EFFECTIVENESS OF PREDATOR REMOVAL FOR PROTECTING JUVENILE FALL CHINOOK SALMON RELEASED FROM BONNEVILLE HATCHERY, 1993

Annual Report

by

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INTRODUCTION

Despite the almost universal belief that removal of northern squawfish (*Ptychocheilus oregonensis*) will increase survival of juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River Basin (Fig. 1), there has yet to be a direct demonstration of the benefit. In 1987, subyearling chinook salmon (*O. tshawytscha*) released along the shoreline just downstream from Bonneville Dam had poor survival relative to those released in midstream (Ledgerwood et al. 1990). Northern squawfish are known to inhabit protected shoreline areas (Petersen et al. 1990), and the poor survival rates of shoreline-released juvenile salmon was attributed, in part, to higher predation by northern squawfish.

To evaluate the advantage of releasing juvenile salmon in midstream Columbia River, the National Marine Fisheries Service (NMFS), in cooperation with the Oregon Department of Fish and Wildlife (ODFW) conducted salmon survival studies at Bonneville Hatchery from 1989 through 1993 (Ledgerwood et al. 1993 and in press). Each year, subyearling fall chinook salmon (upriver bright stock) were marked, then simultaneously released into Tanner Creek, the normal release site which enters the Columbia River about 400 m downstream from the hatchery (Fig. 2), and into the midstream Columbia River, lateral to the confluence of Tanner Creek. In 1989-1993, differences among seine recoveries of juvenile salmon in the estuary indicated that survival following the 157-km migration was dramatically better (65% better in 1989) for midstream Columbia River-release groups than for Tanner Creek-release groups.

In 1991, 1992, and 1993, with the help of personnel from the U.S. Fish and Wildlife Service (now the National Biological Survey), the research was expanded to confirm the effectiveness of removing northern squawfish from the migration route of juvenile salmon from Bonneville Hatchery. Each year, two paired-groups of about 100,000 fish each were

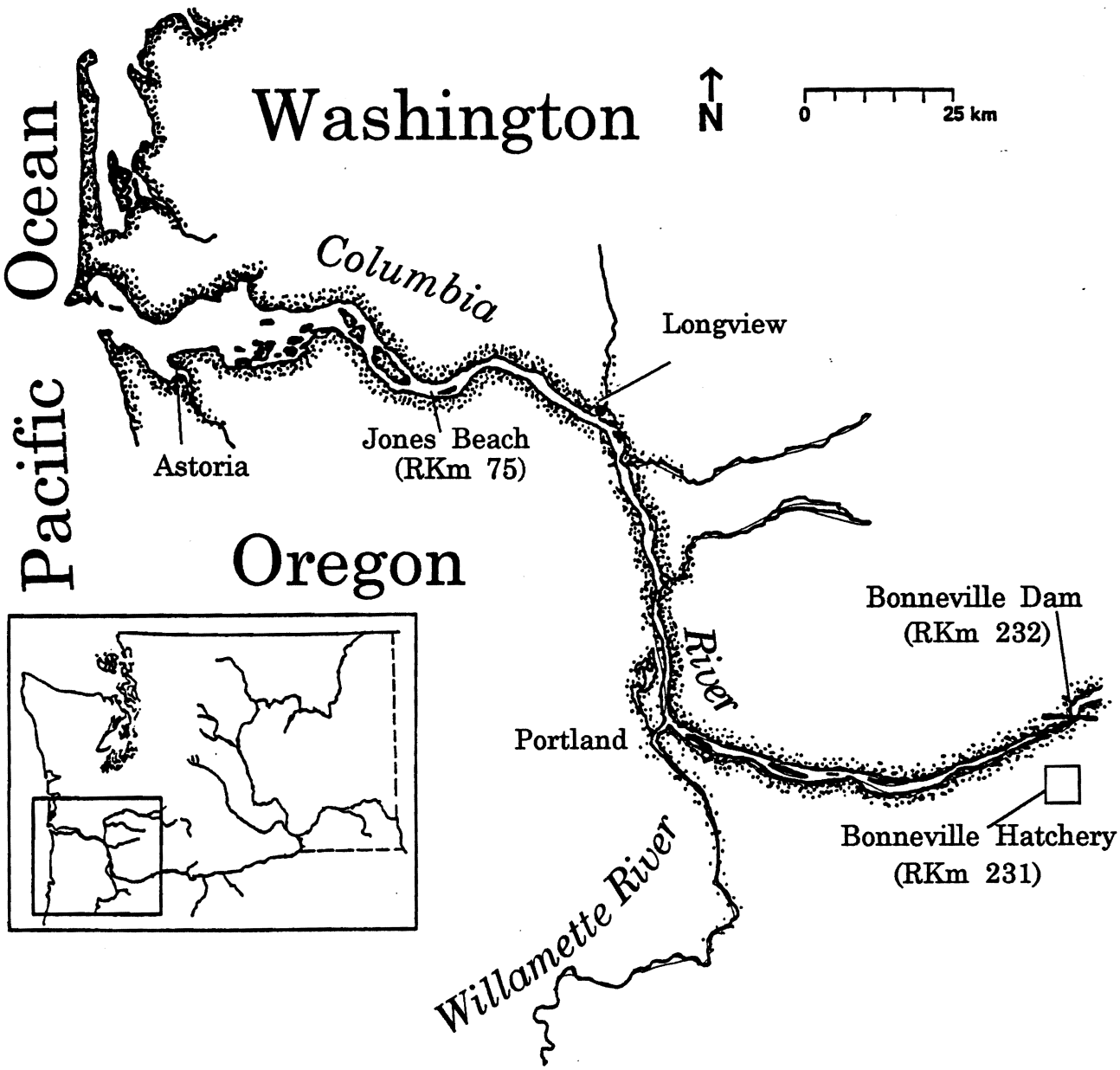

Figure 1.--Columbia River Basin showing the study area.

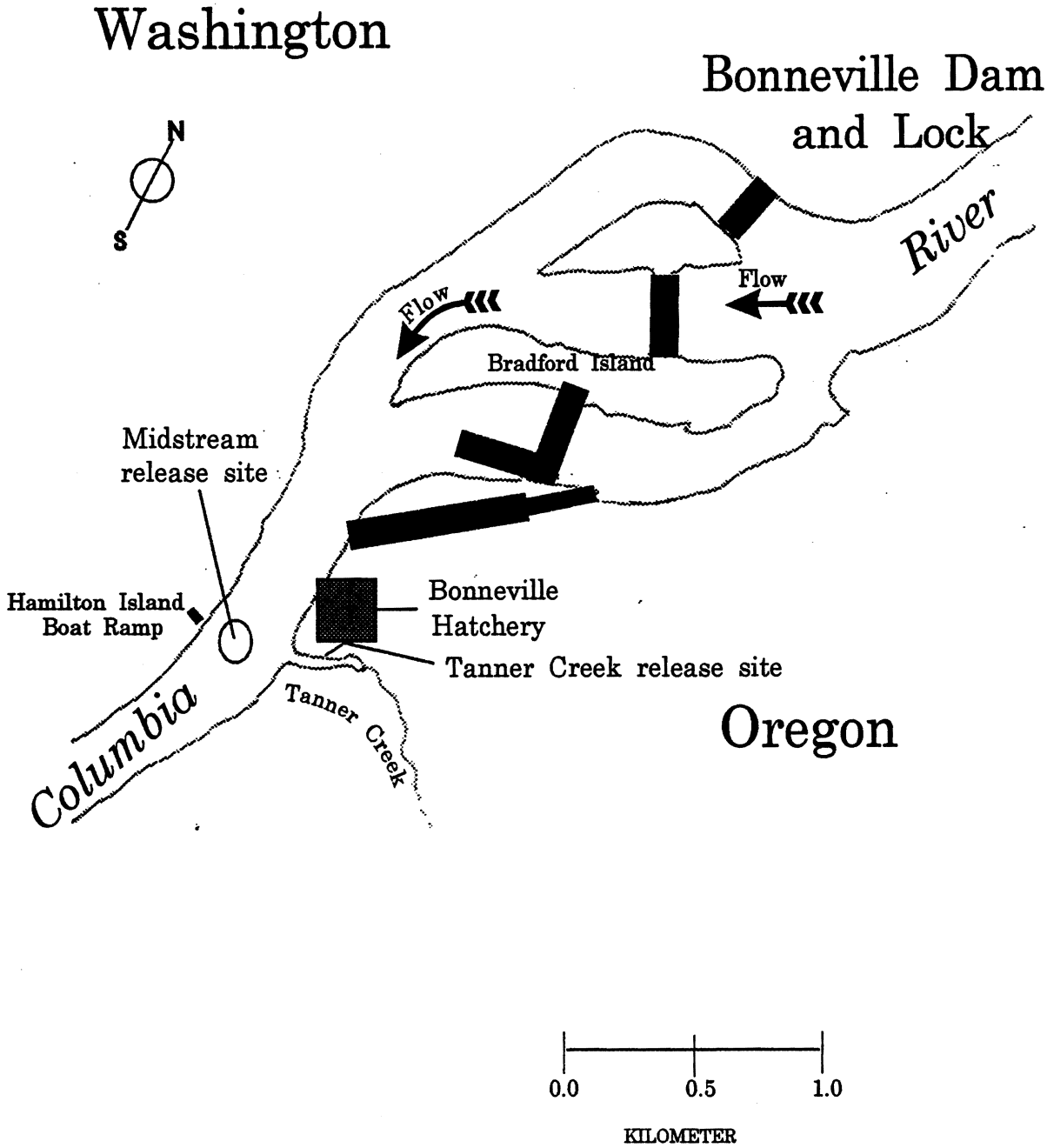

Figure 2.--Release locations for subyearling chinook salmon, 1991-1993.

released into the midstream Columbia River and into Tanner Creek 4 days apart. On intervening nights, some northern squawfish in the vicinity of the hatchery release site were removed by electrofishing. Stomach contents of captured northern squawfish were examined for the presence of coded-wire tags (CWT) from study fish. In 1991 and 1992 it was apparent from CWT recoveries in the stomachs of northern squawfish that Tanner Creek-released juveniles were more vulnerable to predation than juveniles released in midstream (Ledgerwood et al. 1993 and in press). In addition, recoveries of juvenile salmon in the estuary indicated less benefit for release in mid-river over Tanner Creek after northern squawfish removal each year. The decreased benefit was insignificant in 1991 and significant in 1992. These data lend credence to the hypothesis that predation on juvenile salmonids by northern squawfish may be decreased by removal of northern squawfish. The completed set of recovery data from juvenile and adult salmon will be necessary before final conclusions may be drawn.

This report summarizes efforts and results of research conducted in 1993. The objectives were similar to those of 1991 and 1992: 1) assess survival differences for juvenile salmon before and after the removal of northern squawfish from Tanner Creek and adjacent shoreline areas of the Columbia River; 2) assess effectiveness of electrofishing to remove northern squawfish from the migration route of juvenile salmon in the vicinity of the hatchery release site; and 3) assess prey consumption by northern squawfish before and after large-scale predator removal efforts to determine the effects of predator size and density on the rate at which juvenile salmonids are consumed.

METHODS

Experimental Design

Prior to northern squawfish removal efforts, one uniquely marked group of 100,000 juvenile fall chinook salmon was released into Tanner Creek and another into the midstream Columbia River, lateral to the confluence of Tanner Creek. During the following four nights, extensive electrofishing was conducted to remove northern squawfish from Tanner Creek and from the adjacent shoreline areas of the Columbia River extending 1 km upstream and 6 km downstream from the release sites. Catch per unit effort (CPUE), size of fish removed, numbers of salmon ingested, and overall food consumption by northern squawfish were assessed to evaluate changes in the local population and impact on released salmon. Following the northern squawfish removal, a second pair of uniquely marked 100,000-fish groups was released at the two study sites. The second pair of releases was followed by another two nights of extensive electrofishing for northern squawfish to evaluate population changes in response to the re-introduction of juvenile salmon into the study area.

Purse and beach seining were conducted near the upper boundary of the Columbia River estuary at Jones Beach, River Kilometer (RKm) 75, to recover marked salmon. Recovery percentages of study fish were used to evaluate short-term survival differences between groups released at the two study sites before and after northern squawfish removal. Relative contributions of marked fish recovered in ocean and river fisheries and returning to the hatchery will provide a long-term evaluation for all release groups.

Test Fish

Test fish were the progeny of fall chinook salmon (upriver bright stock) collected by ODFW personnel at Bonneville Hatchery. About 400,000 of these fish were reared at the hatchery for this study. At release, the mean size of these subyearling-age fish was 6.5 g (70.3 fish/lb), similar in size to the fish used in previous years, which ranged in size from 6.0 to 7.4 g (75.7 to 61.0 fish/lb).

Marking Procedures

Test fish were marked by two 12-person crews on 7 days (9-11 June and 14-17 June). About 60,000 fish were marked each day. Each marked group had unique CWTs (Bergman et al. 1968). Cold brands (Mighell 1969) were applied to allow visual identification of fish from different treatment groups in samples seined from the estuary.

