Evidence of Handling Mortality in Fall Chum Salmon Caused by Fish Wheel Capture on the Yukon River, Alaska

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by

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Abstract

From 1996 to 1998, tagged fall chum salmon *Oncorhynchus keta* from a mark and recapture experiment in the Yukon River, Alaska, were used to examine the potential effects of fish-wheel capture, handling, and tagging. Four fish wheels equipped with live holding boxes were used to capture fish; two for the marking event and two for the recapture event. The number of fish tagged ranged from 8,513 to 18,632 during the three years of the study. In addition, local fishers returned from 594 to 1,007 tags each year. Individual salmon were captured from one to four times in the four fish wheels used in the mark and recapture experiment. Tags returned by fishers were used to investigate the relationship between the probability of final capture somewhere other than project fish wheels and the capture history within the mark and recapture experiment. Results of likelihood ratio tests and logistic regression results indicated that recapture probabilities declined as the number of times a fish is captured increases. Also, available data indicated that the ratio of marked to unmarked fish decreased as distance from the mark and recapture study area increased. One possible explanation for these observations is that one or more aspect of fish capture and handling in the mark and recapture experiment increased mortality rates. For that reason these results raise concern over the relatively common use of fish wheels for gathering in-season catch-per-unit-effort data and other research purposes. We recommend more definitive investigation of these phenomena, a review of fish wheel construction and operation to minimize potential impacts to salmon populations, and the development of alternatives to current live box capture practices.

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Introduction

Catch-per-unit-effort (CPUE) from fish wheels has been used to monitor the run timing and strength of fall chum salmon *Oncorhynchus* keta in the Yukon River drainage for many years. More recently, fish wheels have been used to capture fall chum salmon in mark and recapture experiments on the Yukon River in Canada (Milligan et al. 1986) and the United States (Gordon et al. 1998; Underwood et al. 2000a, Underwood et al. 2000b), and on the Tanana River (Cappiello and Bromaghin 1997), a major tributary of the Yukon River. Fish are scooped out of the water by the baskets of a fish wheel, after which they slide down a chute into a live box, a submerged box attached to the fish wheel through which water flow is maintained. Fish can be held in the live box until they are processed and released.

The efficiency and nonlethal nature of fish wheels were believed to provide advantages over other gear types. The assumption of no negative effects came into question when Underwood et al. (2000b) reported that the ratio of marked to unmarked fish decreased as distance upstream of the tagging site increased. Underwood et al. (2000b) listed nine hypotheses that might explain this phenomenon (Table 1). Several hypotheses, including incomplete reporting, trap shyness, tag loss, and selectivity, were either shown or thought to be unlikely, whereas others required further investigation. One hypothesis needing additional investigation was that capture, holding, and handling increased mortality rates, a common phenomenon in tagging studies (Seber 1982; Stichney 1983).

In this paper we investigate cumulative handling effects associated with a fall chum salmon mark and recapture experiment on the Yukon River. Our approach explores the possibility that fish wheels increase mortality rates by categorizing the number of times a fish is captured during the course of the mark and recapture experiment (internal capture) and then calculating the probability of a tag being returned from somewhere other than the mark and recapture fish wheels, which we refer to as external recapture. Available data on the proportion of fish having tags and data regarding tag loss at various locations upriver of the mark and recapture site are presented.

Study Area

The Yukon River (Figure 1) is over 3,200 km in length and drains about 860,000 km^2, of which about 330,200 km^2 lie in Canada (Beacham et al. 1988). The Yukon River in Alaska above the confluence of the Tanana River drains portions of the Brooks Range on the north and numerous smaller ranges to the south. In Canada, the northwestern extension of the Rocky Mountains borders the drainage to the east, while the Wrangell-St. Elias Range lies to the southwest. Numerous smaller mountain ranges lie within the drainage. The river is turbid in summer, but clears to some degree in winter when the influence of glacial runoff, erosion, and tannic lowlands are reduced (Buklis and Barton 1984). River ice breaks apart in May and can cause pooling for miles when ice jams dam the river.

A mark and recapture experiment was conducted from 1996 to 1998 on the Yukon River main-stem between river km (rkm) 1,170, a canyon above the confluence with the Tanana River, and the village of Rampart (rkm 1,221), Alaska (Gordon et al. 1998;

Underwood et al. 2000a and Underwood et al. 2000b). This section of the Yukon River is characterized as meandering with a single channel with several islands.

