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Effectiveness of Predator Removal for Protecting Juvenile Fall Chinook Salmon Released from Bonneville Hatchery, 1991

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Effectiveness of Predator Removal for Protecting Juvenile Fall Chinook Salmon Released from Bonneville Hatchery, 1991

Richard D. Ledgerwood[1], Earl M. Dawley[1], Paul J. Bentley[1], Lyle G. Gilbreath[1], Thomas P. Poe[2], and Harold L. Hansen[3]

[1] National Marine Fisheries Service
Northwest Fisheries Science Center
Coastal Zone and Estuarine Studies Division
2725 Montlake Blvd. E., Seattle, WA 98112-2097

[2] U.S. Fish and Wildlife Service
Columbia River Field Station
MP 5.48L Cook Underground Road
Cook, WA 98605-9701

[3] Oregon Department of Fish and Wildlife
Research and Development
17330 S.E. Evelyn Street
Clackamas, OR 97015-9514

May 1993

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

National Oceanic and Atmospheric Administration
John A. Knauss, Administrator

National Marine Fisheries Service
William W. Fox, Jr., Assistant Administrator for Fisheries

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ABSTRACT

Despite a belief that removal of northern squawfish (Ptychocheilus oregonensis) would increase survival of juvenile salmonids (Oncorhynchus spp.) in the Columbia River Basin, there has been no direct demonstration of the benefit of predator removal.

In 1991, we assessed the survival increases for juvenile salmon before and after the removal of northern squawfish in the vicinity of the hatchery release site, while the U.S. Fish and Wildlife Service tested the effectiveness of electrofishing to remove northern squawfish. Short-term survival differences among release groups of juvenile salmon were assessed from comparisons of coded-wire tagged (CWT) fish recovered near the upper boundary of the Columbia River estuary at Jones Beach (River Kilometer 75). Captured northern squawfish were examined to determine the effects of predator size and density on the rate at which juvenile salmonids are consumed.

A total of 2,012 northern squawfish were removed from nine transect areas near the hatchery in about 20 hours of electrofishing between the two release dates. With few exceptions, the daily catch, catch rate, mean fork length, and mean weight of northern squawfish and the number of CWTs recovered in the digestive tracts of northern squawfish (representing ingested juvenile salmon) declined over time. Analysis of CWT-fish recoveries at Jones Beach indicated that the recovery percentages for fish released into the midstream Columbia River were significantly higher than for fish released into Tanner Creek before predator removal (0.37% versus 0.30%; $P = 0.01$) and after predator removal (0.39% versus 0.33%; $P = 0.02$). After the removal of northern squawfish, the difference in recovery percentages between the two release sites was reduced from 23.3 to 18.2% (insignificant; $P = 0.92$).

In 1989 and 1990, the differences in recovery percentages between the two release sites (no predator removal) were considerably greater and may have been related to lower

river flows. We speculate that higher flow volumes in 1991 dispersed test fish more rapidly, reduced their exposure time to predation, and resulted in higher survival rates for Tanner Creek releases. In addition, the Columbia River flow increased about 25% between the first and second release dates and the higher flow may have increased survival of the Tanner Creek-released fish regardless of predator removal efforts. The 18.2% difference in recovery between midstream and Tanner Creek release following northern squawfish removal suggests that the resident population of northern squawfish was large and removal of 2,012 predators was insufficient to significantly improve survival of juvenile fish emigrating from Tanner Creek.

CONTENTS

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 of predator removal. Heretofore, research has largely focused on estimating abundance of northern squawfish in selected locations (e.g., tailraces and forebays of dams, and reservoir reaches) and assessing northern squawfish predation on smolts near hydroelectric projects (Thompson 1959, Uremovich et al. 1980, Nigro 1990, Poe et al. 1991, Vigg et al. 1991). In 1989 and 1990, the National Marine Fisheries Service (NMFS) and Oregon Department of Fish and Wildlife (ODFW) cooperated in a release-site study at Bonneville Hatchery (Harold L. Hansen, unpubl. data, ODFW, Clackamas, Oregon). Subyearling fall chinook salmon (O. tshawytscha) were marked and simultaneously released into Tanner Creek (the normal hatchery release site) and into the midstream Columbia River, lateral to the confluence of Tanner Creek (Fig. 2). Seine recoveries of juveniles in the estuary indicated that survival following the 157-km migration was dramatically better for midstream Columbia River release groups than for Tanner Creek release groups. In 1989 and 1990, the differences were about 65 and 40%, respectively. These differences were thought to be related to greater predation by northern squawfish on fish released into Tanner Creek than on fish released into the deep-water, high-current area of the midstream Columbia River. Northern squawfish are known to inhabit protected shoreline areas; a large population of northern squawfish exists in the tailrace area of Bonneville Dam, adjacent to Tanner Creek (Vigg et al. 1990, Petersen et al. 1990).

This report summarizes a 1991 cooperative study by NMFS, ODFW, and U.S. Fish and Wildlife Service to demonstrate the effectiveness of removing northern squawfish

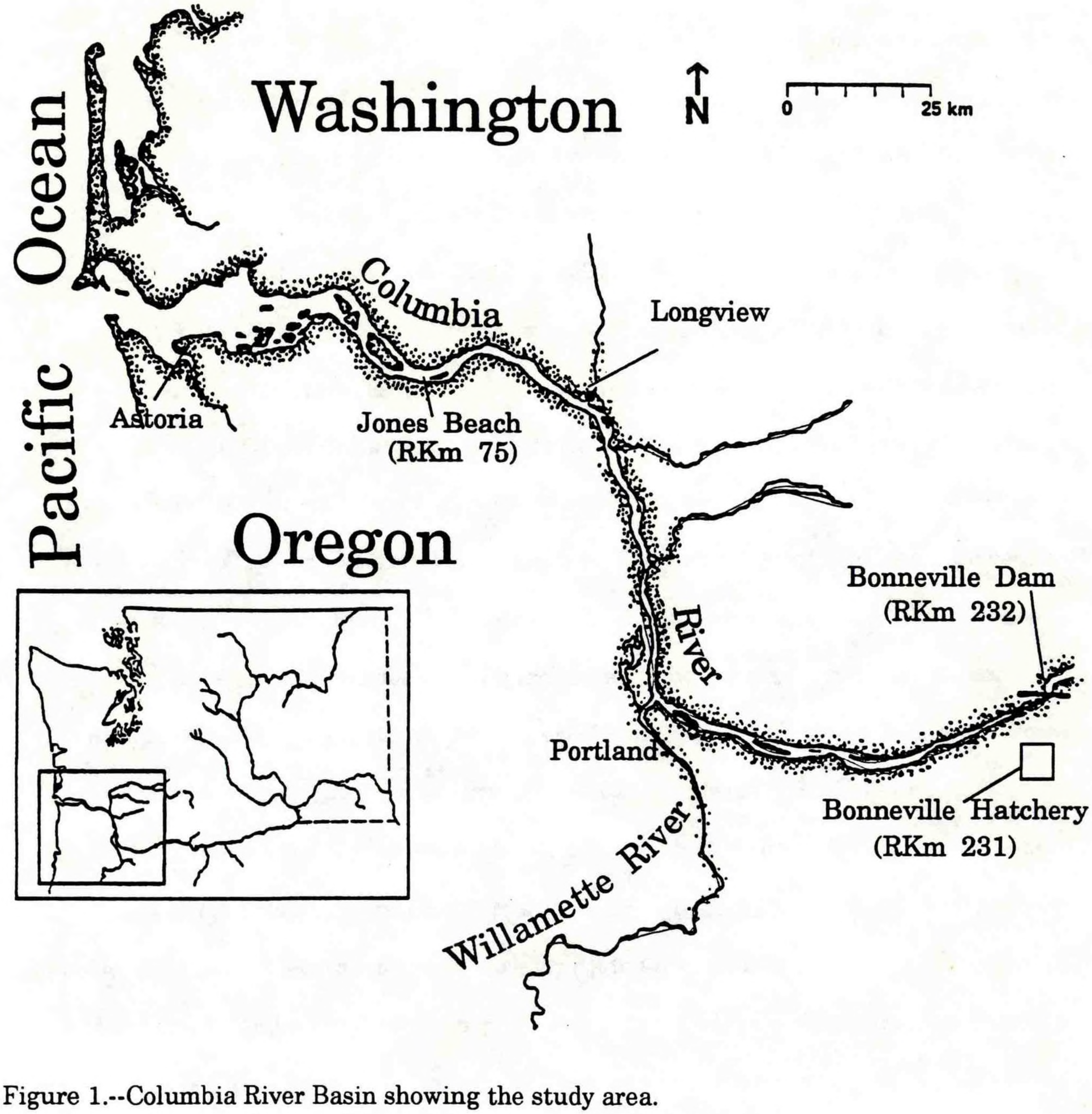

Figure 1.--Columbia River Basin showing the study area.

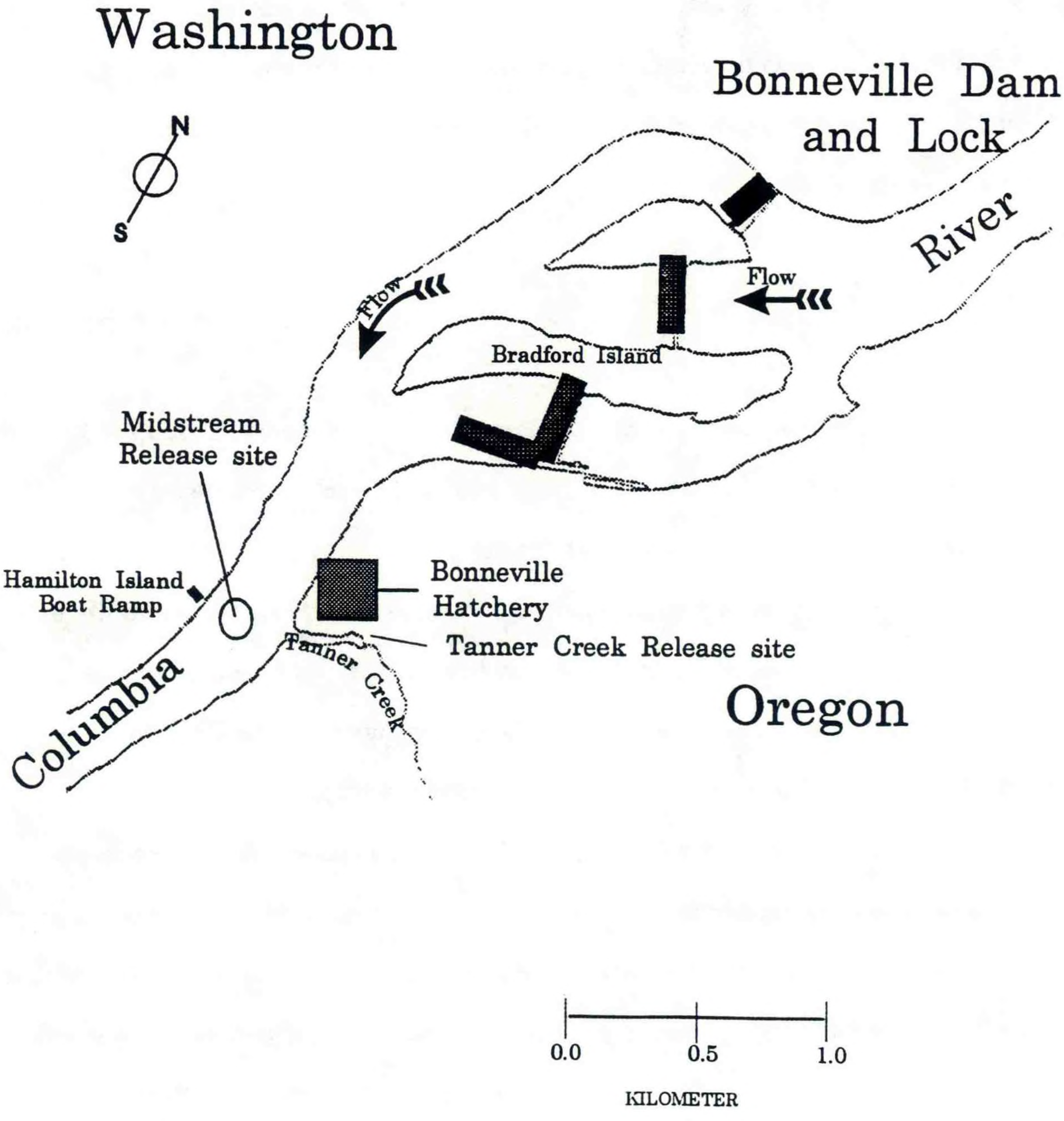

Figure 2.--The study area showing the release locations for subyearling chinook salmon, 1991.