Logistics for marking fish were similar to those described by Ledgerwood et al. (1990). Two measures were taken to ensure that marked groups of fish did not differ in size, condition, rearing history, or mark quality. The four groups were marked simultaneously and differences in mark quality among groups were minimized by rotating mark codes among fish marking stations every 2 hours so that each marker and each station contributed equivalent numbers of marked fish to each treatment group. To assess quality control in the tagging process, samples of about 100 fish from each marked group were collected and checked for the presence of CWTs. These samples were taken periodically at the outfall pipes from the marking trailer. In addition, samples of about seven fish from each marked group were diverted into a separate holding pond at 2-hour intervals throughout the marking day and held for a minimum of 30 days to determine tag loss and brand retention. Samples from each treatment were held in separate net pens. Estimates of tag loss ranged from 2.7 to 7.4% ($\bar{x}$ = 4.6, N = 1,966;

Appendix Table A1). Release numbers for each CWT group (treatment) were adjusted for estimated tag loss based on tag loss for the marked fish held a minimum of 30 days.

Release Locations and Procedures

Groups of marked fish were released into Tanner Creek (the normal hatchery release site) and into the midstream Columbia River, lateral to the confluence of Tanner Creek (Fig. 2). The specific release locations and procedures were as follows:

1) Tanner Creek: test fish were released using the normal hatchery procedure of drawing down the water in the rearing pond and crowding fish into an underground flume. The flume carried fish about 650 m to Tanner Creek, where they were free to migrate to its confluence with the Columbia River, about 400 m downstream. At the confluence, fish were lateral to and about 150 m from the midstream Columbia River release site. Tanner Creek releases began at 2030 h, about 1.5 hours prior to midstream releases, to provide extra time for fish traveling to the Columbia River.
2) Midstream Columbia River: test fish were pumped through a 15-cm diameter hose into 4,000-L tanker trucks; three trucks were used on each release night. Each truck was loaded with about 34,000 fish to maintain transport densities of about 53 g fish/L water (0.5 lb/gal). The trucks were loaded aboard a barge at the boat launch on Hamilton Island with one truck per barge trip. At midstream, the fish were released into the river through a 3-m-long 15-cm diameter hose. Releases occurred between 2200 and 2300 h at about RKm 232.

Northern Squawfish Removals

Two electrofishing boats were used to capture and remove northern squawfish. The bow platform of each boat was equipped with a pair of adjustable booms fitted with

umbrella anode arrays. These arrays consisted of six stainless steel cables, which were lowered into the water when fishing. All electrofishing was pulsed direct current using 60 pulses/second, 400-500 volts, and 4-5 amperes.

Electrofishing began at 0300 h on 22 June, about 6 hours following the first pair of releases (Appendix Table B1). On subsequent nights through 25 June, electrofishing began at 2100 h and continued until 0900 h the next morning. Electrofishing was delayed the first night to allow test fish to disperse following release. Eight areas located between RKm 232 and 225 were electrofished: one in lower Tanner Creek, and seven others in nearshore areas in the Columbia River (Fig. 3)[1]. Each area was electrofished at least twice for about 30 minutes during each electrofishing period. Though transects on both the Oregon and Washington side of the Columbia River were electrofished, efforts were more concentrated in transect areas closest to the release locations.

Northern squawfish, stunned from electrofishing, generally came to the water surface and were collected with a dipnet; some stunned fish were lost in the swift currents. Netted fish were placed in a lethal solution of tricaine methanesulfonate (MS-222) and within about 40 minutes of capture were taken to a processing station on shore where weight (g), fork length (mm), sex, and state of sexual maturity were recorded for each fish. The digestive tract (esophagus to anus) was removed from each fish, placed in a plastic bag, and frozen for later analysis.

In the laboratory, frozen digestive tracts were thawed and prepared for analysis using a digestive enzyme solution (pancreatin) to dissolve flesh but leave intact diagnostic bones and CWTs from ingested fish (Petersen et al. 1990). The 2% (by weight) pancreatin

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[1] A ninth transect area (W4) located on the Washington shore was fished in previous years but was dropped from the sampling scheme in 1993.

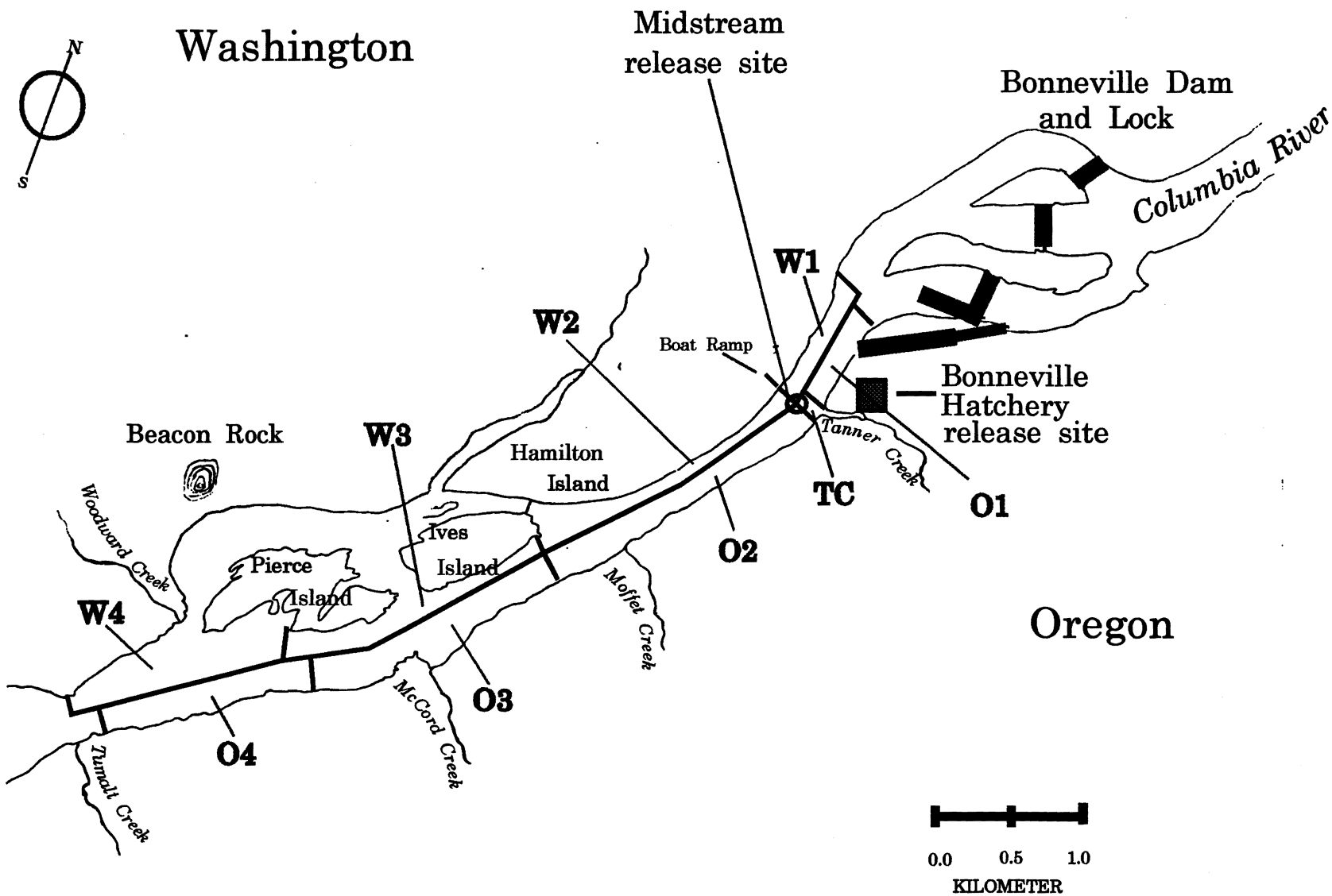

Figure 3.--Electrofishing areas in Tanner Creek and adjacent shoreline areas of the Columbia River, 1991-1993.

solution, prepared using lukewarm tap water, also contained 1% sodium sulfide. This solution was added to the plastic bags containing the digestive tracts; the bags were then placed in a 40°C desiccating oven for 24 hours. The stainless steel CWTs, having a greater density than bone, sank to the bottom after agitation of the digested sample, and were removed. In addition, these samples were checked for missed CWTs using an electronic tag detector. CWTs were decoded using a compound microscope (Appendix Table B2). The solid contents of the bags were then rinsed through a 425-μm sieve using tap water. A compound microscope and forceps were used to remove diagnostic bones (primarily cleithra, dentaries, and opercles) from the samples (Hansel et al. 1988). Diagnostic bones were identified and paired to enumerate salmonids and other prey consumed.

Sampling Juvenile Salmon at Jones Beach

Short-term relative survival differences among release groups of juvenile salmon were derived from percentage differences of tagged fish recovered near the upper boundary of the Columbia River estuary at Jones Beach (Fig. 4). Recovery methods and sampling site were described by Dawley et al. (1985, 1988). In addition to determining recovery differences, captured fish were observed for differences in descaling, injuries, size, and migration behavior.

During the period from 25 June through 12 July, sampling was conducted by two crews working 7 days per week for 8 to 12 hours per day, beginning at sunrise (Appendix Table A2). Both purse seines (midstream) and beach seines (Oregon shore) were used to determine whether study fish were more abundant in midstream or near shore and to maximize effort using the gear type that captured the greatest numbers of study fish.

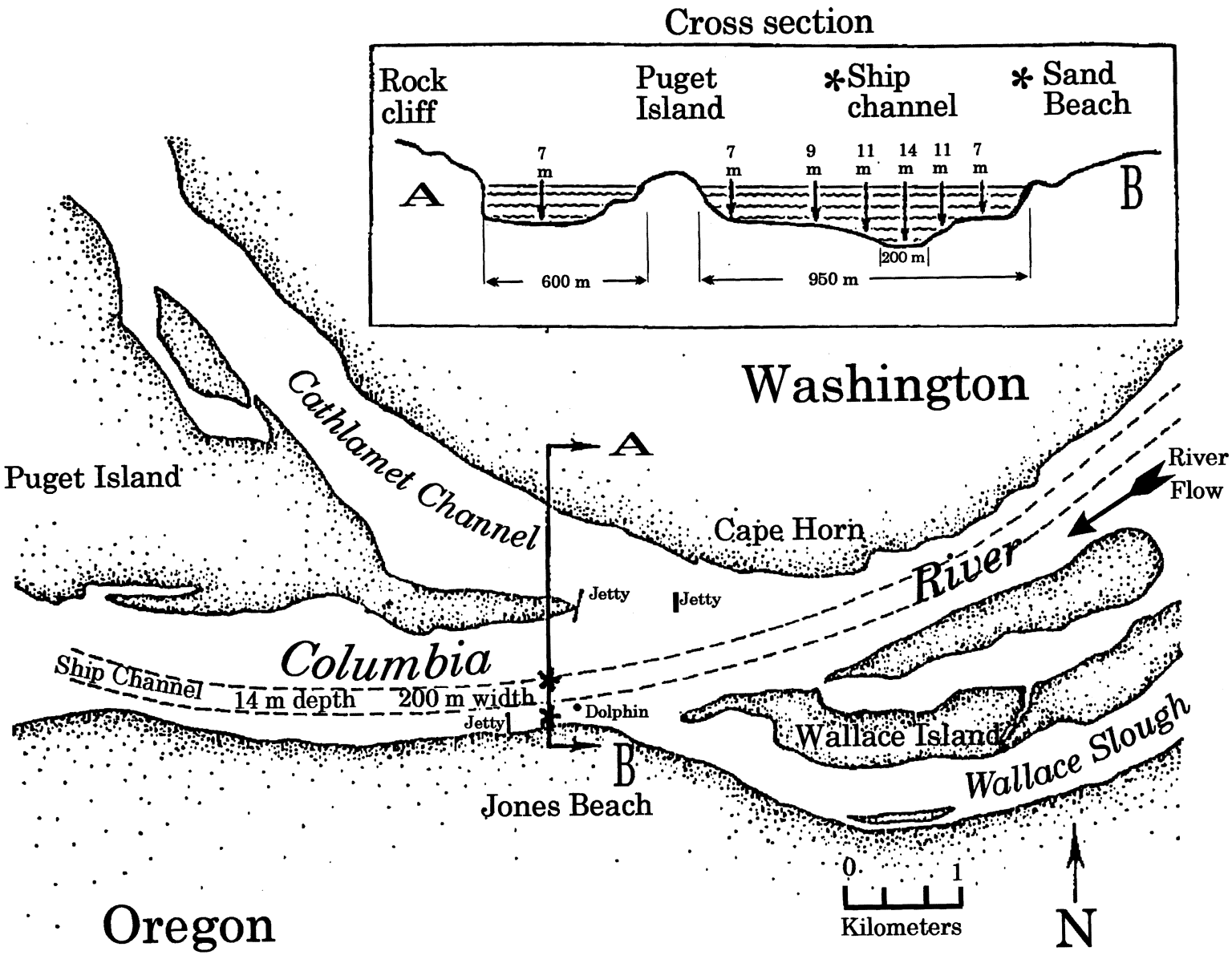

Figure 4.--Jones Beach, Columbia River, sampling sites. The beach and purse seining areas are denoted by asterisks.