Methods

Marking Site Sampling Procedures

The fish wheels at the capture site were composed of floatation logs, two baskets, padded chutes, and live holding boxes (Figure 2). The baskets on these fish wheels were approximately 3.0 m wide and dipped to a depth of 4.5 m below the water's surface. Baskets were lined with wire, nylon or plastic netting, or chain link fencing. Nylon seine netting was installed on the sides of the baskets to minimize injury to fish as they were lifted from the water. Closed-cell foam padding was placed along the chute and the ramp on the path to the holding boxes to reduce impact injury to fish. Live boxes were 2.4 m long, 1.2 m deep, and approximately 1 m wide. The walls and floors of the live boxes contained many 5 cm diameter holes to allow a continuous flow of water while preventing heavy current that could potentially impinge or tire fish.

Wheels were placed across from each other on the north and south banks. Wheel placement, relative to shore, was determined by the depth of the dip on the shoreward edge of the baskets, and the sweep was within 30 cm of the bottom. Wheels were moved inshore or offshore to maintain the proximity to the bottom. A lead, similar to a submerged picket fence, was placed between the wheel and the shore to direct fish towards the dipping baskets.

Tagging commenced by August 3 and ceased approximately September 20 each year. Fish were marked six days a week, Monday through Saturday. During 1996, most fish were marked between 1000 and 1400 hours. In subsequent years, operations were modified to balance the objectives of marking 400 fish per day, the need of spreading the release of marked fish throughout the day and reducing holding times in the live boxes. Generally, crews marked fish starting at four different times (0800, 1200, 1600, and 1900 hours) with a sample size goal of 100 fish each time. Chum salmon were marked with individually numbered spaghetti tags applied with barbed (1996) and hollow (1997 and 1998) applicator needles. During first nine days of sampling in 1996 a caudal punch was applied as a secondary mark. During 1997 and 1998, a left pelvic fin clip was applied as a secondary mark excised about one half of the fin perpendicular to the finrays. Severely injured or diseased fish were released without marking. Fish wheels were operated as long as 24 hours per day during times of low catch rates and fewer than 6 hours per day when catch rates were high.

Recapture Site Sampling Procedures

The river at the recapture site was wider and shallower than at the marking site, so the fish wheels were sized accordingly. The south bank wheel was placed about 2 km downstream from the north bank wheel. Sampling commenced at both recapture wheels approximately one day after tagging commenced. Recapture fish wheels were operated 24 hours per day, seven days a week. The frequency of emptying fish from the live box depended on the catch rates; the live box was emptied from two to four times on most days. The fish wheel contractor was instructed to make every effort to ensure that the number of fish in a live box did not exceed 200 fish; however, this number was exceeded at times in all years. Recorded data included a tally of marked and unmarked fish and the tag number of recaptured fish. All fish were released alive except at times during scheduled openings of the subsistence fishery and in 1998 when 60 fish were sacrificed for blood analysis and necropsy.

Final Recovery of Tags

Four methods were used to recover tags external to the mark and recapture study. First, fishermen returned tags. Second, ongoing fishery research projects in the United States and Canada collected data at other sites within the drainage. Third, targeted data collection from three villages was accomplished through face to face and telephone interviews with fishermen. Fourth, arrangements were made with specific fishermen to collect data in locations not close to a surveyed village. After 1996 these fishermen received a preseason briefing by telephone regarding identification of the primary (a spaghetti tag) and secondary marks (a ventral fin clip). The data collected included the tag number, tallies of marked and unmarked fish, and tallies of fish with the secondary mark but missing the primary mark, although some participants did not return all three types of data.

Analysis of Data

The influence of capture histories, i.e., number of times a fish was captured in project fish wheels, on the probability of external recapture was evaluated using generalized linear models (McCulloch and Searle 2001) and likelihood ratio tests (Stuart et al. 1999). Generalized linear models were fit to the data using SAS PROC GENMOD (SAS Institute, Inc. 1999), with an identity link and a binomial error structure. The design matrix was constructed so that the parameter estimates replicated the observed proportion of tags recaptured externally for each capture history. The CONTRAST option of PROC GENMOD was used to perform a likelihood ratio test that the proportions were equal for all capture histories. Models were fit and hypotheses were tested separately with each of the three years of data.

Logistic regression models were also fit to the data for each year. Each model contained two parameters, an intercept, and a coefficient for the number of times a fish was captured in the four project fish wheels. Logistic regression models were fit using SAS PROC LOGISTIC (SAS Institute, Inc. 1999).