from the migration route of juvenile salmon released at Bonneville Hatchery. The study had three objectives: 1) assess survival increases for juvenile salmon 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 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 efforts were made to remove northern squawfish from the immediate area in and around Tanner Creek and from the adjacent shoreline areas of the Columbia River extending 5 km downstream. Catch per unit effort (CPUE), size of fish removed, numbers of salmon ingested, and overall food consumption of northern squawfish were assessed to evaluate changes in the local population and their impacts on released salmon. Following northern squawfish removal efforts, a second pair of uniquely marked 100,000-fish groups was released at the two study sites. 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 fish. Recovery percentages were used for evaluating short-term survival differences between fish groups released at the two study sites before and after northern squawfish removal efforts. Similar comparisons of the relative contribution of marked fish returning to ocean and river fisheries and 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 7.4 g (61 fish/lb), somewhat larger than the fish used in the 1989 (7.0 g) and 1990 (6.3 g) studies.

Marking Procedures

Test fish were marked from 3 to 17 June, Monday through Friday, by a 14-person crew marking fish 8 hours per day; about 35,000 fish were marked each day. Each marked group had unique coded-wire tags (CWT) (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 did not differ in fish size, fish condition, rearing history, or mark quality: 1) the four groups were marked simultaneously; and 2) differences in mark quality among groups were minimized by rotating fish markers and 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 and maintain quality control in the tagging process, samples of about 100 fish from each treatment were collected about every 2 hours from outfall pipes at the marking trailer and checked for CWTs (Appendix Table A1). Similarly, samples of about five fish from each treatment were diverted into net-pens at 1-hour intervals throughout the marking day and held for a minimum of 30 days to determine tag loss. Samples from each treatment were held in separate net-pens. Estimates of tag loss ranged from 4.0 to 5.4% ($\bar{x}$ = 4.4, n = 2,076; Appendix Table A2). 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 an hour 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 hose with a diameter of 15 cm 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 60 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 hose with a diameter of 15 cm. Releases occurred between about 2130 and 2300 h at about RKm 232.

Electrofishing Northern Squawfish

Two 5.5-m electrofishing boats (Smith-Root brand, model SR-18E)[1] were used to capture 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 with pulsed direct current using 60 pulses/sec, 400-500 volts, and 4-5 amperes.

Electrofishing activities began at 0300 h on 25 June, about 6 hours following the first pair of releases (Appendix Table B1). On subsequent nights through 28 June, electrofishing was conducted from 2100 to 0900 h. Electrofishing was delayed the first night to allow test fish to disperse following release. Nine transect areas were electrofished: one in lower Tanner Creek, and eight others in nearshore areas in the Columbia River (Fig. 3). 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, removal 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 methane sulfonate (MS-222) and within about 40 minutes of capture, 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.

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

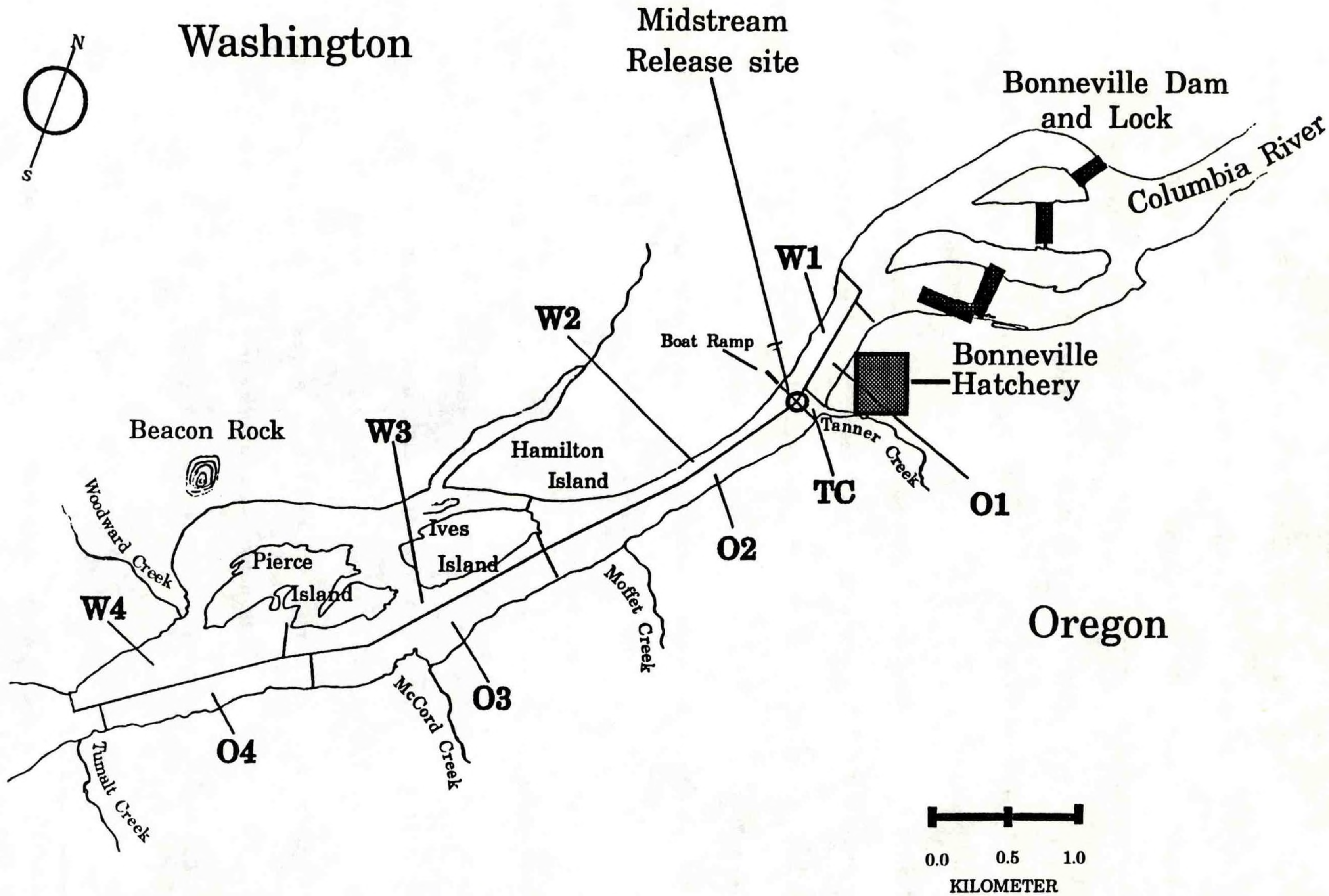


Figure 3.--The study area showing the electrofishing areas in Tanner Creek and adjacent shoreline areas of the Columbia River, 1991.

In the laboratory, frozen digestive tracts were thawed and prepared for analysis using a digestive enzyme solution (pancreatin) to dissolve flesh and leave diagnostic bones and CWTs from ingested fish intact (Petersen et al. 1990). The 2% (by weight) pancreatin solution, prepared using lukewarm tapwater, also contained 1% sodium sulfide. This solution was added to the plastic bags containing the digestive tracts and the bags were placed in a 40°C desiccating oven for 24 hours. The stainless-steel CWTs, having a higher 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. The 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 at Jones Beach

Short-term survival differences among release groups were assessed from comparisons of tagged fish recovered near the upper boundary of the Columbia River estuary at Jones Beach (RKm 75). In addition to determining recovery differences, captured fish were observed for differences in descaling, injuries, size, and migration behavior. Dawley et al. (1985, 1988) described the sampling site and the fishing gear.

Sampling was conducted by two or three crews working 7 days per week for 8 to 12 hours per day, beginning at sunrise (Appendix Table C1). Both purse seines (midriver) and beach seines (Oregon shore) were used to determine whether study fish were more abundant in midriver or near shore (Fig. 4) and to maximize effort using the gear type that captured the greatest numbers of study fish.

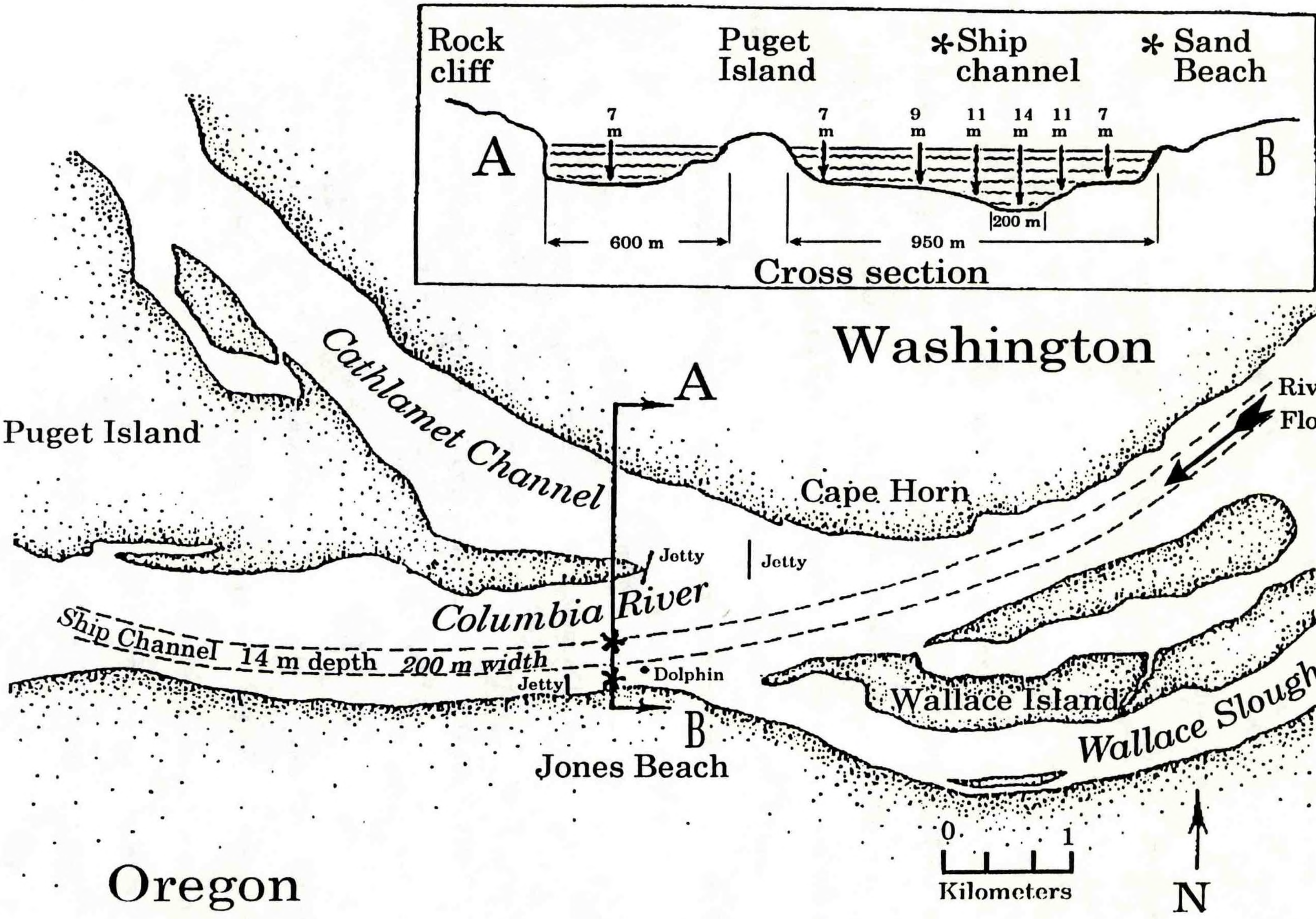


Figure 4.--Jones Beach, Columbia River, sampling sites. The beach and purse seining areas are denoted by asterisks.