All captured fish were processed aboard the purse seine vessels. The catch from each set was anesthetized and enumerated by species. Numbers of dead, injured, or descaled salmonids were recorded and subyearling chinook salmon were examined for excised adipose fins and brands. Marked fish were separated for further processing, while unmarked fish were returned to the river immediately after counting, evaluation, and recovery from anesthesia. Descaling was judged rapidly while counting and separating study fish from non-study fish. Fish were classified as descaled when 25% or more of their scales on one side were missing.

Freeze brands were used to identify study fish; from these fish we collected CWTs, obtained biological samples, compared fish size among treatment groups, and adjusted the daily sampling effort to attain the desired minimum sample size of 0.5% of the number of fish released. Brand information and biological and associated sampling data (e.g., date, vessel code, gear code, set number, time of examination, fork length, and descaling) were immediately entered into a computer database and printed. Fork lengths of marked fish were recorded to the nearest mm. All branded fish (including those with illegible brands) were sacrificed to obtain CWTs, which identified treatment group and day of release.

Branded fish were processed in lots, segregated by recovery day and capture site. An aqueous solution of 40% potassium hydroxide was used to dissolve the heads for ease in extracting CWTs. All CWTs were decoded and later verified; additional details of tag processing followed the methods described by Ledgerwood et al. (1990).

Purse seine data obtained from 25 June to 12 July were adjusted for effort to obtain a standardized catch per day per group. Beach seine catch data were not similarly adjusted due to low sampling effort. The following formula was used to standardize purse seine data to a 12-set-per-day effort for each marked group:

$$A_i = N_i (S \div P_i)$$

where:

A_i = Standardized purse seine catch on day i

N_i = Actual purse seine catch on day i

S = Constant (weighted daily average number of purse seine sets (12) during the sampling period)

P_i = Actual number of purse seine sets on day i.

Dates of median recovery for each marked fish group were determined using the standardized purse seine. Movement rates for each CWT group were calculated as the distance from the midstream Columbia River release site (RKm 232) to Jones Beach (RKm 75) divided by the travel time (in days) from release date to the date of the median fish recovery.

Statistical Analyses

The hypothesis that recovery ratios at Jones Beach were equal for fish released into Tanner Creek and the midstream Columbia River was tested using a paired difference z-test. The hypothesis that different marked groups, released the same day, had equal probability of capture through time was tested using chi-square goodness of fit (Zar 1974).

RESULTS

In 1993, a total of 399,040 subyearling chinook salmon were marked with freeze brands, CWTs, and excision of the adipose fin before release (Table 1). Between the two release dates, 2,291 northern squawfish were captured and removed from the study area (Table 2). An additional 575 northern squawfish were removed from the study area following the second release. We recovered 1,988 study fish in the estuary (ca. 0.6% of

Table 1.--Summary of Tanner Creek and midstream Columbia River releases of marked subyearling chinook salmon, 1993.

Marking dates	Release date	Brand[a]	Number released Total[b]	Untagged[c]	Tagged[d]	Wire tag code (AG D1 D2)[e]
Tanner Creek releases						
9-17 June	21 June	RD Z2	99,702	3,689	96,013	23 30 21
9-17 June	25 June	LD Z2	99,272	7,346	91,926	23 30 22
Midstream Columbia River releases						
9-17 June	21 June	RD Z1	99,516	4,578	94,938	23 30 23
9-17 June	25 June	LD Z1	100,550	2,715	97,835	23 30 24
		Total	399,040	18,328	380,712	

[a] Brand codes: 1st and 2nd characters, RD = right dorsal position; 3rd character is the brand symbol; 4th character is brand rotation where 1 = symbol in the upright position and 2 = symbol rotated clockwise 90° from upright position.
[b] Total fish marked; branded, tagged, and adipose fin clipped (less observed pre-release mortality and fish retained for tag loss evaluation).
[c] Estimated number of fish released without coded-wire tags (Appendix Table A1).
[d] Estimated number of fish released with coded-wire tags.
[e] CWT code key: AG D1 D2 = Agency code, Data 1 code, Data 2 code.

Table 2.--Number of northern squawfish removed by day (all electrofishing sites) and number of coded-wire tags recovered in digestive tracts of northern squawfish, 1993.

Electrofishing date (time)	Northern squawfish removed					CWTs recovered[a]	
	Time shocker on (sec)	Total catch	CPUE[b]	Mean length (mm)	Mean weight (g)	Release site: Tanner[c] Creek	Release site: Mid-[d] stream
Data pertinent to first paired release							
22 June (0300-0900)	10,488	253	87	321	734	114	2
22-23 June (2100-0900)	18,988	872	165	306	412	41	1
23-24 June (2100-0900)	18,738	650	125	293	369	2	--
24-25 June (2100-0900)	18,471	516	101	300	385	--	--
Subtotal	66,685	2,291	119.5	305.0	475.0	157	3
Data pertinent to second paired release							
26-27 June (2100-0900)	18,272	346	68	287	341	--	--
27-28 June (2100-0900)	11,549	229	71	308	410	--	--
Subtotal	29,821	575	69.5	297.5	375.5	--	--
Totals	96,506	2,866	102.8	302.5	441.8	157	3

[a] CWT = coded-wire tag (Agency code/Data 1 code/Data 2 code). Number of CWTs recovered in the digestive tracts of northern squawfish represent a minimum number of juvenile salmon ingested.
[b] CPUE = catch per unit effort, number of fish caught per hour.
[c] CWT code = 23/30/21, released 21 June.
[d] CWT code = 23/30/23, released 21 June.

those released); most were midstream migrants captured with purse seines (Appendix Table A3). Handling mortality for all captured juvenile salmon was less than 0.5% and the descaling rate was less than 2%. Five descaled study fish were captured at Jones Beach, too few for meaningful among-treatment comparison.

Northern Squawfish Removals

We captured and removed a total of 2,866 northern squawfish from the eight transect areas during about 27 hours (96,506 seconds) of electrofishing (Table 2). Sixty-one percent (1,759) of those removed were caught in Tanner Creek or adjacent transect areas along the Oregon shore (O1, O2, and O3) (Fig. 5), similar to catch distributions in 1991 and 1992. During the 22-25 June electrofishing periods (following the 21 June release), catch rates of northern squawfish were higher (mean = 119.5 fish/hour) than during the 26-28 June electrofishing periods (following the 25 June release) (mean = 69.5 fish/hour). There was little indication that northern squawfish recolonized the Tanner Creek or adjacent transect areas immediately after release of juvenile salmon from Bonneville Hatchery (Table 3). The mean fork lengths (302 mm) and weights (442 g) of northern squawfish were fairly consistent throughout the removal periods and considerably less than for northern squawfish captured during 1991 (means 344 mm and 606 g) but similar in size to those captured during 1992 (means 303 mm and 430 g) (Fig. 6). The number of CWTs recovered in the digestive tracts of northern squawfish (representing ingested juvenile salmon), diminished dramatically following the first electrofishing period. Of the 167 CWTs recovered from the digestive tracts of northern squawfish (Appendix Table B2), 94% were from study fish and all of those except 3 were from study fish released 21 June into Tanner Creek; the exceptions were study fish released 21 June into the midstream Columbia River. The CPUE for

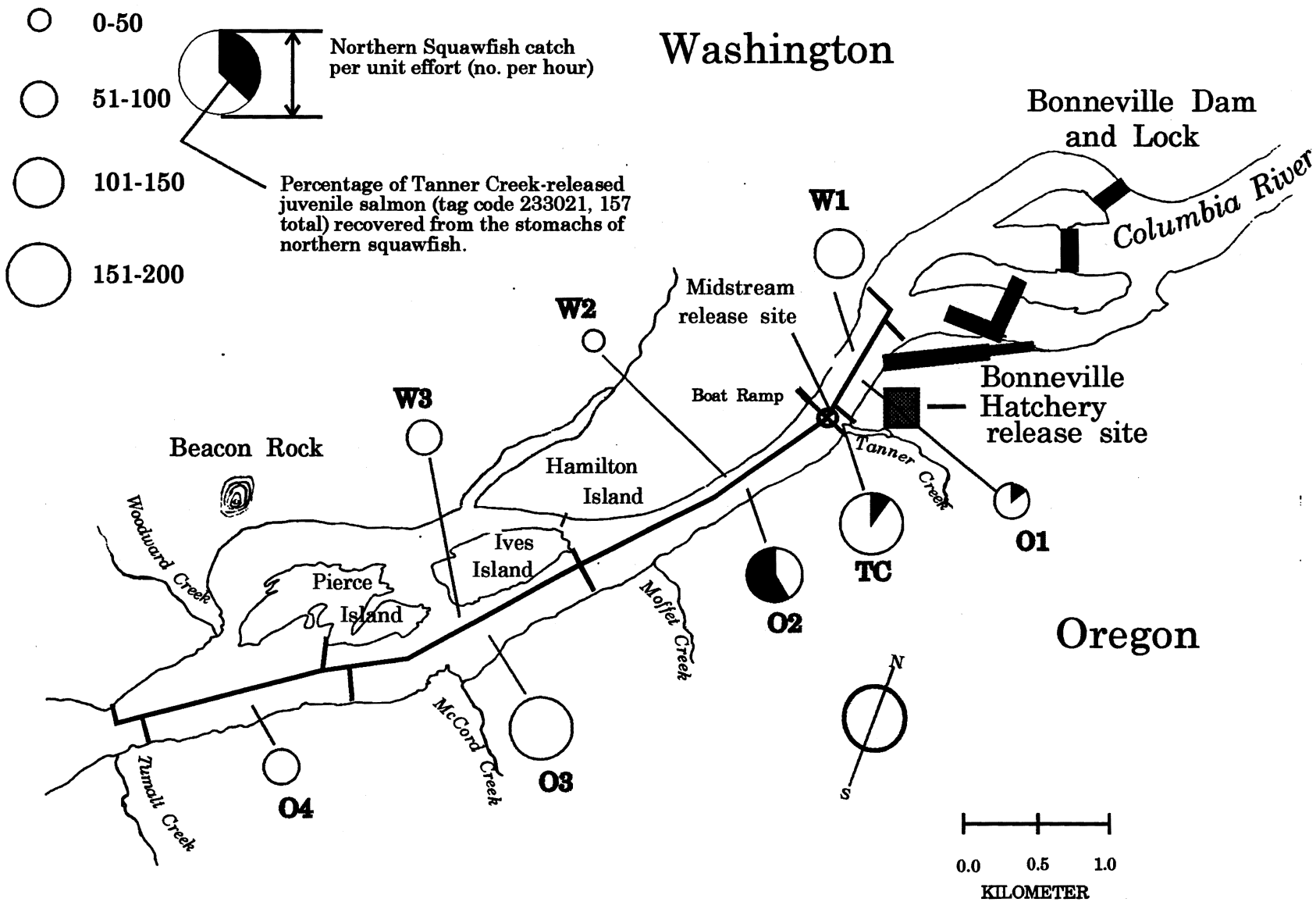

Figure 5.--The study area showing the northern squawfish catch per unit effort at each electrofishing transect area and proportion of tags (representing ingested juvenile salmon) from the 21 June Tanner Creek release group recovered in those northern squawfish, 1993.

Table 3.--Electrofishing effort, number of northern squawfish removed, and number of coded-wire tags recovered from the digestive tracts of northern squawfish for each electrofishing transect, 1993.

		Northern squawfish removed				CWTs recovered[a]	
						Release site	
Location[c]	Mean effort[b] (sec)	Total number	CPUE[d]	Mean length (mm)	Mean weight (g)	Tanner Creek[e]	Mid-stream[f]
O1	12,441	294	85	309	450	27	--
O2	15,573	553	128	295	382	113	3
O3	16,750	800	172	289	358	--	--
O4	1,827	29	57	269	268	--	--
W1	16,439	572	125	316	504	--	--
W2	15,121	204	49	311	472	--	--
W3	16,087	302	68	316	453	--	--
W4	0	--	--	--	--	--	--
TC	2,268	112	178	273	330	17	--
Total	96,506	2,866	107.8	297.3	392.1	157	3

[a] CWT = coded-wire tag (Agency code/Data 1code/Data 2 code). Number of CWTs recovered in the digestive tracts of northern squawfish represent ingested juvenile salmon.

[b] Mean effort per sampling period for each location; total effort (at bottom) is the total time, in seconds, that the shockers were on for all dates and all locations (see Appendix Table B1).

[c] Location codes (2 characters): TC = Tanner Creek transect area; other Columbia River transect areas, where 1st character, O = Oregon shoreline, and W = Washington shoreline; 2nd character, 1-4, transect areas (refer to Figure 3 for precise locations).

[d] CPUE = catch per unit effort, number of fish caught per hour (Appendix Table B1).

[e] CWT code = 23/30/21, released 21 June.

[f] CWT code = 23/30/23, released 21 June.