Results and Discussion

The number of marked fish released during the three years of the study, 1996 to 1998, were 17,568, 18,632, and 8,513, respectively. The number of tags recovered externally using all four data collection methods totaled 594, 1,007, and 1,002 for the years from 1996 to 1998. Rates of recovery appeared to decrease with increased distance from the tagging site (Table 2). Although data were obtained from a variety of sources, the trends were consistent among both data sources and years and they were, therefore, thought to be of value. Simple linear regression models were fit to the data with outliers removed for each year which enhanced the visualization of trends. The rate of change appeared to be greater in 1997 based on visual inspection of the plotted lines (Figure 3).

These results document the declining ratios of marked to unmarked salmon with increasing distance from the mark and recapture study site, hence the development of the nine possible explanations (Table 1). Most explanations were considered to be unlikely because they were either inconsistent with available data or the expected magnitude of the effect was judged insufficient to produce the observed trends. For example, the possibility of incomplete reporting was eliminated because directed efforts to improve reporting were judged to be more than adequate and trend results did not change. Also, failure to report would have had to be substantial and to decline with distance from the project, which was thought to be unlikely. Second, immigration as a cause was deduced to be unreasonable because the magnitude of the immigration would have had to vary with distance and be so large as to be outside the realm of possibility. Third, trap avoidance was eliminated by examining marked percentages in various gear types (fish wheel versus carcass counts versus gill nets) at similar distances from the tagging site (Table 2), which in most cases were similar. Fourth, excessive harvest of marked fish would result in extremely high marked to unmarked ratios in harvests closer to the release site, which was not observed (Table 2). In addition, extremely high harvest of tagged fish would be needed, for example, to reduce the observed marked percentage from 5% at Rampart Alaska to 1% at the Canadian Border in 1997.

The possibility that sampling biases could produce the observed trends was also considered and rejected. Stock based selective sampling would result in some stocks being over represented and others being under represented. However, observations from the four major spawning rivers, Chandalar, Sheenjek, Fishing Branch, and Yukon (Canadian Border) rivers, which are thought to comprise a very high proportion of the entire population, suggests that all of these stocks have marking rates substantially below that observed at Rampart, Alaska (Table 2). Non-stock based selective sampling was thought unlikely based on the magnitude of the dilution needed to result in data like that found in Table 2. For example, hypothetically, one could substitute the recovery rate at Rampart used in the mark and recapture experiment based on any percentage rate in Table 2 and determine a new population estimate. The results are population estimates that are substantially beyond any considered possible.

Initially, tag loss was considered the most likely explanation for the decline in marked to unmarked fish; however, data collected to document tag loss appear to have ruled out that possibility (Table 3). Only minor tag loss was documented and only in the most distant clear-water tributaries near spawning grounds e.g., at the weir on the Fishing Branch River, Canada.

The final explanation considered was that of handling effects. Key to the investigation was not only the detection of such effects, but the imperative that the direction and magnitude be congruent with the other observations in Table 2. Annual capture histories and statistics associated with the proportion of marked fish that were recaptured externally provide the sample sizes and background variation related to the likelihood ratio test (Table 4). Likelihood ratio tests of the equality of the proportions within each year were significant with P_α of 0.0004, < 0.0001, and 0.0348 for 1996 to 1998, respectively, indicating unequal recovery rates. Parameter estimates and statistics associated with the logistic models are consistent with the likelihood ratio test results (Table 5). The sample proportions and 95% confidence intervals from the logistic models show a consistent decrease in tag returns with an increase in captures (Figure 4, Table 5). Figure 4 also indicates that the magnitude of the effect is large.

These observations suggest that cumulative stress and delayed mortality were the most likely explanation of the observed phenomena of decreased marking rates with increased distance. Mortality caused by capturing and handling fish is common in tagging studies (Seber 1982). Mortality caused by stress can be delayed (Stichney 1983), and effects of multiple stressors can be cumulative (Wedemeyer 1990).

The implication of increased mortality caused by fish wheel use should be evaluated carefully. For example, the mark and recapture study captured and handled as many as 60,000 fish during 1996. Even a modest increase in mortality rates could impact significant numbers of fish. Unfortunately, the true impact of the fish wheels is difficult to assess because fish not captured would be the true control group and cannot be considered in the analysis and, second, the fate of unmarked fish captured in the recapture fish wheels are unknown. However, the total effect may be larger than indicated by this study. Of additional concern are the potential negative effects caused by the numerous other fish wheels used for research and monitoring salmon within the Yukon River drainage.

The general concepts regarding handling, stress, and mortality are well documented (Stichney 1983; Adams 1990; Wedemeyer 1990); however, specific investigations into stress and morbidity caused by fish wheels have not been well documented. Possible causes of elevated stress include capture in the fish wheel baskets, holding time in the live box, crowded conditions within the live box, handling procedures, and tagging. Any combination of these effects could be causing the majority of the stress. Given the useful management data produced by fish wheels, further investigation into harmful effects is warranted. Tests to isolate each potential cause may lead to procedures that minimize harmful effects or reduce them to an acceptable level. For some fish wheel uses, such as collection of CPUE data, alternatives to holding fish in live boxes might be explored. For example, video image capture via computer (Hatch et al. 1998) could be applied to fish wheels, eliminating the need to retain captured fish in live boxes.