All captured fish were processed aboard the purse seine vessels. The catch from each set was anesthetized using a 50 mg/L solution of ethyl-*p*-aminobenzoate (benzocaine) and enumerated by species. Numbers of dead, injured, or descaled salmonids were recorded. Subyearling chinook salmon were examined for excised adipose fins and brands (possible study fish) and separated for mark processing. Nonstudy 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 nonstudy fish. Fish were classified as descaled when 25% or more of their scales were missing on one side. Descaling of fish captured at Jones Beach was generally related to waves from wind or passing ships, which rolled fish in the nets. Great care was taken to minimize descaling.

Brands were used to identify study fish for collecting CWTs, to mark biological samples, and to compare fish size among treatment groups. Daily sampling effort was adjusted to attain the desired minimum sample size of 0.5% of the number of fish released. Brand information and biological and associated sampling data (i.e., 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.

The heads of branded fish were processed individually by recovery day, site, and time of capture. A 40% aqueous solution of potassium hydroxide was used to dissolve the heads and obtain CWTs. All CWTs were decoded and later verified; additional details of tag processing are presented in Appendix D of Ledgerwood et al. (1990).

Purse seine data, obtained from 28 June to 16 July, were standardized to a 10-set-per-day effort and beach seine catch data from 28 June to 13 July were standardized to a 5-set-per-day effort. The following formula was used for standardizing each marked group:

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

where:

A_i = Standardized purse or beach seine catch on day i

N_i = Actual purse or beach seine catch on day i

S = Constant (weighted daily average number of purse seine sets (10) or beach seine sets (5) during the sampling period)

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

On the day when there was no sampling effort for a particular gear type (beach seine, 4 July), the standardized catch was derived by averaging standardized catches for one day prior to and one day after the missed day. Few fish were captured after the data standardization periods and effort was reduced during the final week of sampling; thus those data were not included in the standardized data set. Dates of median fish recovery for each marked group were determined using the combined standardized data from purse and beach seine catches. 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 or 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

We marked 400,615 fish with freeze brands, CWTs, and excision of the adipose fin before release (Table 1). Between the two release dates, 2,012 northern squawfish were captured and removed from the study area. We recovered 1,326 study fish in the estuary (about 0.3% of fish released); 71% of these were captured with purse seines in midriver (Appendix Table C2). Handling mortality for all subyearling chinook salmon captured at Jones Beach was less than 0.5% and descaling averaged 1.0%. However, no study fish were descaled.

Electrofishing Northern Squawfish

We captured and removed 2,012 northern squawfish from the nine transect areas in about 20 hours (70,833 seconds) of electrofishing (Table 2). Forty-one percent (817) of these removals were caught in Tanner Creek or its adjacent transect areas (O1 and O2) (Table 3). The daily catch, catch rate, mean fork length, and mean weight of northern squawfish declined over time (with few exceptions, which mostly occurred during the initial abbreviated removal period on 25 June). In addition, the number of CWTs recovered in the digestive tracts of northern squawfish (representing ingested juvenile salmon), also diminished over time. Of the CWTs recovered, 86% (147) were from the digestive tracts of northern squawfish captured in Tanner Creek or its adjacent transect areas, and all were from study fish released into Tanner Creek (Appendix Table B2; Fig. 5). The CPUE was highest in transect area W1, along the Washington side of the river, but no CWTs from study fish were recovered from northern squawfish in this transect area. Only three CWTs from study fish released in the midstream Columbia River were found in northern squawfish. These were caught in transect areas O3 and O4 along the Oregon shore, which are the farthest transects from the release sites.

Table 1.--Summary of releases of marked subyearling chinook salmon, Tanner Creek vs. midstream Columbia River, 1991.

Marking dates	Release date	Brand[a]	Number released: Total[b]	Untagged[c]	Tagged[d]	Wire-tag code (AG D1 D2)[e]
Tanner Creek releases						
3 June	24 June	RD W2	5,000	205	4,795	07 14 16
4-17 June	24 June	RD T2	94,627	3,880	90,747	07 14 16
				Total	95,542	
3 June	28 June	RD W4	5,000	200	4,800	07 14 17
4-17 June	28 June	RD T4	96,735	3,869	92,866	07 14 17
				Total	97,666	
Midstream Columbia River releases						
3-17 June	24 June	RD Y2	99,026	5,347	93,679	07 46 49
3-17 June	28 June	RD Y4	100,227	4,210	96,017	07 56 54
		Totals	400,615	17,711	382,904	

[a] Brand codes: 1st and 2nd characters, RD = right dorsal position; 3rd character is the brand symbol; 4th character is brand rotation where 2 = symbol rotated clockwise 90° from upright position and 4 = symbol rotated clockwise 270° from upright position.
[b] Total fish marked; branded, tagged, and adipose fin clipped (less observed prerelease mortality and fish retained for tag loss evaluation).
[c] Estimated number of fish released without coded-wire tags (Appendix Table A2).
[d] Estimated number of fish released with coded-wire tags.
[e] 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, release site study, 1991.

Electrofishing period	Northern squawfish removed: Time shocker on (sec)	Total catch	CPUE[b]	Mean length (mm)	Mean weight (g)	CWTs recovered[a] Release site: Tanner Creek[c]	Mid-stream[d]
25 June (0300-0900)	9,859	239	87	376	757	34	1
25-26 June (2100-0900)	22,681	746	118	346	617	83	2
26-27 June (2100-0900)	20,782	589	102	348	614	26	0
27-28 June (2100-0900)	17,511	438	90	338	572	8	0
Totals	70,833	2,012	-----	-----	-----	151	3

[a] CWT - coded wire tag (Agency/Data 1/Data 2 codes). 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 = 07/14/16, released 24 June.
[d] CWT code = 07/46/49, released 24 June.

Table 3.--Electrofishing effort, number of northern squawfish removed, and number of coded-wire tags recovered from the digestive tracts of northern squawfish, release site study, 1991.

Location[c]	Mean effort[b] (sec)	Northern squawfish removed: Mean number	Mean CPUE[d]	Mean length (mm)	Mean weight (g)	CWTs recovered[a] Release site: Tanner Creek[e]	Mid-stream[f]
O1	1,270	47	120	364	692	38	0
O2	1,755	46	92	341	583	53	0
O3	1,577	58	135	335	539	1	2
O4	1,758	56	114	316	479	0	1
W1	1,499	62	151	366	712	0	0
W2	2,241	33	53	307	465	3	0
W3	1,389	16	38	351	636	0	0
W4	1,836	18	33	334	549	0	0
TC	777	19	85	380	798	56	0
Total	---	---	--	--	--	151	3
mean	1,567	39	91	343.8	605.9	--	-

[a] CWT = coded wire tag (Agency/Data 1/Data 2 codes). Number of CWTs recovered in the digestive tracts of northern squawfish represent a minimum number of juvenile salmon ingested.
[b] Mean effort per sampling period for each location (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 = 07/14/16, released 24 June.
[f] CWT code = 07/46/49, released 24 June.

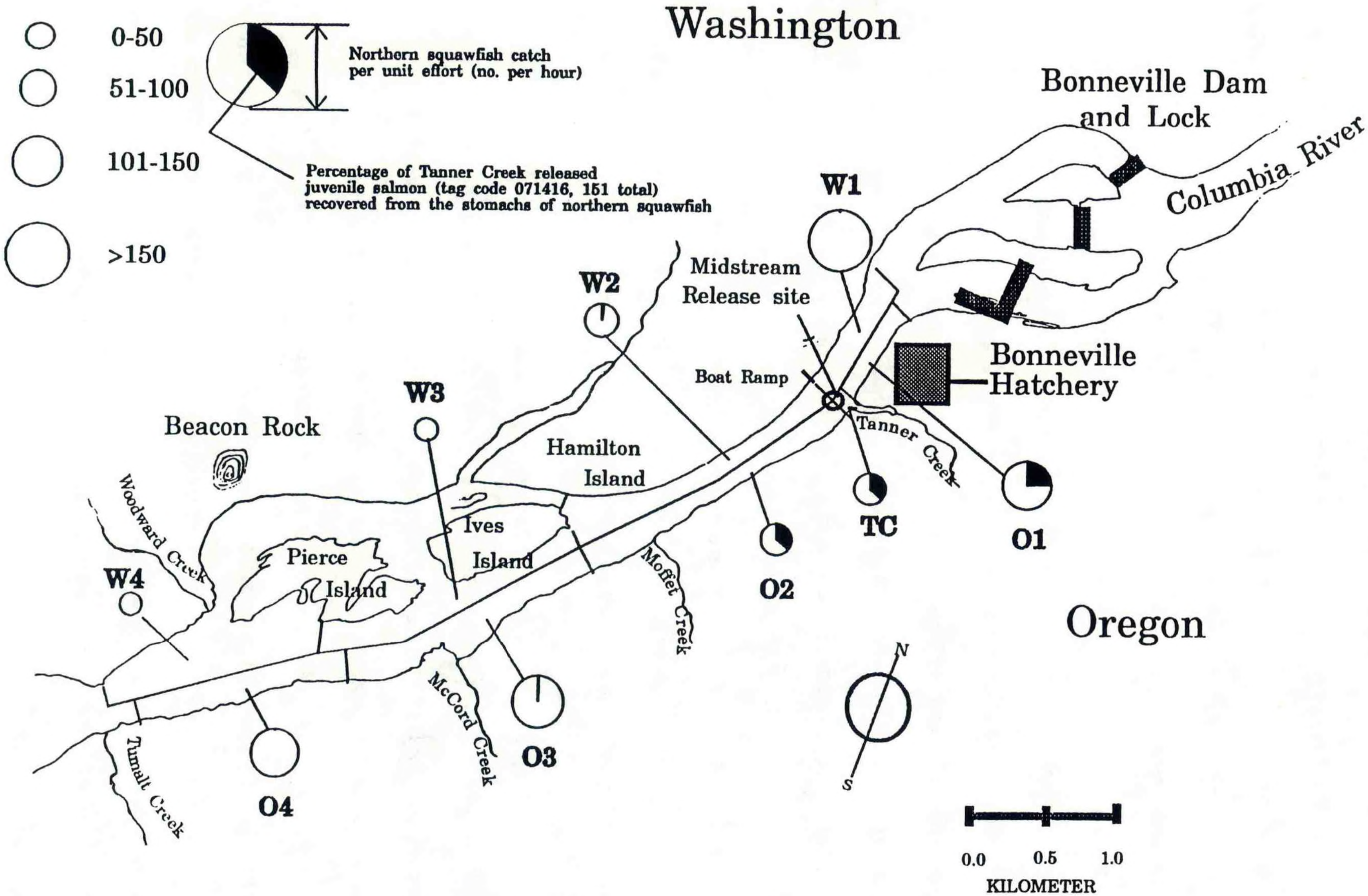


Figure 5.--The study area showing northern squawfish catch per unit effort at each electrofishing transect area and proportion of tags (representing ingested juvenile salmon) from the 24 June Tanner Creek release group recovered in those northern squawfish, 1991.