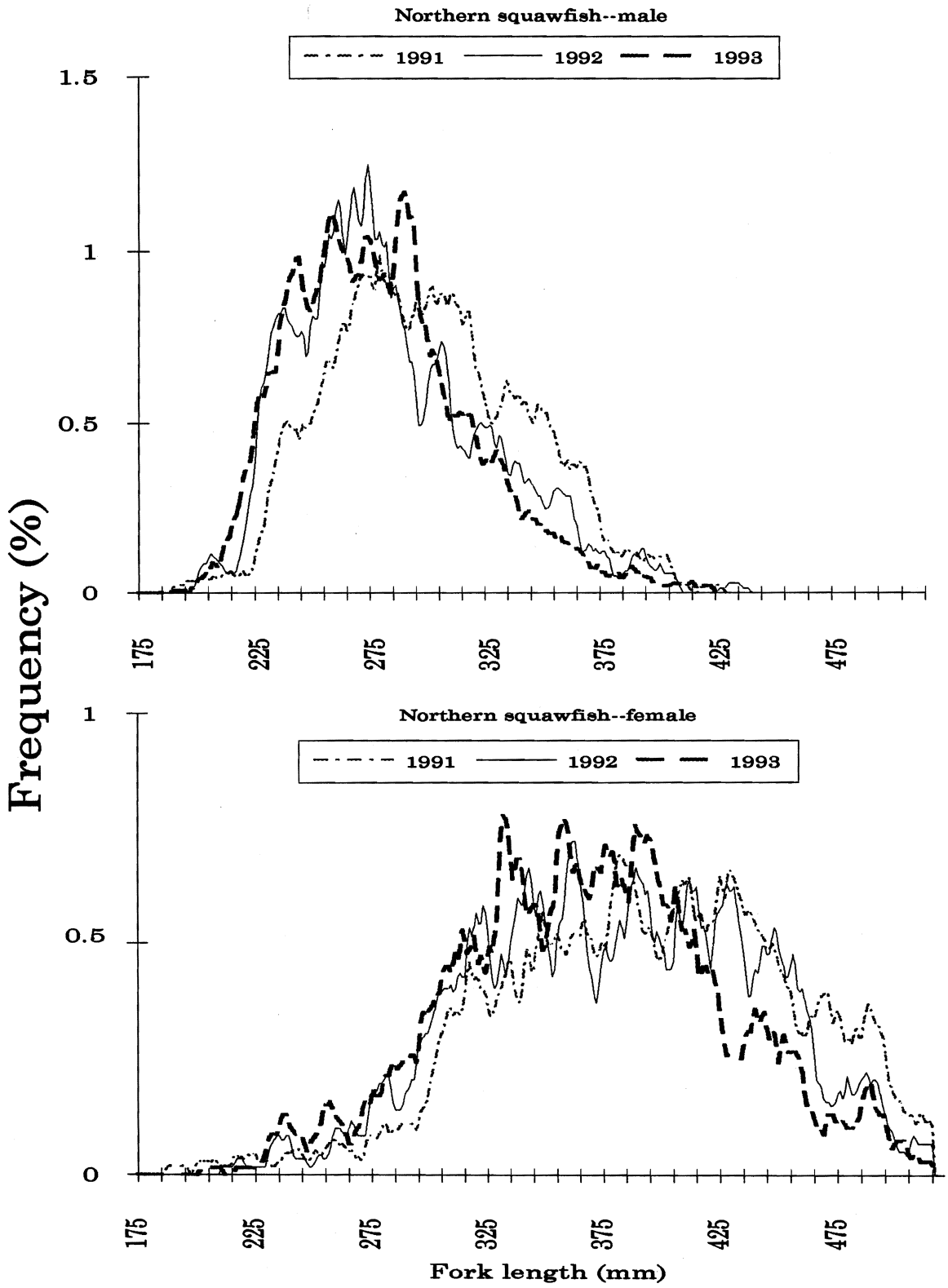

Figure 6.--Fork length distributions of northern squawfish removed from the study area by electrofishing, 1991, 1992, and 1993.

northern squawfish was highest in the Tanner Creek transect area, and 10% of the CWTs from study fish were recovered from those northern squawfish (Table 3). Although the percentage of CWTs recovered in the Tanner Creek transect area was low, it should be noted that this transect area was considerably smaller than the other transect areas and consequently received correspondingly less electrofishing effort. Also, due to a drop in tailwater elevation at Bonneville Dam on 26 June, it was impossible to electrofish within Tanner Creek following the 25 June release of study fish.

Juvenile Salmon Catch Patterns and Movement Rates

There was no evidence from the Jones Beach recovery data to suggest non-homogeneity between treatment recovery distributions of study fish groups released on the same day ($\alpha = 0.05$; Appendix C); thus the recovery data were standardized to a constant daily effort to determine the date of median fish recovery and to calculate movement rates (Appendix Table A3). Temporal catch distributions of each release group are presented in Figure 7.

Movement rates of study fish between the release site and Jones Beach ranged from 19.6 to 22.4 km/day, similar to movement rates in 1991 and 1992, but faster than movement rates in 1989 or 1990 (Table 4). Movement rates of fish from the second release groups were slightly slower than those of the first release groups, due perhaps in part to decreased river flow following the second release (Fig. 8).

Comparisons of fork length distributions of study fish at release to those captured at Jones Beach suggest that all groups grew about 1 mm per day during the migration period (Figs. 9-10). At recovery there were no apparent differences in daily mean lengths among treatment groups (Fig. 11). Generally, fish from both pairs of releases showed little change in mean length during the recovery period.

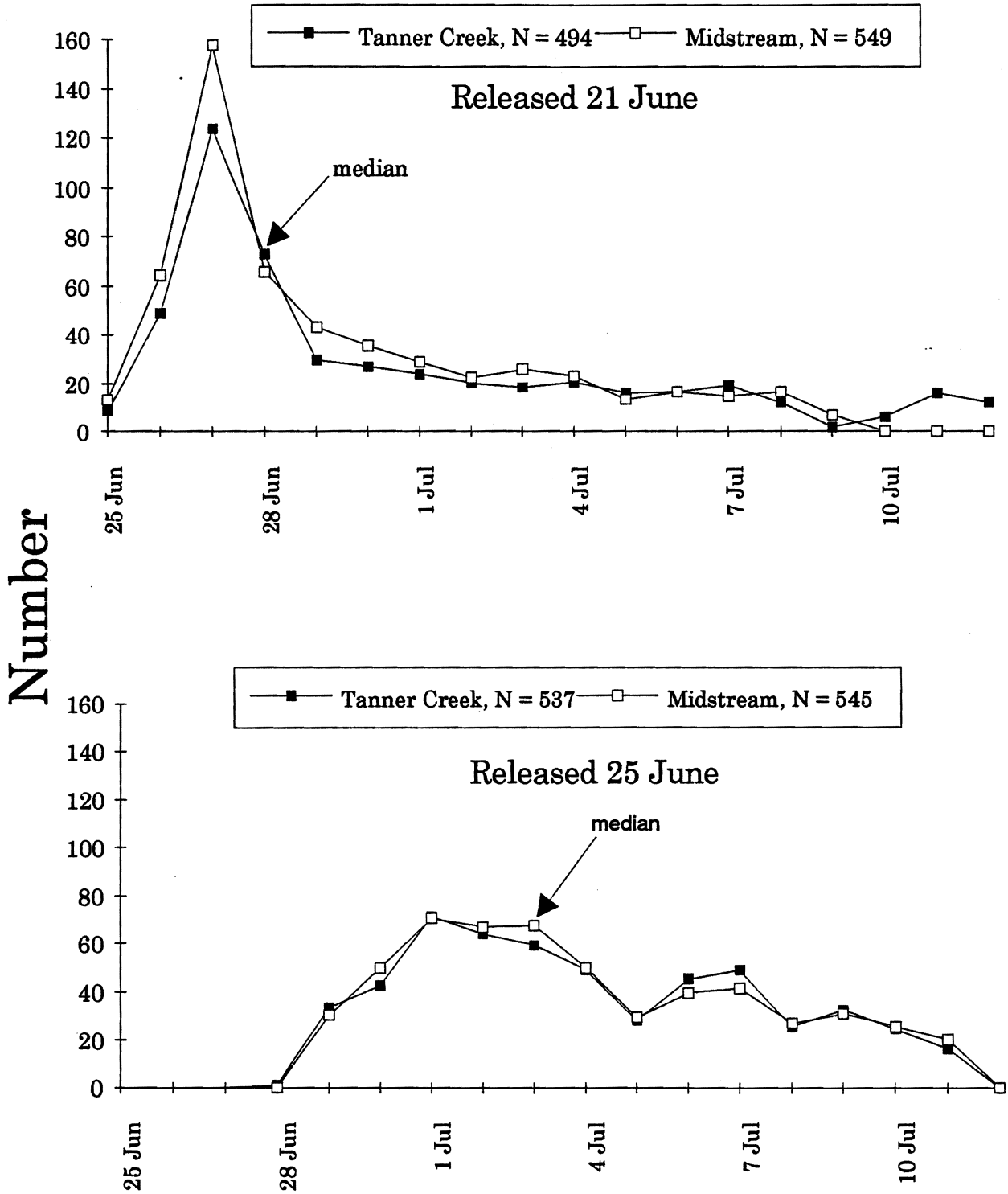

Figure 7.--Daily recoveries of test fish at Jones Beach (standardized for effort) comparing midstream Columbia River to Tanner Creek release-groups, 1993.

Table 4.--Movement rates to Jones Beach for marked groups of subyearling chinook salmon released in Tanner Creek and in midstream Columbia River, 1989, 1990, 1991, 1992, and 1993.

Release date	Movement rate (km/day)[a] Midstream Columbia	Tanner Creek	Mean FL (mm)[b]	Flow ($k \cdot ft^3/sec$) At release[c]	At median[d]
29 June 1989	10.4	9.8	101	142	113
1 July 1990	12.1	12.1	91	247	190
24 June 1991	15.7	17.4	92	215	262
28 June 1991	22.4	22.4	92	272	258
15 June 1992	17.4	17.4	95	191	198
19 June 1992	19.6	19.6	94	207	186
21 June 1993	22.4	22.4	91	199	186
25 June 1993	19.6	19.6	92	202	175

[a] Movement rate = distance from the midstream Columbia River release site (RKm 232) to recovery site (RKm 75) ÷ time in days from release to median fish recovery. Median fish recovery based on standardized daily effort (Appendix Table A3).

[b] Mean fork length of fish recovered at Jones Beach.

[c] Daily average flow at Bonneville Dam on the day that fish were released.

[d] Four-day average flow at Bonneville Dam within 2 days before and after the date that the median fish was captured; by convention, English units were used for river flow volumes ($k \cdot ft^3/sec$ = 1,000 ft^3/sec = 28.3 m^3/sec).

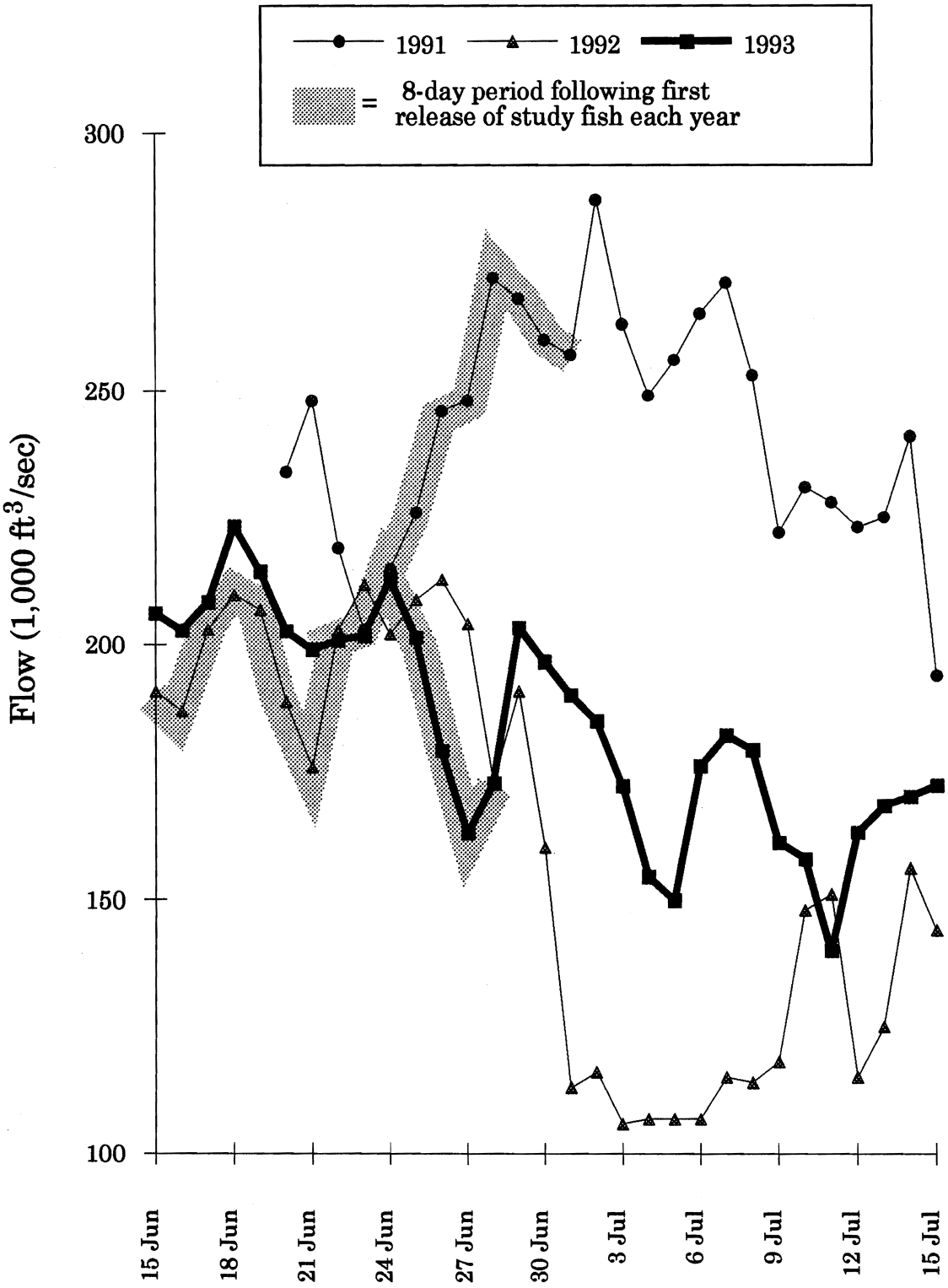

Figure 8.--Daily mean flows of the Columbia River at Bonneville Dam during the estuarine sampling periods, 1991, 1992, and 1993; flow measurements provided by the U. S. Army Corps of Engineers, Portland, Oregon.