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Table 1. Possible reasons for the observed decline in the ratio of marked to unmarked fall chum salmon with increasing distance from the mark and recapture study area.

1. Incomplete reporting of tag returns.
2. Immigration of unmarked fish: The tails of the spawning distribution were not marked allowing for dilution of marked fish by fish not subjected to sampling.
3. Trap avoidance: marked fish avoid sampling gear upriver.
4. Increased harvest rate, marked fish were harvested at a higher rate than unmarked fish.
5. A portion of the run at the marking and recovery site was not sampled due to selective sampling; a specific stock or stocks were unavailable to the sampling gear.
6. A portion of the run at the marking and recovery site was not sampled due to selective sampling; a portion of all stocks of fish were unavailable to the sampling gear.
7. Sampling gear that reported the low R/C ratios did not sample a portion of the run. This is the same as number 5 above but not at the marking and recovery fish wheels used for the estimate.
8. Tags are lost from marked fish.
9. Handling mortality, marked fish die or stop migration prematurely at a higher rate than unmarked fish because of handling stress or capture injury.

Table 2 .— Location, river km from tagging site, source and gear type, sample sizes, and number and percentage marked at sites distributed through out the Yukon River drainage upriver from the tag release site during 1996 to 1998. The sources listed were broken into "management projects" (MP) which were conducted by government agencies or supervised personnel and "Fisheries" which were data from fisherman willing to participate.

Location	River km from tagging site	Source and gear type: management project (MP) or Fishery	Total fish examined	Number of fish with primary marks	Percent age with marks
		1996[a]			
Rampart	52	MP (fish wheel)	45,232	1,259	2.90
Eagle City	777	Fishery (fish wheel)	2,300	14	0.61
Eagle City	777	Fishery (fish wheel)	2,800	21	0.75
Canadian Border [b]	795	MP (fish wheel)	4,300	14	0.33
Old Crow	852	Fishery (gill net)	1,300	16	1.2
Old Crow	852	Fishery (gill net)	1,200	1	0.08
Dawson	948	Fishery (fish wheel)	4,000	36	0.9
Fishing Branch [b]	1402	MP (weir)	77,278	63	0.08
		1997			
Rampart	52	MP (fish wheel)	39,685	1,984	5.0
Stevens Village	187	MP (survey)	131	10	7.5
Chandalar River	474	MP (carcass survey)	1,414	43	3.0
Fort Yukon	437	MP (interviews)	1,240	36	2.9
Sheenjek River	521	MP (carcass survey)	1,051	12	1.1
Circle City	532	Fishery (fish wheel)	~5,000	86	~1.7
Nation River	702	Fishery (gill net)	983	11	1.1
Eagle City	777	Fishery (fish wheel)	2,500	32	1.3
Eagle City	777	Fishery (fish wheel)	2,700	32	1.2
Canadian Border [b]	795	MP (fish wheel)	3,522	36	1.0

Table 2.— Continued

Porcupine River	852	Fishery (gill net)	700	19	2.7
Dawson	948	Fishery (fish wheels)	6,651	34	0.5
Fishing Branch [b]	1402	MP (weir)	26,959	168	0.6
		1998			
Rampart	52	MP (fish wheel)	15,581	759	4.9
Beaver	187	MP (interviews)	557	21	3.7
Fort Yukon	437	MP (interviews)	1,564	58	3.7
Black River	476	Fishery (interview)	52	1	1.9
Black River	476	Fishery (interview)	300	4	1.3
Circle City	532	Fishery (fish wheel)	197	1	0.05
Eagle City	777	Fishery (fish wheel)	80	1	1.2
Eagle City	777	Fishery (fish wheel)	6	3	50.0
Canadian Border [b]	795	MP (fish wheel)	907	24	2.6
Porcupine	852	Fishery (gill net)	450	8	1.7
Dawson	948	Fishery (fish wheels)	1,231	30	2.4
Fishing Branch [b]	1402	MP (weir)	13,564	189	1.4

[a] In 1996 interviews were collected via telephone and while some fishermen had written records of catch others represent the fisherman's best recollection. Often the number of marked fish was supported by having the tags in hand or tag numbers recorded. After 1996 fishermen received a preseason briefing by telephone regarding data recording and what to look for specific to the primary mark (a spaghetti tag) and the presence of the secondary mark (a ventral fin clip).