Migration Behavior and Condition of Study Fish

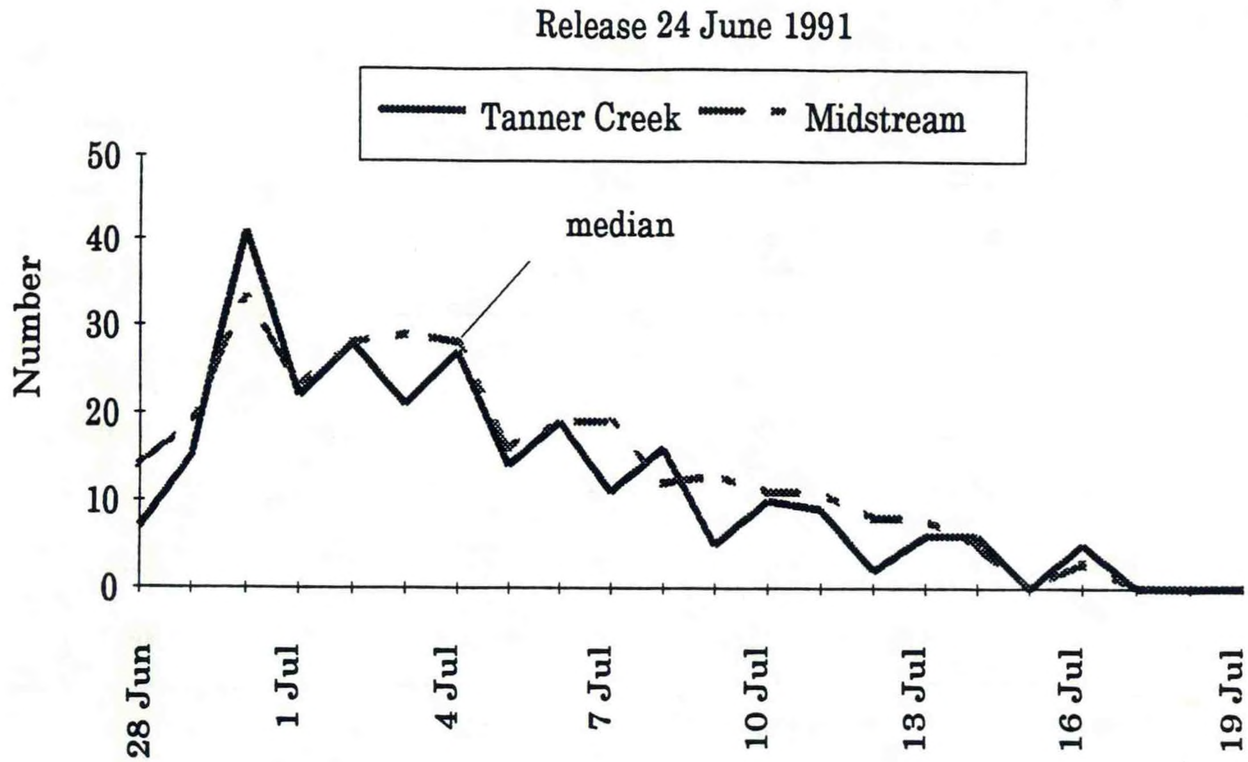
No significant differences were observed in migrational timing of study fish groups between either pair of groups released on the same day ($\alpha = 0.05$; Appendix D). Temporal catch distributions of each release group are presented in Figure 6.

Movement rates of study fish to Jones Beach ranged from 15.7 to 22.4 km/day; faster than in 1989 or 1990 (Table 4). Movement rates of fish from the second pair of release groups were about 26% higher than those of the first pair, probably due in part to increased river flow at the time of the second release (Fig. 7).

Generally, fish from all release groups showed increasing mean lengths during the recovery period, but no differences were apparent among treatment groups (Fig. 8). The randomized marking procedures produced groups with similar size distributions, which enabled comparisons of length-frequency distribution for marked groups after their migration to the estuary (Fig. 9). There was no indication that smaller fish were missing from the Tanner Creek release groups. Evidence of missing size-groups may have been apparent if size-selective predation by northern squawfish had occurred.

Juvenile Recovery Differences

Analysis of CWT-fish recoveries at Jones Beach (Appendix D) indicated that the recovery percentages for fish released from the midstream Columbia River were significantly higher than for fish released from Tanner Creek for both the first (0.37% versus 0.30%; $P = 0.01$) and the second pair of release groups (0.39% versus 0.33%; $P = 0.02$). After the removal of northern squawfish, the difference in recovery percentages between the two release sites was reduced from 23.3 to 18.2% (Table 5; Fig. 10); this 22% reduction in recovery percentage differences ($(23.3 - 18.2) \div 23.3 * 100$) was insignificant ($P = 0.92$). Although the recovery percentages of the second release pair were higher than



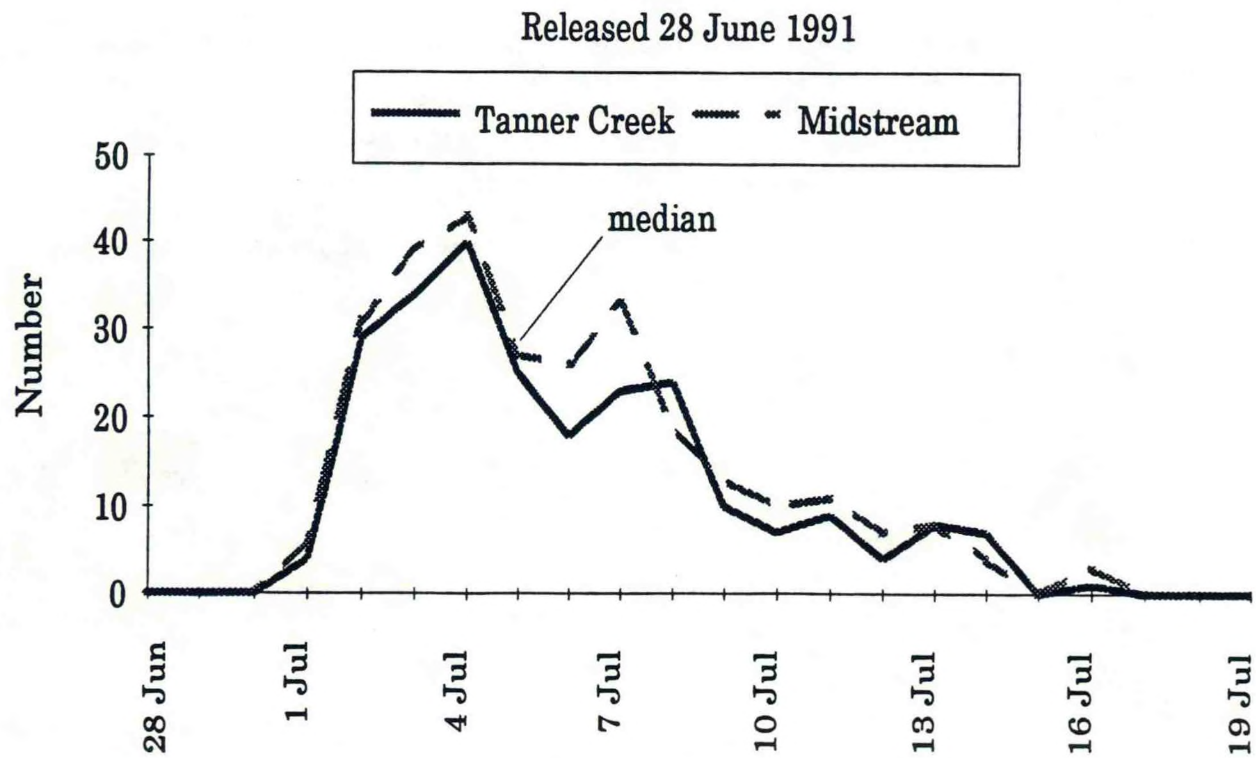


Figure 6.--Daily recoveries of test fish at Jones Beach (standardized for effort) comparing midstream Columbia River to Tanner Creek release groups, 1991.

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, and 1991.

	Movement rate (km/day)[a]			Flow (kcfs)[b]	
Release date	Midstream Columbia	Tanner Creek	Mean FL (mm)[c]	At release[d]	At median[e]
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

[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 purse seine recoveries standardized to a 10-set-per-day effort plus beach seine recoveries standardized to a 5-set-per-day effort (Appendix Table C2).

[b] English units were used for river flow volumes (kcfs = 1,000 ft^3/sec = 35.3 m^3/sec).

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

[d] Average flow through Bonneville Dam on the day that fish were released.

[e] Average flow through Bonneville Dam within 4 days of the date that the median fish was captured.

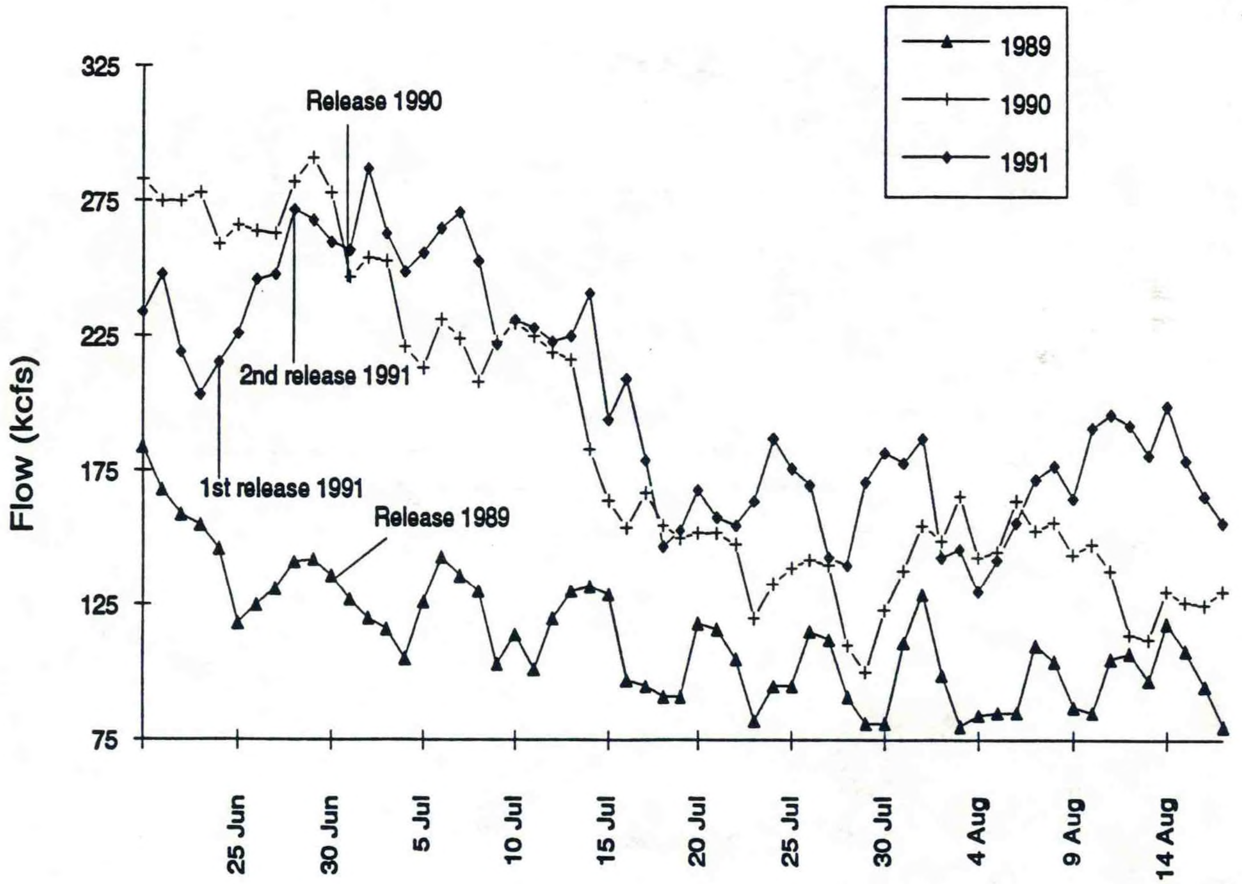
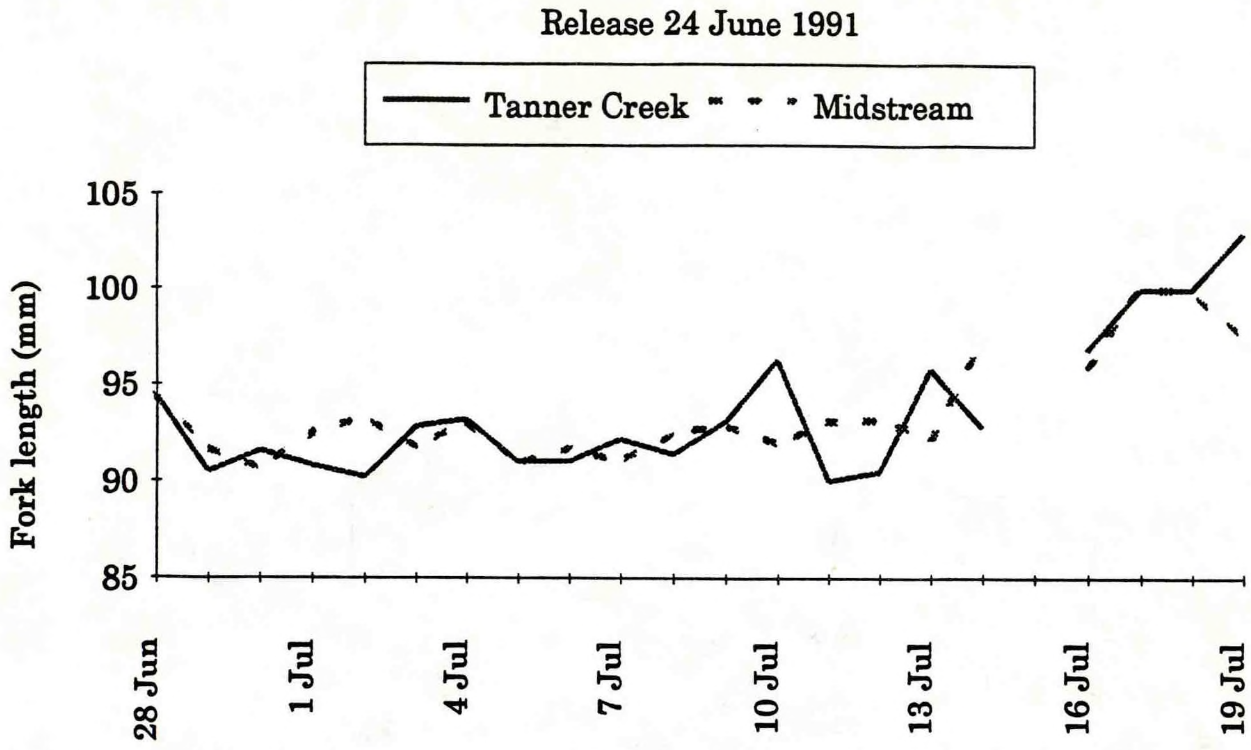