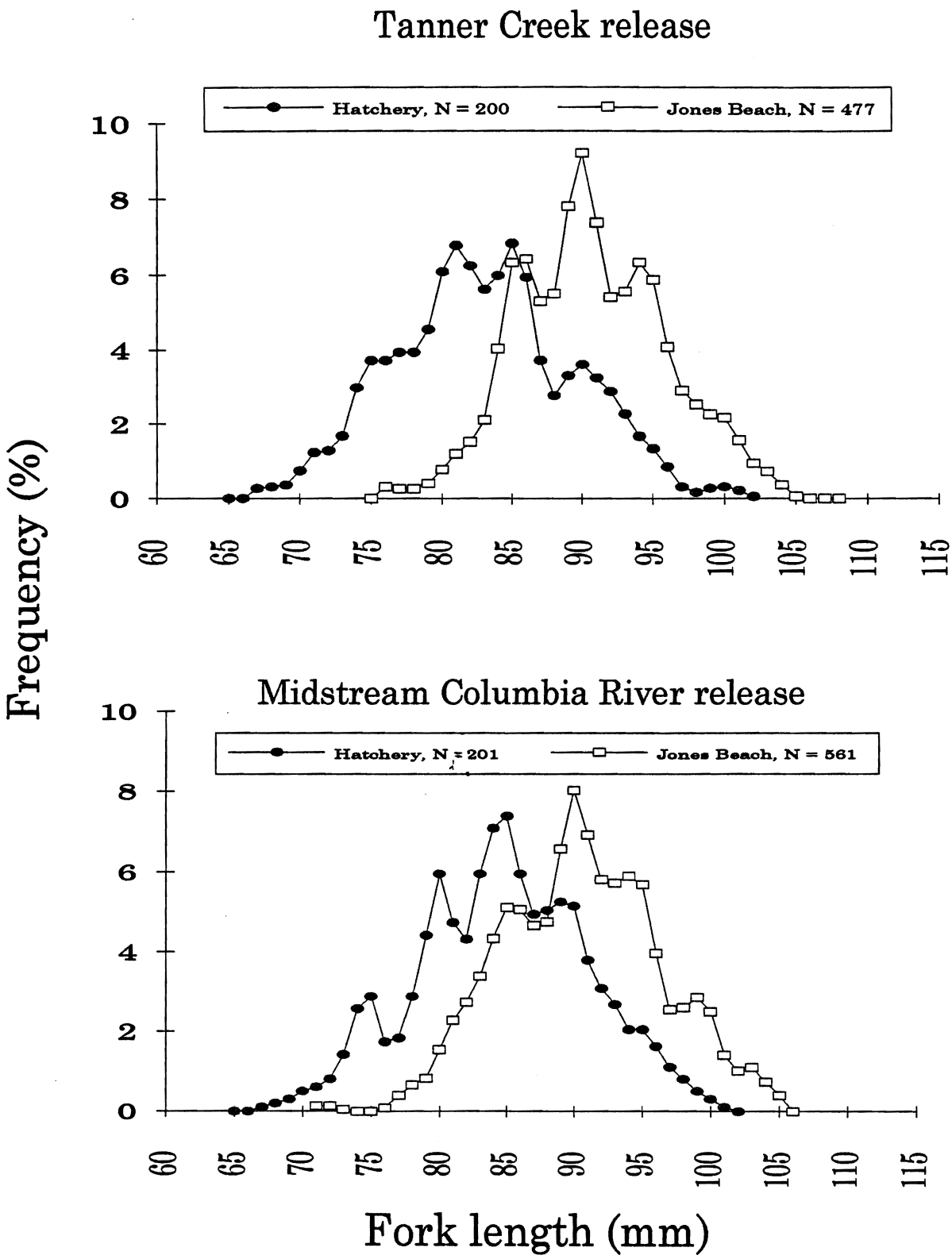

Figure 9.--Fork length distributions of study fish at release and after recovery at Jones Beach for fish released on 21 June 1993.

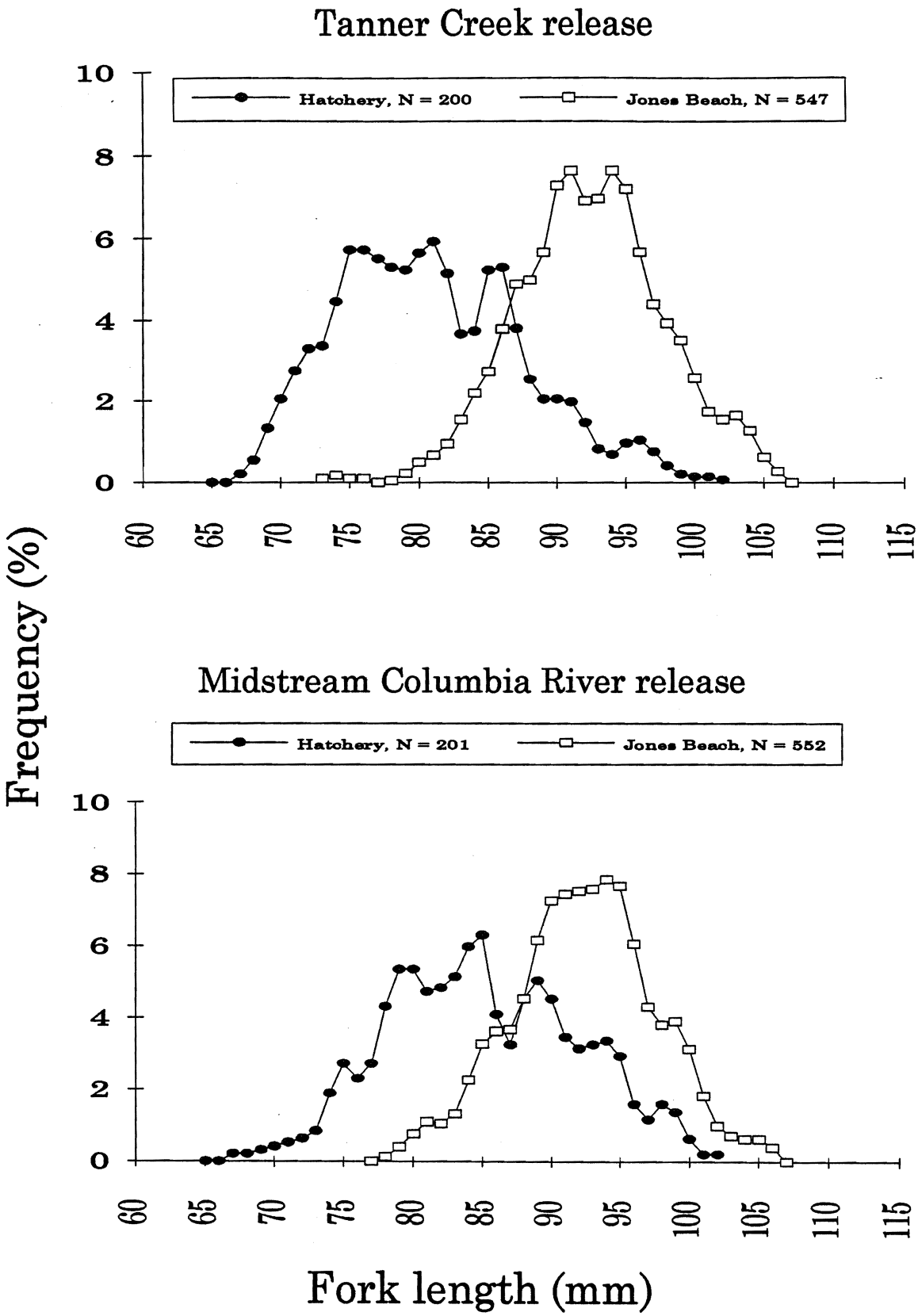

Figure 10.--Fork length distributions of study fish at release and after recovery at Jones Beach; fish released on 25 June 1993.

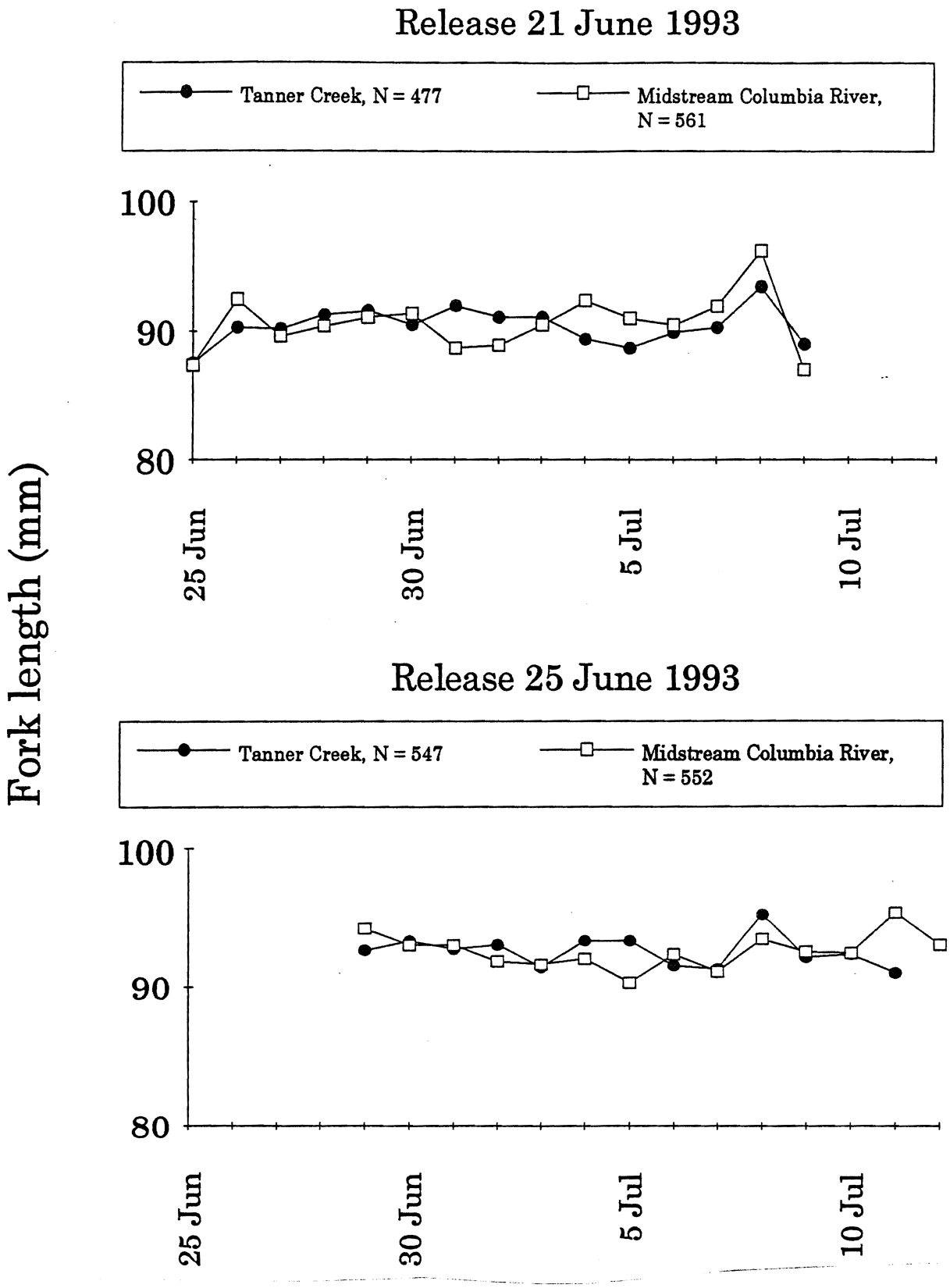

Figure 11.--Daily mean fork lengths of subyearling chinook salmon recovered at Jones Beach, comparing midstream Columbia River to Tanner Creek release groups, 1993.