[b] (Personal Communication Pat Milligan and Ian Boyce, Fisheries and Oceans Canada, Whitehorse) or (Boyce and Wilson 2001; Boyce and Vust In Press)

Table 3 .— Tag loss data recorded at various sites which included river km from tagging site, sources management projects MP or "Fishery", gear type, total fish examined, total fish with primary marks, and total fish with only secondary marks during the years 1996 to 1998. Government agencies projects or supervised personnel were considered MP while "Fisheries" projects were data from select fisherman willing to participate.

Location	Km from tagging site	Source and gear type: management project (MP) or Fishery	Total fish examined for primary and second marks	Fish with primary marks	Reported Tag loss
		1996			
Rampart	52	MP (fish wheel)	2,260	212	0
		1997			
Rampart	52	MP (fish wheel)	9,697	575	0
Fort Yukon	437	MP (interviews)	1,240	36	0
Nation River	707	Fishery (fish wheel)	983	11	0
Eagle City	777	Fishery (fish wheel)	2,500	32	0
Eagle City	777	Fishery (fish wheel)	2,700	32	0
Canadian Border[a]	795	MP (fish wheel)	3,522	36	0
Dawson	948	Fishery (fish wheel)	6,651	34	0
Fishing Branch [a]	1402	MP (weir)	5,356	37	1[b]
		1998			
Beaver	187	MP (interviews)	557	21	1
Fort Yukon	437	MP (interviews)	1,564	58	0
Circle City	532	Fishery (fish wheel)	197	1	0
Canadian Border	795	MP (fish wheel)	907	24	0
Fishing Branch [a]	1402	MP (weir)	10,440	146 [c]	4 [d]

[a] (Pers. Comm. Pat Milligan and Ian Boyce, Fisheries and Oceans Canada, Whitehorse) or (Boyce and Wilson 2001)

[b] The supervisor noted this was unconfirmed and that the tagging needle mark was documented (Boyce and Vust In press).

[c] Approximate number based on a 1.4 % rate of return from Table 2.

[d] One fish was not handled but observed to be torn behind dorsal fin. A second fish was counted through weir (not handled) with pelvic fin clip but no marks around dorsal fin handled. A third fish had tagging needle marks. The fourth fish was not handled, but tagging needle marks were observed.

Table 4. — Annual statistics relating to the proportion of fish recaptured by fishermen,

categorized by the number of times fish were captured in fish wheels associated with the mark-recapture project.

		Number of times captured			
Year	Statistic	1	2	3	4
1996	Number of fish	15,492	2,052	24	0
	Number of external recaptures	547	44	3	
	Proportion recaptured	0.035	0.021	0.125	
	Standard error	0.0015	0.0032	0.0690	
1997	Number of fish	15,136	3,111	351	34
	Number of external recaptures	890	106	10	1
	Proportion recaptured	0.059	0.034	0.028	0.029
	Standard error	0.0019	0.0033	0.0089	0.0294
1998	Number of fish	7,232	1,135	146	0
	Number of external recaptures	876	115	11	
	Proportion recaptured	0.121	0.101	0.075	
	Standard error	0.0038	0.0090	0.0219	

Table 5.— Results of fitting logistic regression models to the proportion of marked fall chum salmon recaptured, using the number of times a fish was recaptured as an explanatory variable.

	Intercept			Coefficient		
Year	Estimate	S. E.	P_α	Estimate	S. E.	P_α
1996	2.9192	0.1663	<0.0001	0.3934	0.1484	0.0080
1997	2.2684	0.1058	<0.0001	0.5087	0.0891	<0.0001
1998	1.7609	0.1061	<0.0001	0.2197	0.0883	0.0128