Figure 7.--Daily mean flows of the Columbia River at Bonneville Dam during the estuarine sampling periods, 1989, 1990, and 1991; flow measurements provided by the U.S. Army Corps of Engineers, Portland, Oregon.



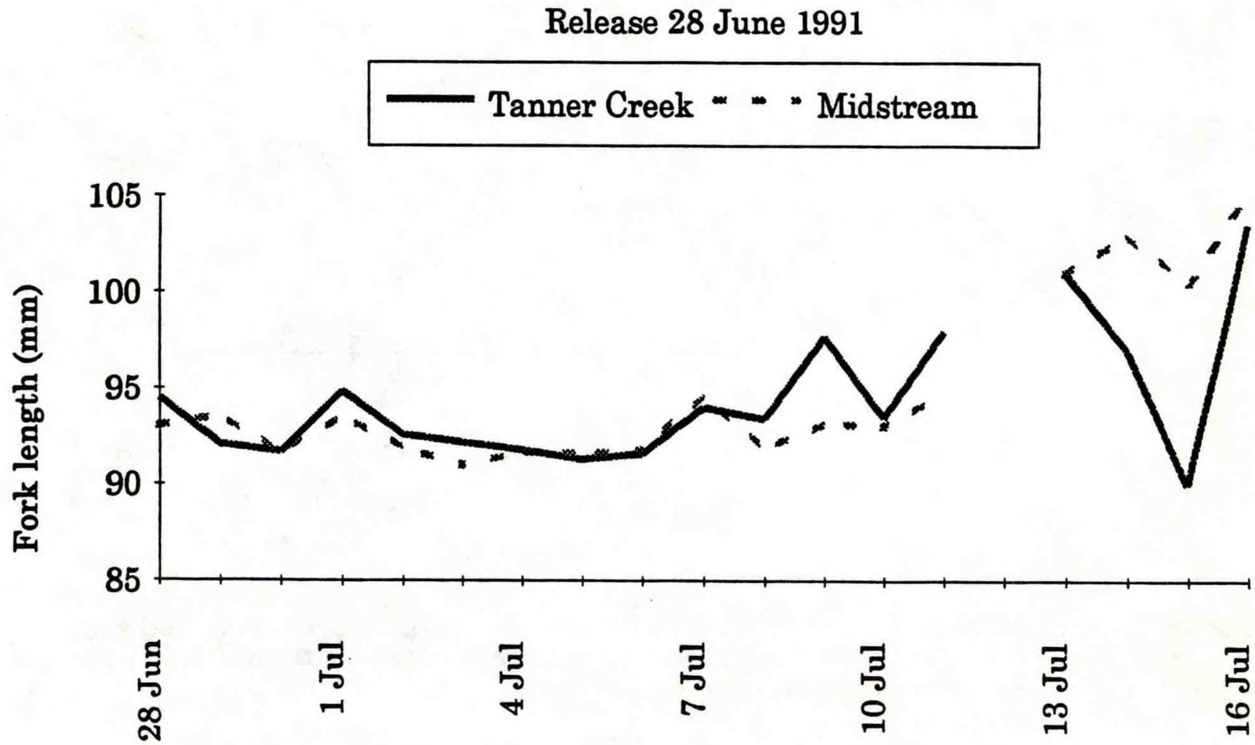
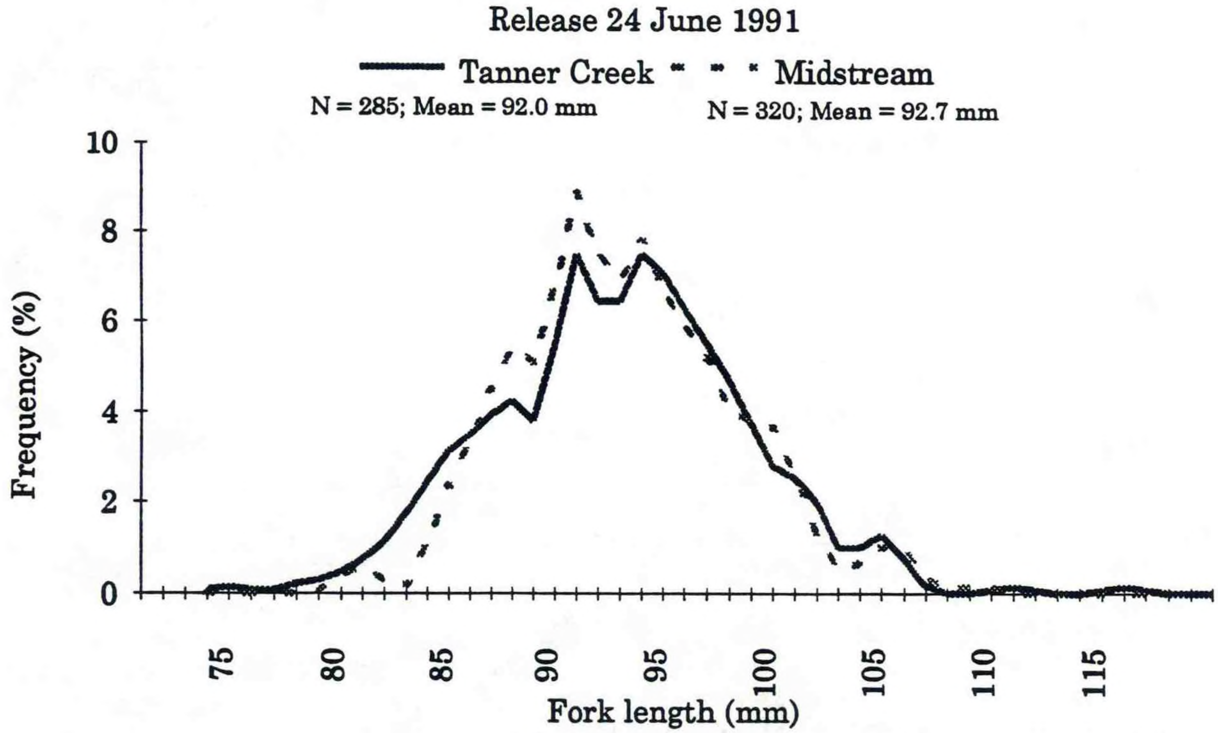


Figure 8.-Daily mean fork lengths of subyearling chinook salmon recovered at Jones Beach, comparing midstream Columbia River to Tanner Creek release groups, 1991.



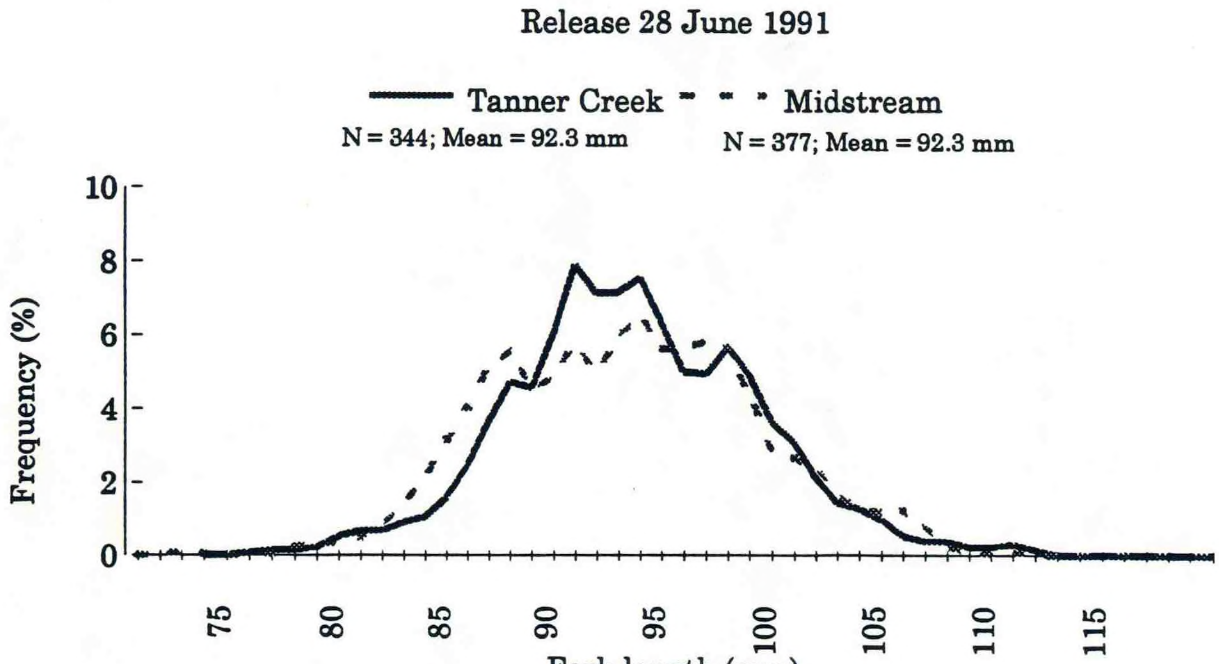


Figure 9.--Fork length distributions of fish after recovery in the estuary, comparing midstream Columbia River to Tanner Creek release groups, 1991.