Juvenile Salmon Recovery Differences

Analysis of CWT-fish recoveries at Jones Beach (Appendix C) indicated that the recovery percentages for fish released into the midstream Columbia River were significantly higher ($P = 0.0023$) than for fish released into Tanner Creek for the first release group (0.64% versus 0.60%). However, for the second pair of release groups, the differences in recovery percentages were reversed but not significantly different ($P = 0.3120$), with Tanner Creek recoveries higher than midstream Columbia River recoveries (0.64% versus 0.60%, respectively). Although the relative recovery percentages of the two treatment groups changed between the two release dates (Fig. 12), these percentages are not directly comparable because fish releases made on the two different dates were subject to different river conditions, which may affect both migration survival and sampling efficiency, and thus recovery. After the localized removal of northern squawfish, the difference in recovery percentages between the two release sites was reduced from 19.7% to -5.7% (Fig. 12) (Appendix C, Part 1c); this 129% reduction in recovery differences ($((19.7 - (-5.7) \div 19.7) * 100)$) was significant ($P = 0.0041$).

To further assess data consistency, we analyzed purse seine recoveries separate from total recoveries (Appendix Table A3, Appendix C). Conclusions regarding differences among recovery ratios derived from the purse seine data were the same as those reached with the total catch data; recoveries of study fish released from the midstream Columbia River were significantly higher ($P < 0.01$) than those for fish released into Tanner Creek for the first release pair and insignificant ($P = 0.31$) for the second release pair. Similarly, there was a significant change ($P < 0.01$) in the difference between recovery percentages following removal of northern squawfish. Beach seine recoveries separate from total recoveries were too few as a data subset for meaningful analysis (less than 2%).

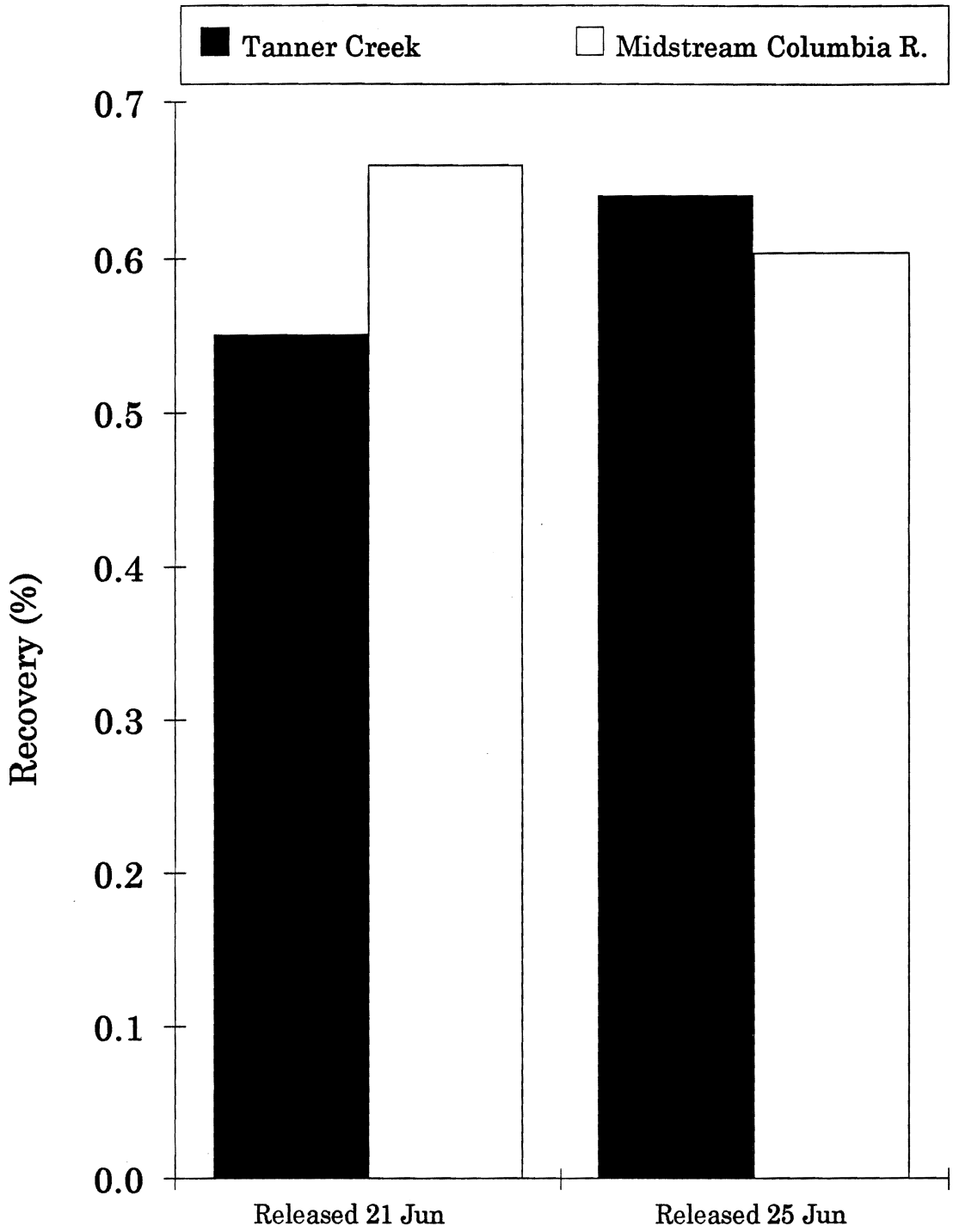

Figure 12.--Mean recovery percentages comparing midstream Columbia River to Tanner Creek release groups, 1993. Northern squawfish were removed by electrofishing between the two release dates. Recovery rate for the midstream release group was significantly higher ($P < 0.05$) than for the Tanner Creek release group on 21 June.

DISCUSSION

In 1993, for the first time in eight comparisons over a 5-year period, the recovery percentage in the estuary of a marked group of subyearling chinook salmon released into Tanner Creek was higher than the recovery percentage of a similar marked group released into the midstream Columbia River (Table 5). This exception occurred following electrofishing to remove northern squawfish from the presumed migration route of the Tanner Creek released fish. In all previous marked-group comparisons, dating back to studies in 1989, the midstream Columbia River release groups had significantly higher ($P < 0.05$) recovery percentages after migration to the estuary than groups released directly from Bonneville Hatchery into Tanner Creek.

In 1993, also for the first time, the reduction in benefit for midstream Columbia River release following the electrofishing effort was significant ($P = 0.0041$). In 1991 and 1992, although the benefit for midstream release declined following electrofishing, there remained a significant benefit to releasing subyearling chinook salmon from Bonneville Hatchery at the midstream Columbia River site. We questioned whether the observed declines following electrofishing to remove northern squawfish during 1991 and 1992 were actually a result of electrofishing, or merely responses to changing river flow or other coincidental events occurring between the two release dates each year.

Based on results from studies conducted from 1991 through 1993, we believe that the effectiveness of localized predator removal in protecting juvenile salmon released from Bonneville Hatchery is affected by Columbia River flows at the time of test fish release, as well as the system-wide northern squawfish removal program (Willis and Nigro 1994). We speculate that higher river-flow at the time of release allowed for faster downstream dispersal of Tanner Creek-released fish, resulting in less predation by northern squawfish

Table 5.--Recovery percentages of tagged subyearling chinook salmon at Jones Beach for Tanner Creek and midstream Columbia River release groups, 1989, 1990, 1991, 1992, and 1993.

Release date	Midstream Columbia River[b]	Bonneville Hatchery at Tanner Creek[c]	Benefit[a] for midstream release (%)
29 June 1989	0.43	0.26	65.4*[d]
1 July 1990	0.42	0.30	40.0*
24 June 1991	0.37	0.30	23.3*
28 June 1991	0.39	0.33	18.2* post-removal[e]
15 June 1992	0.57	0.42	35.7*
19 June 1992	0.60	0.51	17.6* post-removal[e]
21 June 1993	0.66	0.55	20.0*
25 June 1993	0.60	0.64	-6.3 post-removal[e]

[a] The percent benefit for midstream Columbia River release (MC) over Tanner Creek release (TC) is calculated as:

$$[(MC\% \text{ recovery} - TC\% \text{ recovery}) \div TC\% \text{ recovery}] \times 100.$$

[b] Fish transported by truck and barged to the middle of the Columbia River adjacent to the confluence with Tanner Creek.

[c] Normal hatchery release site.

[d] * = significant difference in recovery percentages for fish released in midstream Columbia River or Tanner Creek ($P \leq 0.05$).

[e] Benefit for midstream release following 4 days of extensive electrofishing to remove northern squawfish.

in the Tanner Creek-Columbia River confluence area and increased survival. We further speculate that the local population of northern squawfish was lower in 1993 than in earlier years of study as a result of the basin-wide northern squawfish sport-reward fishery, and this reduced population was more effectively controlled by electrofishing. In total, about 200,000 northern squawfish[2] were removed from the tailrace area of Bonneville Dam between 1991 and 1993.

In 1991 and 1992, the Columbia River flows on the second release date were higher than on the first release date; about 8% higher in 1992 and 27% higher in 1991. In 1993, flows were almost identical on the two release dates (Table 4). About 2,000 northern squawfish were removed from the study area between the two release dates in all three years, and the difference in survival benefit for midstream Columbia River releases compared to Tanner Creek releases following electrofishing efforts declined through the years (22, 51, and 129% decline in survival benefit for 1991, 1992, and 1993, respectively). The effectiveness of localized northern squawfish removal at reducing the survival differences between midstream Columbia River and Tanner Creek releases may also be affected by the dispersal rate of study fish from the area of release. Dispersal rate would affect the period of time that study fish were exposed to the local northern squawfish population.

It is difficult to determine if the generally high numbers and catch rates of predators in the study area occurred because northern squawfish congregated near the hatchery release site or because high densities of northern squawfish were prevalent throughout the entire study area. The high catches of northern squawfish along the

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[2] Scott Smith, Washington Department of Fish and Wildlife, Pullman, WA. Pers. commun., March 1994.

Oregon shoreline at transects O3 and O4 support the latter explanation (Fig. 5). In all three years (1991-1993), CWT recoveries from the stomachs of northern squawfish were concentrated at transects closest to the Tanner Creek release site, and nearly all the CWTs recovered were from the Tanner Creek release groups, which suggested that juvenile salmonids released from the hatchery were more vulnerable to predation by northern squawfish in the river region near Bonneville Hatchery than juveniles released in midstream. In 1993, the CPUE for northern squawfish fluctuated during the removal period, and was lower for the dates following the second pair of juvenile salmon releases, which indicated little influx of northern squawfish into the study area in response to the second release of juvenile salmon. The sharp drop in numbers of CWTs in the digestive tracts of northern squawfish by the final day of electrofishing indicated emigration of the released salmon.

It is difficult to attribute the apparent lack of survival benefit for midstream Columbia River-released fish in 1993 to the removal of only 2,866 northern squawfish. Rather, a general decline in the proportion of the larger-sized northern squawfish in 1992 and 1993 may better explain the decline.

CONCLUSIONS

1) Subyearling chinook salmon from Bonneville Hatchery released into the midstream Columbia River prior to electrofishing efforts exhibited significantly higher survival rates than fish released into Tanner Creek. We believe the difference in survival is in part related to predation by northern squawfish on fish released at the hatchery.
2) The predominance of CWTs from Tanner Creek-released juvenile salmon in the digestive tracts of northern squawfish indicated that juvenile salmon released from

the hatchery were more vulnerable to predation by northern squawfish located in the river region near Bonneville Hatchery than juveniles released in midstream.

3) The survival difference between midstream Columbia River and Tanner Creek release groups may be affected by the dispersal rate of study fish from the area of release. More rapid dispersal may be a result of tailwater elevation below Bonneville Dam and consequent hydraulic conditions at the confluence of Tanner Creek, and degree of smoltification.

4) It was difficult to determine if the high numbers and catch rates of predators at the transects nearest Tanner Creek occurred in response to the hatchery release or to high densities of northern squawfish throughout the study area.

5) It appeared that the numbers and size of northern squawfish in the study area have declined in recent years and that this general decline in population abundance contributed to the effectiveness of localized predator removal during the 1993 research. Electrofishing to remove northern squawfish from the migration route of juvenile salmon released from Bonneville Hatchery appeared to eliminate the survival difference between midstream Columbia River and Tanner Creek release groups under the conditions in 1993.

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APPENDIX A

Juvenile Salmon Marking, Release, and Jones Beach Recovery Information

APPENDIX B

Northern Squawfish Electrofishing Information

APPENDIX C

Statistical Analysis of Juvenile Salmon Recovery Data

Appendix Table A1.--Tag loss estimates among marked groups of subyearling chinook salmon after a 30-day holding period for Tanner Creek and midstream Columbia River release-groups, 1993.

Release dates	Coded Wire Tag (AG D1 D2)[a]	Sample[b]	No tag[c] (no.)	(%)
Tanner Creek releases				
21 June	23 30 21	492	18	3.7
25 June	23 30 22	489	36	7.4
Midstream releases				
21 June	23 30 23	503	23	4.6
25 June	23 30 24	482	13	2.7

[a] CWT code key: AG D1 D2 = Agency code, Data 1 code, Data 2 code.
[b] Number of fish checked for the presence of coded wire tags.
[c] No tag = number and percent of branded fish in the sample with no coded-wire tag. Percentage used in estimating the total numbers of tagged fish released.

