122	83	205	122	83	205
9/14	24	1	1	2	0	2	114	88	202	115	89	204
9/15	24	0	0	0	0	0	112	68	180	112	68	180
9/16	24	2	2	4	0	4	61	38	99	63	40	103
9/17	24	1	1	2	0	2	36	25	61	37	26	63
9/18	24	2	0	2	0	2	50	44	94	52	44	96
9/19	24	1	0	1	0	1	38	25	63	39	25	64
9/20	20	1	2	3	0	3	33	26	59	34	28	62
9/21	24	1	1	2	0	2	41	34	75	42	35	77
9/22	24	1	0	1	0	1	42	29	71	43	29	72
9/23	24	0	0	0	0	0	19	29	48	19	29	48
9/24	24	0	2	2	0	2[c]	71	70	141	71	72	143
9/25	26	2	2	4	0	4	41	37	78	43	39	82
9/26	23	2	3	5	0	5	24	38	62	26	41	67
9/27	24	1	0	1	0	1[h]	29	32	61	30	32	62
9/28	24	0	0	0	0	0	28	44	72	28	44	72
9/29	24	1	0	1	0	1	22	33	55	23	33	56
9/30	0	0	0	0	0	0	0	0	0	0	0	0
10/1	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal		42	32	65	9	74	2,231	1,868	4,099	2,273	1,900	4,173
Grand Total		42	32	65	9	74	2,403	2,044	4,447	2,445	2,076	4,521

[a] includes fish harvested and released alive without marks
[b] includes 1 female (org.) tagged prior to 16 August
[c] includes 1 female (org.) caught a second time
[d] includes 2 females (org.) tagged prior to 16 August
[e] includes 1 male (org.) tagged prior to 16 August
[f] includes 1 female (yel.) tagged prior to 16 August
[g] includes 3 males (org.) tagged prior to 16 August
[h] includes 1 male (org.) caught second time

Appendix B.4. Daily fishing effort and catches of summer and fall chum salmon in the right-bank recovery fish wheel in the Tanana River, 1995.

	Effort	Recaptures					Unmarked Catch[a]			Total Catch		
Date	(h/d)	Male	Fem.	Org.	Yel.	Total	Male	Fem.	Total	Male	Fem.	Total
Summer Run												
8/7	24	0	0	0	0	0	94	108	202	94	108	202
8/8	24	0	0	0	0	0	95	112	207	95	112	207
8/9	24	0	0	0	0	0	86	90	176	86	90	176
8/10	24	0	0	0	0	0	73	66	139	73	66	139
8/11	18	0	0	0	0	0	31	30	61	31	30	61
8/12	24	1	0	0	1	1	53	38	91	54	38	92
8/13	24	1	0	0	1	1	60	59	119	61	59	120
8/14	24	0	1	1	0	1	104	83	187	104	84	188
8/15	24	0	0	0	0	0	31	50	81	31	50	81
Subtotal		2	1	1	2	3	627	636	1,263	629	637	1,266
Fall Run												
8/16	24	0	1	1	0	1[b]	28	50	78	28	51	79
8/17	24	0	1	1	0	1[b]	66	89	155	66	90	156
8/18	24	0	1	1	0	1[b]	76	75	151	76	76	152
8/19	24	0	0	0	0	0	35	60	95	35	60	95
8/20	24		1	1	2	0	2[b]	36	52	88	37	5390
8/21	24	1	2	2	1	3[b]	57	71	128	58	73	131
8/22	24	0	0	0	0	0	75	68	143	75	68	143
8/23	24	3	2	4	1	5	57	52	109	60	54	114
8/24	24	2	2	4	0	4	31	57	88	33	59	92
8/25	24	4	0	2	2	4	42	41	83	46	41	87
8/26	15	0	0	0	0	0	28	29	57	28	29	57
8/27	22	1	0	1	0	1[c]	31	28	59	32	28	60
8/28	9	0	0	0	0	0	12	5	17	12	5	17
8/29	24	0	2	0	2	2	78	60	138	78	62	140
8/30	24	0	0	0	0	0	57	38	95	57	38	95
8/31	24	2	1	2	1	3[c,e]	65	43	108	67	44	111
9/1	24	0	1	0	1	1	72	69	141	72	70	142
9/2	24	3	0	3	0	3	114	25	139	117	25	142
9/3	24	1	0	1	0	1	92	22	114	93	22	115
9/4	1	0	0	0	0	0	3	1	4	3	1	4
9/5	0	0	0	0	0	0	0	0	0	0	0	0
9/6	0	0	0	0	0	0	0	0	0	0	0	0
9/7	0	0	0	0	0	0	0	0	0	0	0	0
9/8	24	1	1	1	1	2[c]	56	65	121	57	66	123
9/9	24	0	2	2	0	2	191	115	306	191	117	308
9/10	24	5	2	7	0	7	232	101	333	237	103	340
9/11	24	4	3	7	0	7	217	83	300	221	86	307
9/12	24	3	1	4	0	4	257	147	404	260	148	408
9/13	24	1	0	1	0	1	166	85	251	167	85	252
9/14	24	1	1	2	0	2	241	137	378	242	138	380
9/15	24	1	2	3	0	3	122	44	166	123	46	169
9/16	24	4	6	10	0	10	165	97	262	169	103	272
9/17	24	3	0	3	0	3	101	64	165	104	64	168
9/18	24	2	2	4	0	4	147	72	219	149	74	223
9/19	20	2	1	3	0	3	166	89	255	168	90	258
9/20	24	3	0	3	0	3	164	79	243	167	79	246
9/21	24	2	1	3	0	3	93	41	134	95	42	137
9/22	24	2	4	6	0	6	181	155	336	183	159	342
9/23	24	0	1	1	0	1	31	37	68	31	38	69
9/24	24	2	0	1	0	2[c,d]	28	30	58	30	30	60
9/25	26	0	1	1	0	1	120	130	250	120	131	251
9/26	23	1	2	3	0	3	81	97	178	82	99	181
9/27	24	0	0	0	0	0	43	58	101	43	58	101
9/28	24	0	1	1	0	1	37	72	109	37	73	110
9/29	24	2	4	6	0	6[f]	53	84	137	55	88	143
9/30	24	0	2	2	0	2	25	43	68	25	45	70
10/1	24	0	1	1	0	1	24	43	67	24	44	68
Subtotal		57	52	99	9	109	3,996	2,903	6,899	4,053	2,955	7,008
Grand Total		59	53	100	11	112	4,623	3,539	8,162	4,682	3,592	8,274

[a] includes fish harvested and released alive without marks
[b] includes 1 female (org.) tagged prior to 16 August
[c] includes 1 female (org.) caught a second time
[d] includes 1 tag loss
[e] includes 1 male (yel.) caught a second time
[f] includes 1 male (org.) caught a third time; previous 2 captures were in left-bank fish wheel