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

Release date	Midstream Columbia River[a]	Tanner Creek[b]	Benefit for midstream release (%)[c]
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*

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

[b] Normal hatchery release site.

[c] The percent benefit for midstream Columbia River release (MC) over Tanner Creek release (TC) is calculated as [(MC% recovery - TC% recovery) ÷ TC% recovery] x 100.

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

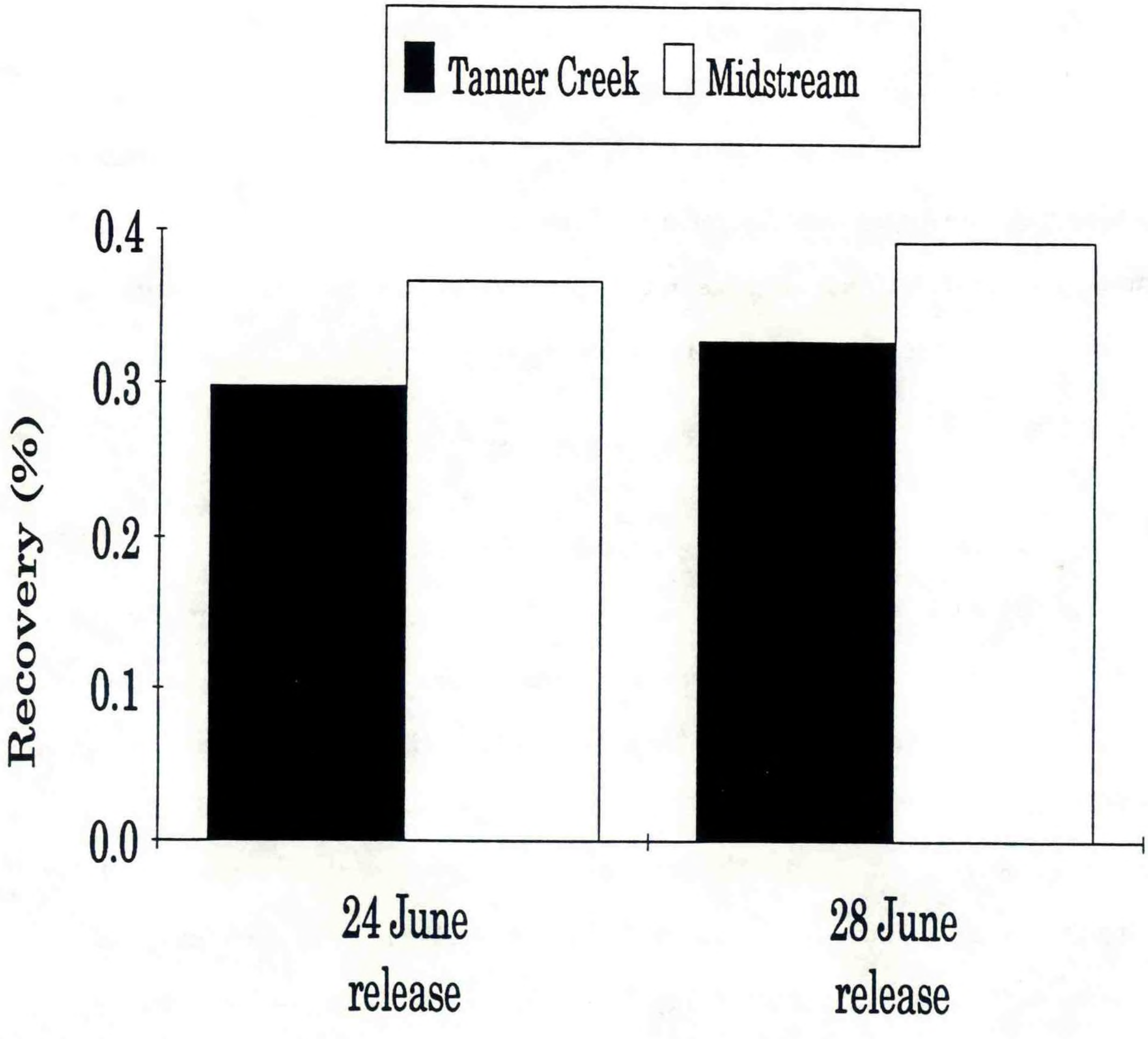


Figure 10.--Mean recovery percentages comparing midstream Columbia River to Tanner Creek release groups, 1991. Northern squawfish were removed by electrofishing between the two release dates. Recovery rates for the midstream release groups were significantly higher (P > 0.05) than for the Tanner Creek release groups on both dates.

those for the first release pair, they are not directly comparable because releases made on different dates were subject to different river conditions and sampling effort.

To further assess data consistency, we analyzed purse seine, beach seine, and total recoveries, and standardized these recovery data to a constant daily effort (Appendix D). Conclusions regarding differences among recovery ratios derived from the standardized data were similar to those reached with the actual catch data. Recoveries of study fish released from the midstream Columbia River were higher than those for fish released into Tanner Creek; no significant change in the difference between recovery percentages occurred following removal of northern squawfish.

DISCUSSION

In 1991, recovery of subyearling chinook salmon released from the midstream Columbia River was significantly higher ($\alpha = 0.05$), averaging about 21% greater, than for fish released from Bonneville Hatchery into Tanner Creek. The difference in recovery percentages for midstream Columbia River releases in 1991 was considerably less than the differences of 40% in 1990 and 65% in 1989. One factor in the reduced difference between midstream and Tanner Creek releases may have been the increased river flow during the majority of the 1991 outmigration compared to previous years, especially compared to the drought year 1989 (Fig. 7). We speculate that higher flow volumes dispersed test fish more rapidly, reduced their exposure time to predation, and resulted in higher survival rates for Tanner Creek releases. The percent survival benefit for midstream releases was inversely correlated with the movement rate of Tanner Creek-released fish (Fig. 11). Movement rate may be a function of both river flow and state of smoltification (Zaugg and Mahnken 1991). Smoltification was not assessed in this study; however, release dates were similar each year (between 24 and 30 June).

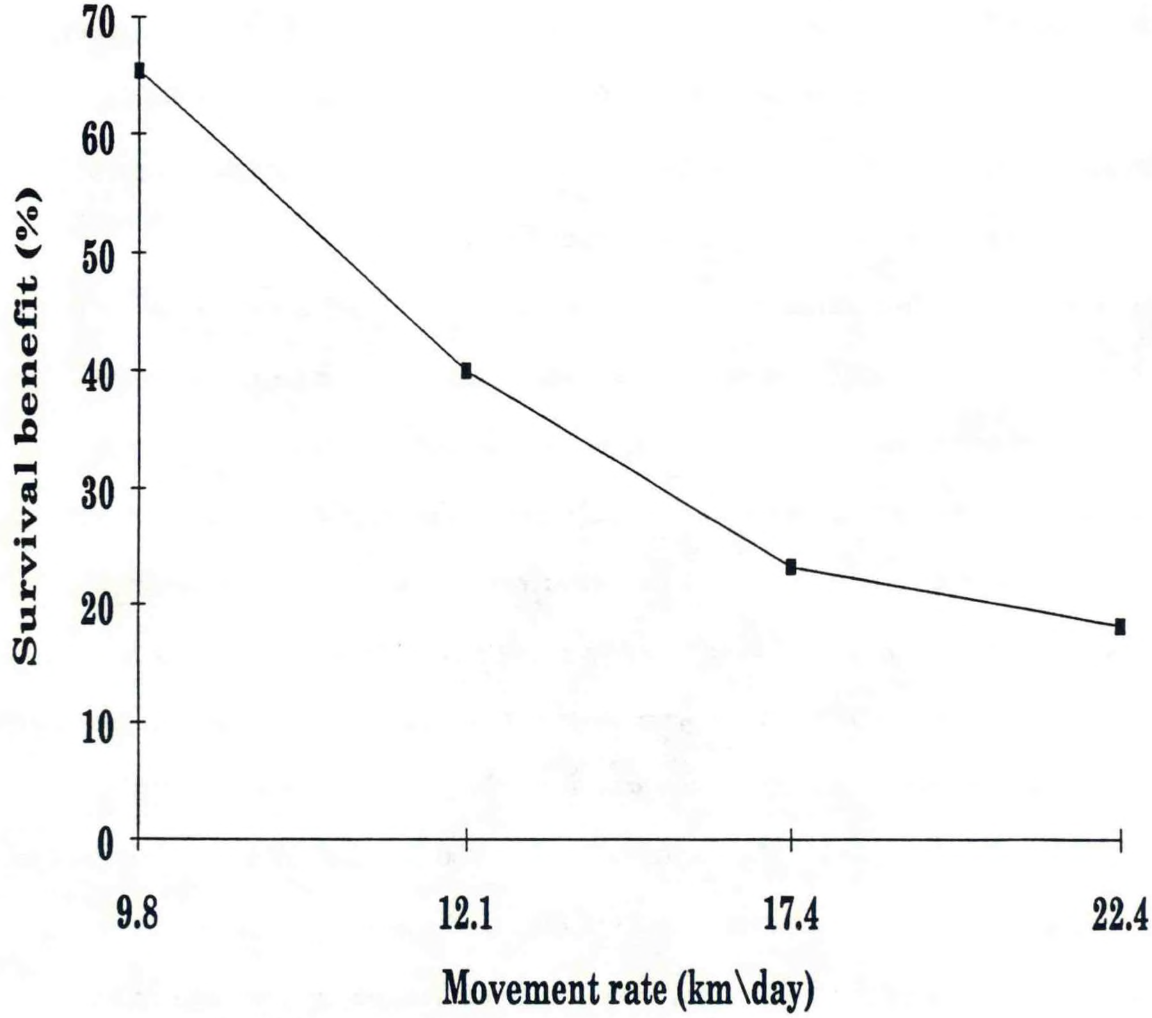


Figure 11.--Movement rate of Tanner Creek-released fish versus percent survival benefit (Table 5, footnote c) for midstream Columbia River releases over Tanner Creek releases of subyearling fall chinook salmon, 1989-91.

In 1991, the Columbia River flow increased about 25% between the first and second release dates (Table 4). The higher flow resulted in faster movement to Jones Beach for the groups released on 28 June and may have increased survival of the Tanner Creek-released fish regardless of predator removal efforts. Yet the difference between midstream and Tanner Creek release declined only slightly (22%) following northern squawfish removal. This may suggest that the resident population of northern squawfish was large, and removal of 2,012 predators was insufficient to significantly improve survival of juvenile fish emigrating from Tanner Creek.

It was difficult to determine if the higher numbers and catch rates of predators in the transect areas nearest Tanner Creek occurred because of northern squawfish congregation near the hatchery release site or because high densities of northern squawfish were prevalent throughout the study area. The high catches of northern squawfish in transect area W1 support the latter explanation. The observations that CWT recoveries were concentrated in transect areas closest to the Tanner Creek release site, and that nearly all the CWTs recovered were from the Tanner Creek release groups, are evidence that juvenile salmonids released from the hatchery were more vulnerable to predation by northern squawfish than juveniles released in midstream. The decline in catch and size of northern squawfish captured may indicate a depletion of the local population, especially of the larger fish, during the removal period. Other explanations for the decline in catch may be emigration of predators from the study area (along with the released salmon), or a change in avoidance reaction to electrofishing gear. In total, over 60,000 northern squawfish were removed from the tailrace area of Bonneville Dam during 1991 (with most removals done after this study)[2]. The sharp drop in numbers of

[2] Craig C. Burley, Washington Department of Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., May 1992.