Appendix Table A2.--Daily purse seine and beach seine fishing effort, water temperatures, and Secchi disk transparency measurements at Jones Beach, 1993.

Date	Number of sets Purse	Number of sets Beach	Temp. °C	Secchi depth (m)	Date	Number of sets Purse	Number of sets Beach	Temp. °C	Secchi depth (m)
18 Jun	2	0	17	--[a]	30 Jun	20	0	18	1.2
19 Jun	0	0	--	--	1 Jul	15	3	18	1.2
20 Jun	0	0	--	--	2 Jul	16	0	17	1.1
21 Jun	3	2	17	--	3 Jul	13	2	17	1.1
22 Jun	4	2	17	1.1	4 Jul	13	0	17	--
23 Jun	8	0	17	1.2	5 Jul	9	0	18	1.2
24 Jun	8	1	16	1.1	6 Jul	13	2	18	1.1
25 Jun	10[b]	0	17	1.2	7 Jul	13	0	18	1.2
26 Jun	13	0	17	1.1	8 Jul	8	2	18	1.1
27 Jun	13	2	17	1.4	9 Jul	7	0	18	1.2
28 Jun	12	1	18	1.1	10 Jul	2	0	18	1.4
29 Jun	15	0	18	1.2	11 Jul	3	0	18	1.2
					12 Jul	1	0	18	--

[a] Dashes indicate data not available.
[b] First recovery of study fish.

Appendix Table A3.--Daily recoveries, recoveries standardized for effort, dates of median fish recovery, and movement rates to Jones Beach of marked subyearling chinook salmon released from Bonneville Hatchery into Tanner Creek or transported from the hatchery for release in midstream Columbia River, 1993.

	Released 21 June											
	Treatments and tag code (AG D1 D2)[a]											
	Tanner Creek 23 30 21						Midstream Columbia 23 30 23					
Date of	Purse		Beach		Total		Purse		Beach		Total	
recovery	A[b]	S[c]	A	S	A	S	A	S	A	S	A	S
25 Jun	7	8	NE	--	7	8	11	13	NE	--	11	13
26 Jun	53	49	NE	--	53	49	70	65	NE	--	70	65
27 Jun	134	124	3	--	137	124	171	158	3	--	174	158
28 Jun	73	73	3	--	76	73[d]	66	66	3	--	69	66[d]
29 Jun	37	30	NE	--	37	30	54	43	NE	--	54	43
30 Jun	45	27	NE	--	45	27	59	35	NE	--	59	35
1 Jul	30	24	6	--	36	24	36	29	4	--	40	29
2 Jul	27	20	NE	--	27	20	30	23	NE	--	30	23
3 Jul	20	18	1	--	21	18	28	26	5	--	33	26
4 Jul	24	22	NE	--	24	22	27	25	NE	--	27	25
5 Jul	12	16	NE	--	12	16	10	13	NE	--	10	13
6 Jul	18	17	0	--	18	17	18	17	0	--	18	17
7 Jul	21	19	NE	--	21	19	16	15	NE	--	16	15
8 Jul	8	12	0	--	8	12	11	17	0	--	11	17
9 Jul	1	2	NE	--	1	2	4	7	NE	--	4	7
10 Jul	1	6	NE	--	1	6	0	0	NE	--	0	0
11 Jul	4	16	NE	--	4	16	0	0	NE	--	0	0
12 Jul	1	12	NE	--	1	12	0	0	NE	--	0	0
Total	516	495	13	--	529	495	611	550	15	--	626	550
Recovery (%)	0.54	0.52	0.01	--	0.55	0.52	0.64	0.58	0.02	--	0.66	0.58
Mvmt rate[e]						22.4						22.4

Appendix Table A3.--Continued.

	Released 25 June											
	Treatments and tag code (AG D1 D2)											
	Tanner Creek 23 30 22						Midstream Columbia 23 30 24					
Date of	Purse		Beach		Total		Purse		Beach		Total	
recovery	A[b]	S[c]	A	S	A	S	A	S	A	S	A	S
25 Jun	0	0	NE	--	0	0	0	0	NE	--	0	0
26 Jun	0	0	NE	--	0	0	0	0	NE	--	0	0
27 Jun	0	0	0	--	0	0	0	0	0	--	0	0
28 Jun	1	1	0	--	1	1	0	0	0	--	0	0
29 Jun	42	34	NE	--	42	34	38	30	NE	--	38	30
30 Jun	71	43	NE	--	71	43	83	50	NE	--	83	50
1 Jul	89	71	3	--	92	71	88	70	4	--	92	70
2 Jul	85	64	NE	--	85	64	89	67	NE	--	89	67
3 Jul	64	59	4	--	68	59[d]	73	67	0	--	73	67[d]
4 Jul	53	49	NE	--	53	49	54	50	NE	--	54	50
5 Jul	21	28	NE	--	21	28	22	29	NE	--	22	29
6 Jul	49	45	0	--	49	45	43	40	0	--	43	40
7 Jul	53	49	NE	--	53	49	45	42	NE	--	45	42
8 Jul	17	26	1	--	18	26	18	27	0	--	18	27
9 Jul	19	33	NE	--	19	33	18	31	NE	--	18	31
10 Jul	12	24	NE	--	12	24	10	25	NE	--	10	25
11 Jul	4	16	NE	--	4	16	5	20	NE	--	5	20
12 Jul	0	0	NE	--	0	0	0	0	NE	--	0	0
Total	580	541	8	--	588	541	586	548	4	--	590	548
Recovery (%)	0.63	0.59	0.01	--	0.64	0.59	0.60	0.56	0.00	--	0.60	0.56
Mvmt rate[e]						19.6						19.6

[a] AG D1 D2 = Agency code, Data 1 code, Data 2 code.
[b] A = Actual daily purse seine or beach seine catch. NE = no sampling effort.
[c] S = Standardized daily catch. Purse seine data standardized to a 12 set per day effort; beach seine effort was limited and not used for data standardization.
[d] Day that the median fish was captured (standardized purse seine effort).
[e] Mvmt rate = Movement rate (km/day) = distance traveled (RKm 232 to RKm 75) ÷ travel time (days from release to median fish recovery).

Appendix Table B1.--Northern squawfish electrofishing daily effort and catch results, 1993.

Electrofishing period[a]	Electrofishing date	Electrofishing location[b]	Start time[c]	Effort (sec)[d]	Catch (no.)	CPUE (no./h)[e]
1	22 Jun	O1	0326	1,802	27	53.9
2	23 Jun	O1	0216	1,271	29	82.1
2	22 Jun	O1	2133	970	51	189.3
3	24 Jun	O1	0208	1,112	27	87.4
3	23 Jun	O1	2115	1,027	25	87.6
4	25 Jun	O1	0110	804	29	129.9
4	24 Jun	O1	2112	1,104	23	75.0
5	27 Jun	O1	0100	1,602	7	15.7
6	28 Jun	O1	0155	599	13	78.1
6	27 Jun	O1	2107	1,375	31	81.2
6	27 Jun	O1	2124	775	32	148.6
Subtotal				12,441	294	--
Mean				1,131.0	26.7	93.5
SE				109.0	3.4	14.2
1	22 Jun	O2	0408	1,911	60	113.0
2	23 Jun	O2	0335	1,738	70	145.0
2	22 Jun	O2	2226	1,995	115	207.5
3	24 Jun	O2	0304	1,975	64	116.7
3	23 Jun	O2	2150	1,861	76	147.0
4	24 Jun	O2	2215	2,400	83	124.5
5	27 Jun	O2	0309	1,792	26	52.2
5	26 Jun	O2	2248	1,901	59	111.7
Subtotal				15,573	553	--
Mean				1,946.6	69.1	127.2
SE				71.6	8.9	15.4
1	22 Jun	O3	0517	1,866	41	79.1
2	23 Jun	O3	0450	1,766	47	95.8
2	22 Jun	O3	2313	1,807	223	444.3
3	24 Jun	O3	0356	1,242	40	115.9
3	23 Jun	O3	2327	1,820	164	324.4
4	25 Jun	O3	0412	1,800	51	102.0
4	24 Jun	O3	2305	1,800	110	220.0
5	27 Jun	O3	0406	1,580	31	70.6
5	26 Jun	O3	2336	1,319	78	212.9
6	27 Jun	O3	2045	1,750	15	30.9
Subtotal				16,750	800	--
Mean				1,675.0	80.0	169.6
SE				70.2	21.1	41.4
4	25 Jun	O4	0300	1,827	29	57.1
Subtotal				1,827	29	--

Appendix Table B1.--Continued.

Electrofishing period[a]	Electrofishing date	Electrofishing location[b]	Start time[c]	Effort (sec)[d]	Catch (no.)	CPUE (no./h)[e]
Mean				1,827.0	29.0	57.1
SE				--	--	--
1	22 Jun	TC	0506	99	7	254.5
2	23 Jun	TC	0315	231	9	140.3
2	22 Jun	TC	2215	407	33	291.9
3	24 Jun	TC	0325	449	13	104.2
3	23 Jun	TC	2205	250	14	201.6
4	25 Jun	TC	0200	319	12	135.4
4	24 Jun	TC	2200	513	24	168.4
Subtotal				2,268	112	--
Mean				324.0	16.0	185.2
SE				54.1	3.5	25.7
1	22 Jun	W1	0315	1,806	84	167.4
2	23 Jun	W1	0238	1,531	132	310.4
2	22 Jun	W1	2058	1,443	57	142.2
3	24 Jun	W1	0202	1,896	68	129.1
3	23 Jun	W1	2058	1,492	11	26.5
4	25 Jun	W1	0200	1,800	78	156.0
4	24 Jun	W1	2100	931	5	19.3
5	27 Jun	W1	0150	1,802	74	147.8
5	26 Jun	W1	2057	1,930	28	52.2
6	27 Jun	W1	2315	1,808	35	69.7
Subtotal				16,439	572	--
Mean				1,643.9	57.2	122.1
SE				96.2	12.2	27.3
1	22 Jun	W2	0645	1,098	15	49.2
2	23 Jun	W2	0405	1,060	13	44.2
2	22 Jun	W2	2310	1,800	25	50.0
3	24 Jun	W2	0413	1,038	7	24.3
3	23 Jun	W2	2225	1,557	48	111.0
4	25 Jun	W2	0341	1,265	13	37.0
4	24 Jun	W2	2241	1,528	25	58.9
5	27 Jun	W2	0145	1,629	18	39.8
5	26 Jun	W2	2247	1,130	2	6.4
6	28 Jun	W2	0245	1,578	24	54.8
6	27 Jun	W2	2254	1,438	14	35.0
Subtotal				15,121	204	--
Mean				1,374.6	18.5	46.4
SE				80.3	3.7	7.8

Appendix Table B1.--Continued.

Electrofishing period[a]	Electrofishing date	Electrofishing location[b]	Start time[c]	Effort (sec)[d]	Catch (no.)	CPUE (no./h)[e]
1	22 Jun	W3	0643	1,906	19	35.9
2	23 Jun	W3	0020	1,167	23	71.0
2	23 Jun	W3	0455	1,802	45	89.9
3	24 Jun	W3	0445	1,631	63	139.1
3	23 Jun	W3	2052	1,388	30	77.8
4	25 Jun	W3	0001	621	5	29.0
4	25 Jun	W3	0430	1,759	29	59.4
5	27 Jun	W3	0232	2,311	9	14.0
5	26 Jun	W3	2330	1,276	14	39.5
6	28 Jun	W3	0350	1,169	29	89.3
6	27 Jun	W3	2338	1,057	36	122.6
Subtotal				16,087	302	--
Mean				1,462.5	27.5	69.8
SE				142.5	5.0	11.8
Totals				96,506	2,866	--
Mean				1,423.1	40.5	108.9
SE				181.6	8.7	18.1

[a] Sampling periods generally began at 2100 h and terminated the following morning about 0900 h.

[b] Locations codes (2 characters): TC = Tanner Creek transect; other Columbia River transects, where 1st character O = Oregon shoreline and W = Washington shoreline; 2nd character, 1-4, transects located progressively downstream (refer to Figure 3 for precise locations).

[c] Time that the electrofishing effort began.

[d] Time that the electrofishing unit was powered on.

[e] CPUE = catch of northern squawfish per unit effort of electrofishing.