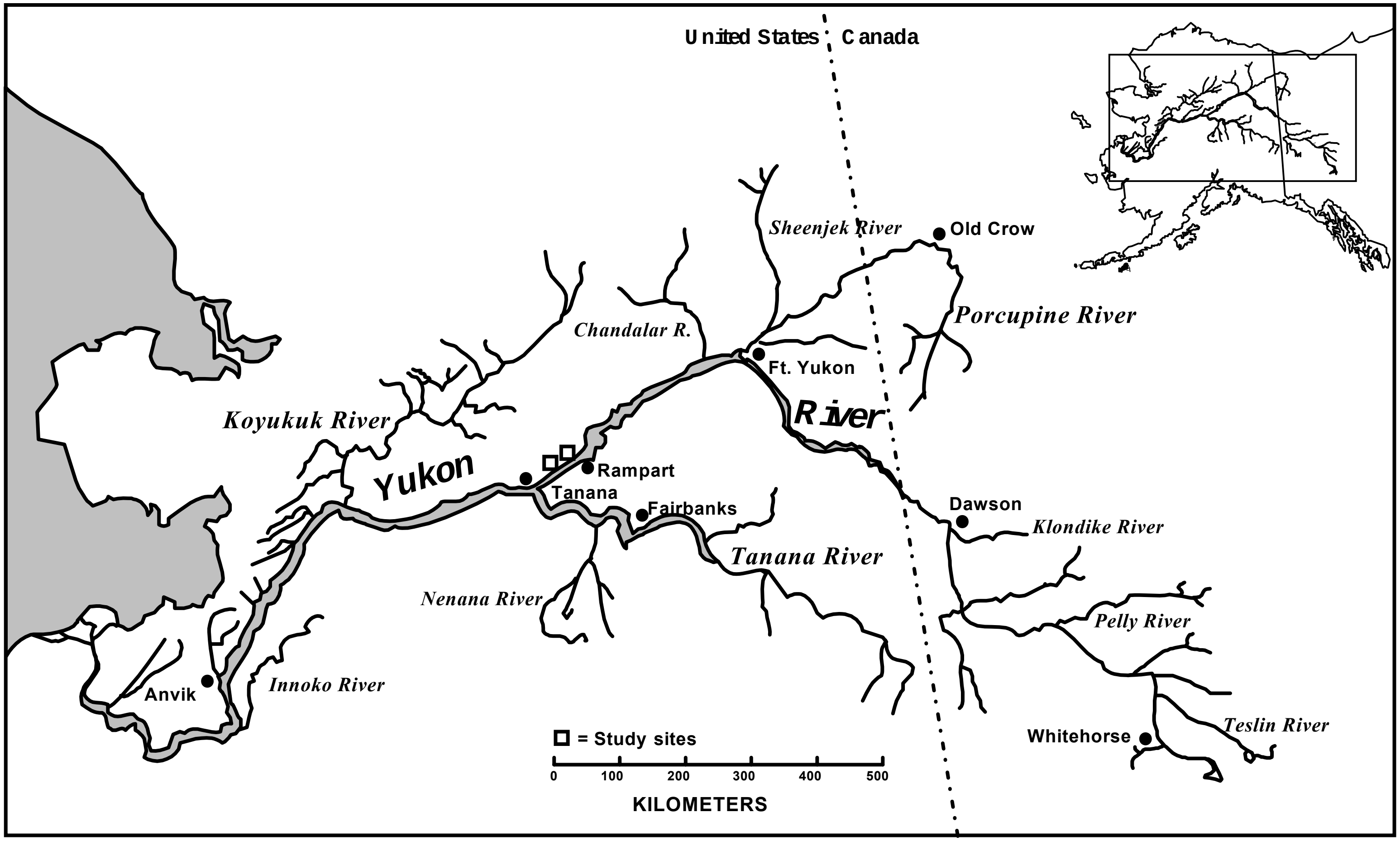