CWTs in the digestive tracts of northern squawfish by the final day of electrofishing indicates emigration of the released salmon.

CONCLUSIONS

1) Releases of subyearling chinook salmon from Bonneville Hatchery into the midstream Columbia River exhibited significantly higher short-term survival rates than fish released into Tanner Creek. The difference in survival is thought to be related to predation by northern squawfish on fish released at the hatchery.

2) It was difficult to determine if the higher numbers and catch rates of predators in the transect areas nearest Tanner Creek occurred because of northern squawfish congregation near the hatchery release site or because high densities of northern squawfish were prevalent throughout the study area.

3) 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 than juveniles released in midstream.

4) The percent survival benefit between midstream Columbia River and Tanner Creek release groups appears to be inversely related to the movement rate of Tanner Creek release groups. Higher movement rates for fish were associated with higher river flows and may also have been influenced by smoltification differences between years.

5) Electrofishing efforts to remove northern squawfish from the migration route of juvenile salmon emanating from Bonneville Hatchery did not significantly reduce the survival difference between midstream Columbia River and Tanner Creek release groups.

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APPENDIXES

APPENDIX A

MARKING INFORMATION, TAG LOSS ESTIMATES, RELEASE INFORMATION, AND RIVER CONDITIONS

Appendix Table A1.--Short-term[a] tag loss for subyearling chinook salmon, 1991.

		Released 24 June				Released 28 June			
		Tanner Creek		Midstream Columbia R.		Tanner Creek		Midstream Columbia R.	
Date marked	Time sampled	NT[b]	Sample[c]	NT	Sample	NT	Sample	NT	Sample
3 June	1330	0	100	1	100	8	100	0	100
	1500	-[d]	---	-	---	1	100	-	---
4 June	0830	3	100	0	100	4	100	0	100
	1030	2	100	0	100	0	100	0	100
	1330	0	100	2	100	0	100	1	100
	1500	1	100	5	100	0	100	3	100
5 June	0830	0	100	0	100	2	100	0	100
	1030	0	100	0	100	1	100	2	100
	1315	0	100	0	100	0	100	1	100
	1445	0	100	0	100	1	100	1	100
6 June	0845	0	100	0	100	2	100	0	100
	1045	1	100	0	100	0	100	0	100
	1300	0	100	0	100	1	100	0	100
	1430	0	100	0	100	1	100	0	100
7 June	0830	2	100	0	100	0	100	0	100
	1036	0	100	0	100	1	100	0	100
	1317	2	100	0	100	0	100	0	100
	1510	1	100	0	100	0	100	2	100
8 June	0815	0	100	0	100	1	100	0	100
	1038	0	100	0	100	0	100	0	100
	1320	0	100	1	100	0	100	0	100
	1520	0	100	0	100	0	100	0	100
9 June	0840	0	100	0	100	0	100	0	100
	1036	0	100	0	100	0	100	0	100
	1310	0	100	0	100	0	100	2	100
	1515	0	100	0	100	0	100	0	100
12 June	0845	0	100	0	100	0	100	1	100
	1040	1	100	0	100	0	100	1	100
	1310	0	100	0	100	0	100	0	100
	1505	1	100	0	100	0	100	0	100
13 June	0840	0	100	2	100	0	100	0	100
	1040	0	100	0	100	0	100	0	100
	1320	0	100	2	100	0	100	0	100
	1510	0	100	0	100	0	100	0	100
14 June	0840	1	100	0	100	0	100	0	100
	1040	0	100	1	100	5	100	0	100
	----	1	100	1	100	0	100	0	100
	1500	0	100	0	100	0	100	0	100

Appendix Table A1.--Continued.

Date marked	Time sampled	Released 24 June: Tanner Creek NT[b]	Released 24 June: Tanner Creek Sample[c]	Released 24 June: Midstream Columbia R. NT	Released 24 June: Midstream Columbia R. Sample	Released 28 June: Tanner Creek NT	Released 28 June: Tanner Creek Sample	Released 28 June: Midstream Columbia R. NT	Released 28 June: Midstream Columbia R. Sample
17 June	0840	0	100	1	100	0	100	0	100
	1050	0	100	0	100	0	100	1	100
	1250	0	100	1	100	0	100	0	100
	1640	0	100	0	100	0	100	0	100
Total		16	4,100	17	4,100	28	4,200	15	4,100
Percent		0.4		0.4		0.7		0.4	

[a] Samples taken from the outfall pipe from marking trailer immediately after tagging.
[b] NT = Number of fish passed through the tag detector which tested negative for a tag.
[c] Number of fish sampled for tag loss.
[d] - = data not available.

Appendix Table A2.--Tag loss estimates among marked groups of subyearling chinook salmon after a 30-day holding period; Tanner Creek vs. midstream Columbia River release, 1991.

Release dates	Coded-wire tag (AG D1 D2)[a]	NT[b]	Sample[c]
Tanner Creek releases			
24 June	071416	22	539
28 June	071417	17	427
Midstream releases			
24 June	074649	29	539
28 June	075654	24	571

[a] AG D1 D2 = Agency code, Data 1 code, Data 2 code.
[b] NT = Number of branded fish in the sample with no coded-wire tag.
[c] Number of fish checked for the presence of coded-wire tags.

APPENDIX B

NORTHERN SQUAWFISH ELECTROFISHING INFORMATION

Appendix Table B1.--Northern squawfish electrofishing daily effort and catch results, 1991.

Electrofishing period[a]		Electrofishing date	Electrofishing location[b]	Start time[c]	Effort (sec)[d]	Catch (no.)	CPUE (no./h)[e]
1		25 Jun	O1	0315	340	4	42.5
1		25 Jun	O1	0340	729	8	39.5
1		25 Jun	O1	0605	1,123	59	189.1
2		25 Jun	O1	2115	1,476	66	161.0
2		26 Jun	O1	0335	1,987	96	173.9
3		26 Jun	O1	2107	1,411	82	209.2
3		27 Jun	O1	0300	1,641	24	52.7
4		27 Jun	O1	2200	1,451	55	136.5
4		28 Jun	O1	0405	1,268	28	79.5
	Subtotal				11,426	422	--
	mean				1,270	47	120.4
	SE[f]				163.6	10.8	22.5
1		25 Jun	O2	0419	1,350	26	69.3
2		25 Jun	O2	2139	2,049	49	86.1
2		26 Jun	O2	0345	1,298	40	110.9
3		26 Jun	O2	2208	2,137	64	107.8
3		27 Jun	O2	0444	1,761	42	85.9
4		27 Jun	O2	2210	2,249	69	110.5
4		28 Jun	O2	0444	1,441	30	75.0
	Subtotal				12,285	320	--
	mean				1,755	46	92.2
	SE				150.2	6.1	6.6
1		25 Jun	O3	0510	1,595	22	49.7
2		25 Jun	O3	2213	1,376	102	266.9
2		26 Jun	O3	0428	1,237	47	136.8
3		26 Jun	O3	2343	2,024	66	117.4
4		27 Jun	O3	2314	1,369	42	110.5
4		28 Jun	O3	0345	1,862	66	127.6
	Subtotal				9,463	345	--
	mean				1,577	58	134.8
	SE				126.6	11.2	29.2
2		25 Jun	O4	2353	1,621	53	117.7
3		27 Jun	O4	0352	1,895	58	110.2
	Subtotal				3,516	111	--
	mean				1,758	56	113.9
	SE				137.0	2.5	3.8

Appendix Table B1.--Continued.

Electrofishing period[a]		Electrofishing date	Electrofishing location[b]	Start time[c]	Effort (sec)[d]	Catch (no.)	CPUE (no./h)[e]
2		26 Jun	TC	0305	640	32	180.0
3		26 Jun	TC	2200	1,609	33	73.8
4		27 Jun	TC	2115	688	8	41.9
4		28 Jun	TC	0440	171	2	42.1
	Subtotal				3,108	75	--
	mean				777	19	84.5
	SE				301	3.0	32.7
1		25 Jun	W1	0304	1,035	52	180.9
1		25 Jun	W1	0600	1,049	35	120.1
2		25 Jun	W1	2105	1,232	61	178.3
2		26 Jun	W1	0258	1,553	89	206.3
3		26 Jun	W1	2110	1,924	59	110.4
3		27 Jun	W1	0252	1,482	83	201.6
4		27 Jun	W1	2101	1,652	37	80.6
4		28 Jun	W1	0247	2,065	76	132.5
	Subtotal				11,992	492	--
	mean				1,499	62	151.3
	SE				135	7.1	16.5
1		25 Jun	W2	0400	2,638	33	45.0
2		25 Jun	W2	2215	2,591	46	63.9
2		26 Jun	W2	0435	1,599	24	54.0
3		26 Jun	W2	2300	2,240	39	62.7
4		27 Jun	W2	2250	2,136	23	38.8
	Subtotal				11,204	165	--
	mean				2,241	33	52.9
	SE				188	4.4	4.9
2		25 Jun	W3	2345	1,551	16	37.1
3		27 Jun	W3	0010	1,458	29	71.6
4		28 Jun	W3	0300	1,159	2	6.2
	Subtotal				4,168	47	--
	mean				1,389	16	38.3
	SE				118	7.8	18.9

Appendix Table B1.--Continued.

Electrofishing period[a]		Electrofishing date	Electrofishing location[b]	Start time[c]	Effort (sec)[d]	Catch (no.)	CPUE (no./h)[e]
2		26 Jun	W4	0045	2,471	25	36.4
3		27 Jun	W4	----	1,200	10	30.0
	Subtotal				3,671	35	--
	mean				1,836	18	33.2
	SE				636	7.5	3.2
	Totals				70,833	2012	--
	mean				1,567	39.4	91.3
	SE				136.8	6.1	14.2

[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; others Columbia River transects, where 1st character O = Oregon shoreline and W = Washington shoreline; 2nd character, 1-4, transect areas (refer to Fig. 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.

[f] SE = Standard error.

Appendix Table B2.--Coded-wire tags from ingested juvenile salmon recovered in the stomachs of northern squawfish during electrofishing efforts, 1991.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location[d]	Tag code (AG D1 D2)[e]
1	25 Jun	0340	51	7	O1	07 14 16
1	25 Jun	0340	51	7	O1	07 14 16
1	25 Jun	0340	51	7	O1	07 14 16
1	25 Jun	0340	51	7	O1	07 14 16
1	25 Jun	0340	51	7	O1	07 14 16
1	25 Jun	0340	51	7	O1	07 14 16
1	25 Jun	0605	53	48	O1	05 24 46
1	25 Jun	0605	53	1	O1	07 14 16
1	25 Jun	0605	53	1	O1	07 14 16
1	25 Jun	0605	53	1	O1	07 14 16
1	25 Jun	0605	53	27	O1	07 14 16
1	25 Jun	0605	53	27	O1	07 14 16
1	25 Jun	0605	53	27	O1	07 14 16
1	25 Jun	0605	53	27	O1	07 14 16
1	25 Jun	0605	53	3	O1	07 14 16
1	25 Jun	0605	53	3	O1	07 14 16
1	25 Jun	0605	53	3	O1	07 14 16
1	25 Jun	0605	53	3	O1	07 14 16
2	25 Jun	2115	150	55	O1	07 14 16
2	25 Jun	2115	150	55	O1	07 14 16
2	25 Jun	2115	150	55	O1	07 14 16
2	25 Jun	2115	150	55	O1	07 14 16
2	25 Jun	2115	150	55	O1	07 14 16
2	25 Jun	2115	150	55	O1	07 14 16
2	25 Jun	2115	150	54	O1	63 08 56
2	26 Jun	0335	155	12	O1	07 14 16
2	26 Jun	0335	155	12	O1	07 14 16
2	26 Jun	0335	155	12	O1	07 14 16
2	26 Jun	0335	155	12	O1	07 14 16
2	26 Jun	0335	155	42	O1	07 14 16
2	26 Jun	0335	155	42	O1	07 14 16
2	26 Jun	0335	155	42	O1	07 14 16
2	26 Jun	0335	155	42	O1	07 14 16
2	26 Jun	0335	155	42	O1	07 14 16
3	26 Jun	2107	250	67	O1	63 40 32
3	26 Jun	2107	250	67	O1	63 40 32
3	26 Jun	2107	250	63	O1	63 41 43
3	27 Jun	0300	254	6	O1	07 14 16
3	27 Jun	0300	254	19	O1	63 40 31
3	27 Jun	0300	254	11	O1	63 40 32
3	27 Jun	0300	254	1	O1	63 41 43
3	27 Jun	0300	254	7	O1	63 41 43
3	26 Jun	2107	250	76	O1	07 14 16
4	28 Jun	0405	354	2	O1	07 14 16