Appendix Table B2.--Coded-wire tags from ingested juvenile salmon recovered in the stomachs of northern squawfish during electrofishing efforts, 1993.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location[d]	Tag code (AG D1 D2)[e]
			Data for Tanner Creek release 21 June 1993			
1	22 Jun	0326	2000	4	O1	233021
1	22 Jun	0326	2000	4	O1	233021
1	22 Jun	0326	2000	4	O1	233021
1	22 Jun	0326	2000	4	O1	233021
1	22 Jun	0326	2000	4	O1	233021
1	22 Jun	0326	2000	4	O1	233021
1	22 Jun	0326	2000	4	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	9	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
1	22 Jun	0326	2000	19	O1	233021
Subtotal						24
1	22 Jun	0506	2001	1	TC	233021
1	22 Jun	0506	2001	3	TC	233021
1	22 Jun	0506	2001	3	TC	233021
1	22 Jun	0506	2001	3	TC	233021
1	22 Jun	0506	2001	3	TC	233021
1	22 Jun	0506	2001	3	TC	233021
1	22 Jun	0506	2001	3	TC	233021
1	22 Jun	0506	2001	5	TC	233021
1	22 Jun	0506	2001	5	TC	233021
1	22 Jun	0506	2001	6	TC	233021
Subtotal						10
1	22 Jun	0408	2252	6	O2	233021
1	22 Jun	0408	2252	6	O2	233021
1	22 Jun	0408	2252	6	O2	233021
1	22 Jun	0408	2252	7	O2	233021
1	22 Jun	0408	2252	7	O2	233021
1	22 Jun	0408	2252	7	O2	233021
1	22 Jun	0408	2252	7	O2	233021
1	22 Jun	0408	2252	8	O2	233021
1	22 Jun	0408	2252	8	O2	233021
1	22 Jun	0408	2252	8	O2	233021

Appendix Table B2--Continued.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location	Tag code (AG D1 D2)[e]
1	22 Jun	0408	2252	9	O2	233021
1	22 Jun	0408	2252	9	O2	233021
1	22 Jun	0408	2252	9	O2	233021
1	22 Jun	0408	2252	9	O2	233021
1	22 Jun	0408	2252	9	O2	233021
1	22 Jun	0408	2252	13	O2	233021
1	22 Jun	0408	2252	13	O2	233021
1	22 Jun	0408	2252	13	O2	233021
1	22 Jun	0408	2252	16	O2	233021
1	22 Jun	0408	2252	18	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	20	O2	233021
1	22 Jun	0408	2252	21	O2	233021
1	22 Jun	0408	2252	21	O2	233021
1	22 Jun	0408	2252	23	O2	233021
1	22 Jun	0408	2252	27	O2	233021
1	22 Jun	0408	2252	27	O2	233021
1	22 Jun	0408	2252	28	O2	233021
1	22 Jun	0408	2252	28	O2	233021
1	22 Jun	0408	2252	28	O2	233021
1	22 Jun	0408	2252	31	O2	233021
1	22 Jun	0408	2252	31	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	49	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	50	O2	233021
1	22 Jun	0408	2252	52	O2	233021
1	22 Jun	0408	2252	52	O2	233021

Appendix Table B2--Continued.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location	Tag code (AG D1 D2)[e]
1	22 Jun	0408	2252	52	O2	233021
1	22 Jun	0408	2252	54	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	55	O2	233021
1	22 Jun	0408	2252	58	O2	233021
1	22 Jun	0408	2252	58	O2	233021
1	22 Jun	0408	2252	58	O2	233021
1	22 Jun	0408	2252	58	O2	233021
1	22 Jun	0408	2252	58	O2	233021
1	22 Jun	0408	2252	58	O2	233021
1	22 Jun	0408	2252	58	O2	233021
1	22 Jun	0408	2252	58	O2	233021
Subtotal						80
Total period 1 (all sites)						114
2	22 Jun	2133	2011	22	O1	233021
2	22 Jun	2133	2011	23	O1	233021
Subtotal						2
2	22 Jun	2215	2012	22	TC	233021
2	22 Jun	2215	2012	22	TC	233021
2	22 Jun	2215	2012	27	TC	233021
2	22 Jun	2215	2012	27	TC	233021
2	22 Jun	2215	2012	27	TC	233021
2	23 Jun	0315	2016	6	TC	233021
Subtotal						6
2	22 Jun	2226	2262	6	O2	233021
2	22 Jun	2226	2262	6	O2	233021
2	22 Jun	2226	2262	8	O2	233021
2	22 Jun	2226	2262	8	O2	233021
2	22 Jun	2226	2262	8	O2	233021
2	22 Jun	2226	2262	8	O2	233021
2	22 Jun	2226	2262	8	O2	233021
2	22 Jun	2226	2262	29	O2	233021
2	22 Jun	2226	2262	29	O2	233021
2	22 Jun	2226	2262	29	O2	233021

Appendix Table B2--Continued.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location	Tag code (AG D1 D2)[e]
2	22 Jun	2226	2262	29	O2	233021
2	22 Jun	2226	2262	112	O2	233021
2	23 Jun	0335	2265	7	O2	233021
2	23 Jun	0335	2265	7	O2	233021
2	23 Jun	0335	2265	7	O2	233021
2	23 Jun	0335	2265	7	O2	233021
2	23 Jun	0335	2265	15	O2	233021
2	23 Jun	0335	2265	16	O2	233021
2	23 Jun	0335	2265	16	O2	233021
2	23 Jun	0335	2265	16	O2	233021
2	23 Jun	0335	2265	27	O2	233021
2	23 Jun	0335	2265	27	O2	233021
2	23 Jun	0335	2265	50	O2	233021
2	23 Jun	0335	2265	50	O2	233021
2	23 Jun	0335	2265	50	O2	233021
2	23 Jun	0335	2265	50	O2	233021
2	23 Jun	0335	2265	50	O2	233021
2	23 Jun	0335	2265	50	O2	233021
2	23 Jun	0335	2265	50	O2	233021
2	23 Jun	0335	2265	57	O2	233021
2	23 Jun	0335	2265	63	O2	233021
2	23 Jun	0335	2265	63	O2	233021
2	23 Jun	0335	2265	63	O2	233021
Subtotal						33
Total period 2 (all sites)						41
3	24 Jun	0208	2022	1	O1	233021
3	24 Jun	0325	2023	5	TC	233021
Total period 3 (all sites--1 each for O1 and TC)						2
Grand total this tag number all periods all sites.						157
Data for Midstream Columbia River release 21 June 1993						
1	22 Jun	0408	2252	13	O2	233023
1	22 Jun	0408	2252	27	O2	233023
2	22 Jun	2226	2262	8	O2	233023
Grand total this tag number all periods all sites.						3

Appendix Table B2--Continued.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location	Tag code (AG D1 D2)[e]
			Data for tagged nonstudy fish			
2	23 Jun	0216	2015	22	O1	635003
2	23 Jun	0238	2264	42	W1	076135
2	23 Jun	0238	2264	3	W1	076137
2	23 Jun	0238	2264	108	W1	076137
3	23 Jun	2225	2020	3	W2	076137
3	23 Jun	2225	2020	3	W2	076332
4	25 Jun	0200	2280	43	W1	076332
Grand total nonstudy tags all periods all sites.						7

[a] Individual specimens of northern squawfish are identified as a combination of collection number and predator number.

[b] Sampling periods generally began at 2100 h and terminated the following morning about 0900 h.

[c] Time that the electrofishing effort began.

[d] Location codes (2 characters): TC = Tanner Creek transect; other Columbia River transects, where 1st character O = Oregon shoreline and W = Washington shoreline; 2nd character, 1-4, transects located progressively downstream (refer to Figure 3 for precise locations).

[e] CWT code key AG D1 D2 = Agency code, Data 1 code, and Data 2 code.

APPENDIX C

Statistical Analysis of Juvenile Recovery Data

A. Chi-square goodness of fit analysis was used to evaluate differences among observed recoveries (Appendix Table A3) through time for different treatment groups released on the same day (Sokal and Rohlf 1981). A non-significant result indicated that there was equal probability of capture at Jones Beach for each treatment group (i.e., that the groups were adequately mixed). Results of this analysis are shown below. For additional details of this procedure see Dawley et al. (1989, Appendix D).

H_o: There was homogeneity between recovery distributions of treatments.

Release date	Seine type	Chi-square	df	P
21 June	purse plus beach	10.33	14	0.7377
25 June	purse plus beach	2.91	12	0.9962

Conclusion: No evidence to suggest there is non-homogeneity between treatment recovery distributions.

B. Paired difference z-tests were used to evaluate the benefits of midstream Columbia River release over Tanner Creek release and to evaluate the effects of northern squawfish removal efforts on the difference between midstream- and Tanner Creek-releases. Similar analyses were preformed on purse-seine plus beach-seine recoveries (section 1a-1c) and purse-seine recoveries alone (section 2a-2c). Recoveries in the beach seine were insufficient for a meaningful analysis (<0.1%).

Where :

P_{tc1} = true survival to and recovery at Jones Beach of fish released in Tanner Creek before squawfish removal on 21 June.

p_{tc1} = estimate of P_{tc1} = recovery proportion at Jones Beach of fish released at Tanner Creek on 21 June

Similar explanations follow for P_{tc2}, p_{tc2}, P_{mc1}, p_{mc1}, P_{mc2} and p_{mc2}

where: tc denotes Tanner Creek.

mc denotes midstream Columbia River

1 denotes releases on 21 June, before squawfish removal

2 denotes releases on 25 June, after squawfish removal

R_{ij} = release number for group i, j

where i = tc, mc and j = 1, 2

$v(p_{ij}) = p_{ij}(1-p_{ij}) \div R_{ij}$ is the estimated variance of p_{ij}

For the three null hypotheses tested below, we assumed z (as defined below) would follow a standard normal distribution.

1) Total catch--purse seine plus beach seine.

   a) The null hypothesis for testing whether recoveries of midstream Columbia River-released fish were different than Tanner Creek-released fish for the first release pair was:

H_o: $(P_{mc1} - P_{tc1}) = 0$

The test statistic was:

$$z = \frac{(p_{mc1} - p_{tc1})}{\sqrt{v(p_{mc1}) + v(p_{tc1})}}$$

The relevant statistics for the first release pair were:

$p_{mc1} = 626 \div 94{,}938 = 0.006594$

$p_{tc1} = 529 \div 96{,}013 = 0.005510$

$$z = \frac{(0.006594 - 0.005510)}{\sqrt{\frac{0.006594(0.993406)}{94938} + \frac{0.005510(0.994490)}{96013}}}$$

$$= \frac{0.001084}{0.000355} = 3.053, \; p\text{-}value = 0.0023$$

Then,

Conclusion: The recovery rate for midstream Columbia River-released fish was significantly higher than for Tanner Creek-released fish; the difference was 19.7%.

b) The null hypothesis for testing whether recoveries of midstream Columbia River-released fish were different than Tanner Creek-released fish for the second release pair was:

H_o: $(P_{mc2} - P_{tc2}) = 0$

The test statistic was:

$$z = \frac{(p_{mc2} - p_{tc2})}{\sqrt{v(p_{mc2}) + v(p_{tc2})}}$$

The relevant statistics for the second release pair were:

$p_{mc2} = 590 \div 97{,}835 = 0.006031$

$p_{tc2} = 588 \div 91{,}926 = 0.006396$

Then,

$$z = \frac{(0.006031 - 0.006396)}{\sqrt{\frac{0.006031(0.993969)}{97835} + \frac{0.006396(0.993604)}{91926}}}$$

$$= \frac{-0.000365}{0.000361} = -1.0111, \quad p\text{-}value = 0.3120$$

Conclusion: The recovery rate for midstream Columbia River-released fish was not significantly higher than for Tanner Creek-released fish; the difference was -5.7%.

c) The null hypothesis for testing whether northern squawfish removal had a significant benefit for Tanner Creek-released fish was:

H_o: $(P_{mc1} - P_{tc1}) - (P_{mc2} - P_{tc2}) = 0$

The test statistic was:

$$z = \frac{(p_{mc1} - p_{tc1}) - (p_{mc2} - p_{tc2})}{\sqrt{v(p_{mc1}) + v(p_{tc1}) + v(p_{mc2}) + v(p_{tc2})}}$$

The relevant statistics for the study were:

$p_{mc1} = 626 \div 94{,}938 = 0.006594$

$p_{tc1} = 529 \div 96{,}013 = 0.005510$

$p_{mc2} = 590 \div 97{,}835 = 0.006031$

$p_{tc2} = 588 \div 91{,}926 = 0.006396$

Then,

$$z = \frac{(0.006594 - 0.005510) - (0.006031 - 0.006396)}{\sqrt{\frac{0.006594(0.993406)}{94938} + \frac{0.005510(0.994490)}{96013} + \frac{0.006031(0.993969)}{97835} + \frac{0.006396(0.993604)}{91926}}}$$

$$= \frac{0.00145}{0.000505} = 2.871 \quad p\text{-}value = 0.0041$$

Conclusion: The effect of removing northern squawfish from the migration route of Tanner Creek-released fish was significant; the reduction was 128.9% ((19.7% - (-5.7)% ÷ 19.7) * 100).

2) Purse seine recoveries .

a) The null hypothesis for testing whether recoveries of midstream Columbia River-released fish were different than Tanner Creek-released fish for the first release pair was:

H_o: $(P_{mc1} - P_{tc1}) = 0$; $z = 3.028$; *p-value* = 0.0025

b) The null hypothesis for testing whether recoveries of midstream Columbia River-released fish were different than Tanner Creek-released fish for the second release pair was:

H_o: $(P_{mc2} - P_{tc2}) = 0$; $z = -1.0160$; *p-value* = 0.3096

c) The null hypothesis for testing whether northern squawfish removal had a significant benefit for Tanner Creek-released fish was:

H_o: $(P_{mc1} - P_{tc1}) - (P_{mc2} - P_{tc2}) = 0$; $z = 2.7510$; *p-value* = 0.0059