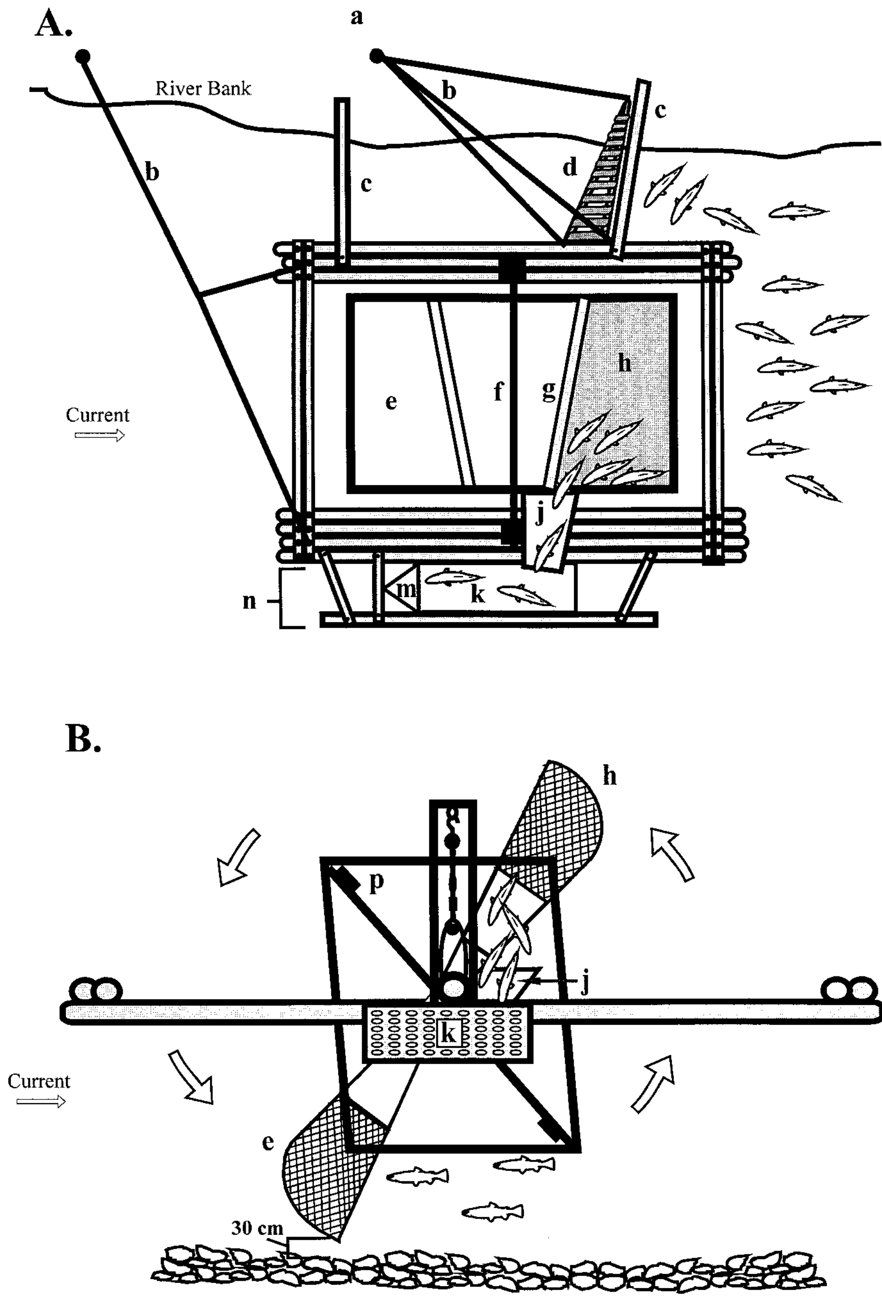


Figure 1.— Map of the Yukon River with the marking and recovery sites for the mark and recapture study denoted by open squares.



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

Figure 2.— Two-basket fish wheel used to capture chum salmon during the capture and recapture events; A: aerial view, B. side view.

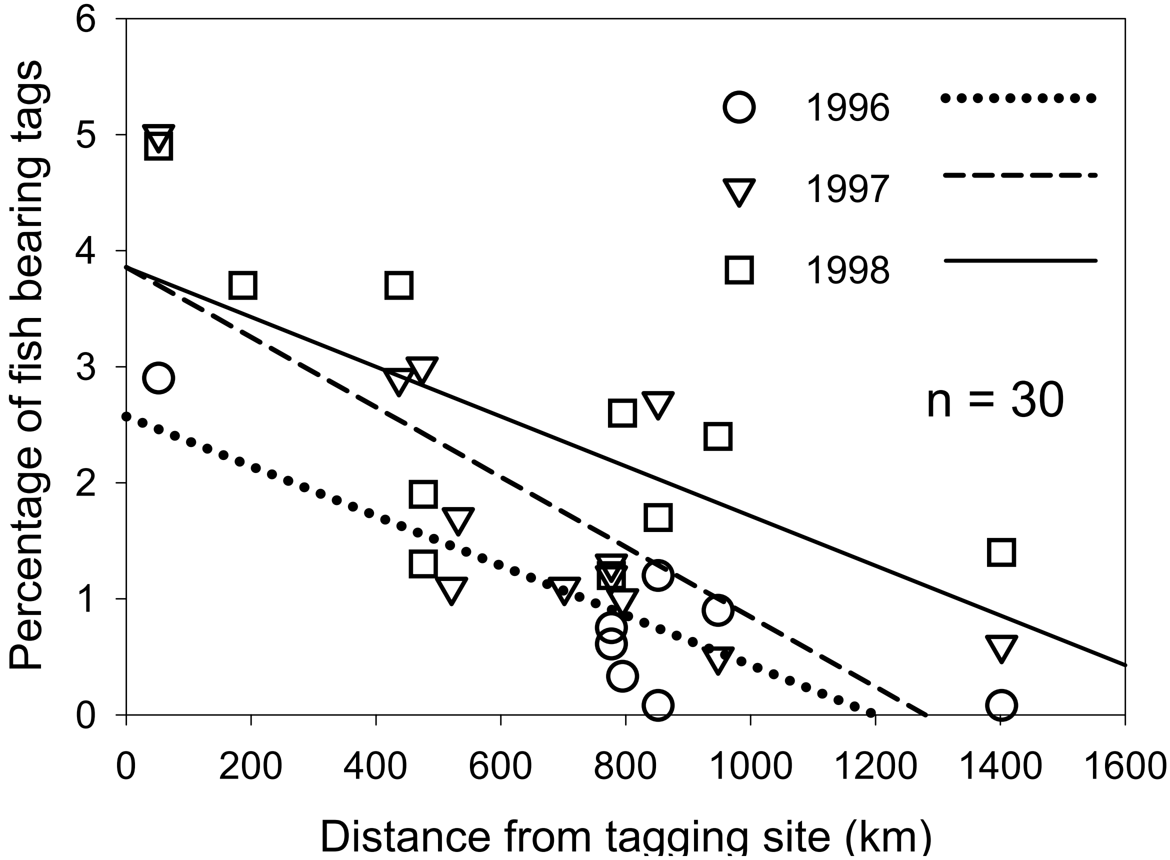


Figure 3.— Percentage of fall chum salmon bearing tags versus the distance from the tagging site, 1996 to 1998.

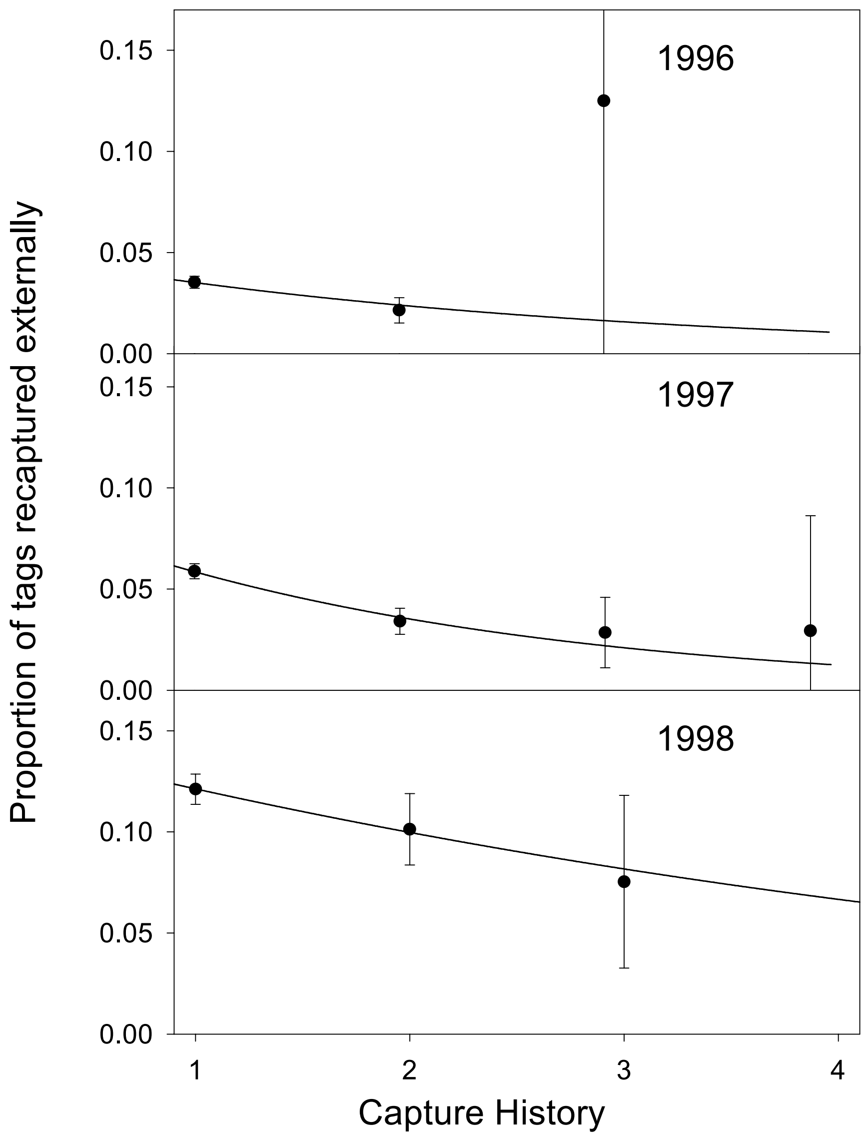


Figure 4.— Point estimates, 95% confidence limits, and logistic regression model of the proportion of marked chum salmon externally recaptured, by capture history.