Appendix Table B2.--Continued.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location[d]	Tag code (AG D1 D2)[e]
4	28 Jun	0405	354	2	O1	07 14 16
4	28 Jun	0405	354	7	O1	07 14 16
4	28 Jun	0405	354	6	O1	63 55 61
1	25 Jun	0419	2	13	O2	07 14 16
1	25 Jun	0419	2	13	O2	07 14 16
1	25 Jun	0419	2	14	O2	07 14 16
1	25 Jun	0419	2	15	O2	07 14 16
1	25 Jun	0419	2	26	O2	07 14 16
1	25 Jun	0419	2	26	O2	07 14 16
1	25 Jun	0419	2	26	O2	07 14 16
1	25 Jun	0419	2	26	O2	07 14 16
1	25 Jun	0419	2	26	O2	07 14 16
1	25 Jun	0419	2	26	O2	07 14 16
1	25 Jun	0419	2	4	O2	07 14 16
1	25 Jun	0419	2	6	O2	07 14 16
1	25 Jun	0419	2	6	O2	07 14 16
1	25 Jun	0419	2	6	O2	07 14 16
1	25 Jun	0419	2	6	O2	07 14 16
1	25 Jun	0419	2	6	O2	07 14 16
1	25 Jun	0419	2	6	O2	07 14 16
1	25 Jun	0419	2	9	O2	07 14 16
2	25 Jun	2139	101	24	O2	07 14 16
2	25 Jun	2139	101	24	O2	07 14 16
2	25 Jun	2139	101	24	O2	07 14 16
2	25 Jun	2139	101	41	O2	07 14 16
2	25 Jun	2139	101	8	O2	07 14 16
2	26 Jun	0345	105	13	O2	07 14 16
2	26 Jun	0345	105	16	O2	07 14 16
2	26 Jun	0345	105	30	O2	07 14 16
2	26 Jun	0345	105	30	O2	07 14 16
2	26 Jun	0345	105	30	O2	07 14 16
2	26 Jun	0345	105	30	O2	07 14 16
2	26 Jun	0345	105	30	O2	07 14 16
2	26 Jun	0345	105	37	O2	07 14 16
2	26 Jun	0345	105	37	O2	07 14 16
3	26 Jun	2208	201	8	O2	07 14 16
3	26 Jun	2208	201	8	O2	07 14 16
3	26 Jun	2208	201	8	O2	07 14 16
3	26 Jun	2208	201	46	O2	63 40 32
3	27 Jun	0444	205	27	O2	07 14 16
3	27 Jun	0444	205	27	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16

Appendix Table B2.--Continued.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location[d]	Tag code (AG D1 D2)[e]
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	33	O2	07 14 16
3	27 Jun	0444	205	34	O2	07 14 16
4	28 Jun	0444	305	16	O2	07 14 16
4	28 Jun	0444	305	22	O2	07 14 16
4	28 Jun	0444	305	22	O2	07 14 16
1	25 Jun	0510	3	6	O3	07 46 49
2	25 Jun	2213	102	36	O3	07 14 16
2	25 Jun	2213	102	36	O3	07 46 49
2	26 Jun	2353	103	13	O4	07 46 49
2	26 Jun	0305	154	10	TC	07 14 16
2	26 Jun	0305	154	10	TC	07 14 16
2	26 Jun	0305	154	10	TC	07 14 16
2	26 Jun	0305	154	10	TC	07 14 16
2	26 Jun	0305	154	11	TC	07 14 16
2	26 Jun	0305	154	11	TC	07 14 16
2	26 Jun	0305	154	11	TC	07 14 16
2	26 Jun	0305	154	11	TC	07 14 16
2	26 Jun	0305	154	12	TC	07 14 16
2	26 Jun	0305	154	12	TC	07 14 16
2	26 Jun	0305	154	15	TC	07 14 16
2	26 Jun	0305	154	17	TC	07 14 16
2	26 Jun	0305	154	17	TC	07 14 16
2	26 Jun	0305	154	18	TC	07 14 16
2	26 Jun	0305	154	18	TC	07 14 16
2	26 Jun	0305	154	18	TC	07 14 16
2	26 Jun	0305	154	18	TC	07 14 16
2	26 Jun	0305	154	18	TC	07 14 16
2	26 Jun	0305	154	19	TC	07 14 16
2	26 Jun	0305	154	19	TC	07 14 16
2	26 Jun	0305	154	20	TC	07 14 16
2	26 Jun	0305	154	21	TC	07 14 16
2	26 Jun	0305	154	23	TC	07 14 16
2	26 Jun	0305	154	23	TC	07 14 16
2	26 Jun	0305	154	24	TC	07 14 16
2	26 Jun	0305	154	24	TC	07 14 16
2	26 Jun	0305	154	27	TC	07 14 16
2	26 Jun	0305	154	27	TC	07 14 16

Appendix Table B2.--Continued.

Electrofishing period[b]	Date	Start time[c]	Northern squawfish[a] Collection no.	Predator no.	Location[d]	Tag code (AG D1 D2)[e]
2	26 Jun	0305	154	27	TC	07 14 16
2	26 Jun	0305	154	29	TC	07 14 16
2	26 Jun	0305	154	29	TC	07 14 16
2	26 Jun	0305	154	3	TC	07 14 16
2	26 Jun	0305	154	32	TC	07 14 16
2	26 Jun	0305	154	32	TC	07 14 16
2	26 Jun	0305	154	4	TC	07 14 16
2	26 Jun	0305	154	4	TC	07 14 16
2	26 Jun	0305	154	4	TC	07 14 16
2	26 Jun	0305	154	4	TC	07 14 16
2	26 Jun	0305	154	4	TC	07 14 16
2	26 Jun	0305	154	4	TC	07 14 16
2	26 Jun	0305	154	4	TC	07 14 16
2	26 Jun	0305	154	5	TC	07 14 16
2	26 Jun	0305	154	5	TC	07 14 16
2	26 Jun	0305	154	6	TC	07 14 16
2	26 Jun	0305	154	7	TC	07 14 16
2	26 Jun	0305	154	7	TC	07 14 16
2	26 Jun	0305	154	7	TC	07 14 16
2	26 Jun	0305	154	7	TC	07 14 16
2	26 Jun	0305	154	7	TC	07 14 16
3	26 Jun	2200	251	23	TC	07 14 16
3	26 Jun	2200	251	23	TC	07 14 16
3	26 Jun	2200	251	23	TC	07 14 16
3	26 Jun	2200	251	28	TC	07 14 16
3	26 Jun	2200	251	28	TC	07 14 16
4	27 Jun	2115	350	3	TC	07 14 16
4	27 Jun	2115	350	3	TC	07 14 16
1	25 Jun	0304	1	20	W1	10 43 37
2	25 Jun	2105	100	1	W1	63 56 13
3	26 Jun	2110	200	5	W1	63 40 32
3	27 Jun	0252	203	29	W1	63 41 43
4	27 Jun	2101	300	15	W1	07 58 53
2	26 Jun	0435	156	21	W2	07 14 16
2	26 Jun	0435	156	21	W2	07 14 16
2	26 Jun	0435	156	21	W2	07 14 16

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

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

[c] Time that the electrofishing effort began.

[d] 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).

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

APPENDIX C

ESTUARINE RECOVERY INFORMATION

Appendix Table C1.--Daily purse seine and beach seine fishing effort, water temperatures, and Secchi disk transparency measurements at Jones Beach, Tanner Creek vs. midstream Columbia River release, 1991.

Date	Number of sets		Temp.	Secchi	Date	Number of sets		Temp.	Secchi
	Purse	Beach	°C	depth (m)		Purse	Beach	°C	depth (m)
24 Jun	1	3	15	0.8	7 Jul	7	16	18	0.9
25 Jun	3	3	16	1.1	8 Jul	10	11	17	0.9
26 Jun	4	3	--[a]	0.9	9 Jul	13	13	18	0.8
27 Jun[b]	7	3	15	0.8	10 Jul	7	5	18	0.8
28 Jun	10	5	15	0.9	11 Jul	8	5	18	0.9
29 Jun	12	3	15	0.9	12 Jul	7	5	18	0.9
30 Jun	8	4	16	1.1	13 Jul	8	3	19	0.8
1 Jul	9	5	16	1.1	14 Jul	10	2	17	0.9
2 Jul	10	2	15	1.1	15 Jul	4	2	18	0.9
3 Jul	16	2	18	0.9	16 Jul	8	1	18	0.9
4 Jul	12	0	18	1.0	17 Jul	4	0	18	0.9
5 Jul	17	5	18	0.9	18 Jul	4	0	18	0.9
6 Jul	11	16	18	0.9	19 Jul	3	0	18	1.1

[a] --- = data not available.
[b] First recovery of study fish.

Appendix Table C2.--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 and transported from the hatchery to midstream Columbia River, 1991.

	Released 24 June (Julian 175)											
	Treatments and tag code (AG D1 D2)[a]											
	Tanner Creek 07 14 16						Midstream Columbia River 07 46 49					
Date of	Purse		Beach		Total		Purse		Beach		Total	
recovery[b]	A[c]	S[d]	A	S	A	S	A	S	A	S	A	S
178 (27 Jun)	0	-	0	-	0	-	1	-	0	-	1	-
179	5	5	2	2	7	7	7	7	7	7	14	14
180	10	8	4	7	14	15	15	12	4	7	19	19
181	26	33	6	8	32	41	18	23	8	10	26	33
182 (1 Jul)	11	12	10	10	21	22	15	17	6	6	21	23
183	23	23	2	5[e]	25	28	25	25	1	3[e]	26	28
184	25	16	2	5	27	21[e]	42	26	1	3	43	29
185	28	23[e]	NE[f]	4	28	27	30	25[e]	NE	3	30	28[e]
186 (5 Jul)	19	11	3	3	22	14	22	13	3	3	25	16
187	17	15	13	4	30	19	17	15	12	4	29	19
188	5	7	15	4	20	11	7	10	29	9	36	19
189	14	14	5	2	19	16	10	10	4	2	14	12
190	5	4	2	1	7	5	15	12	3	1	18	13
191 (10 Jul)	7	10	0	0	7	10	7	10	1	1	8	11
192	7	9	0	0	7	9	7	9	2	2	9	11
193	1	1	1	1	2	2	4	6	2	2	6	8
194	3	4	1	2	4	6	4	5	2	3	6	8
195	6	6	0	-	6	6	5	5	0	-	5	5
196 (15 Jul)	0	0	0	-	0	0	0	0	0	-	0	0
197	4	5	0	-	4	5	2	3	0	-	2	3
198	1	-	0	-	1	-	1	-	NE	-	1	-
199	1	-	0	-	1	-	3	-	NE	-	3	-
200	1	-	0	-	1	-	2	-	NE	-	2	-
Total	219	206	66	58	285	264	259	233	85	66	344	299
Mvmt rate[g]		15.7		19.6		17.4		15.7		19.6		15.7

Appendix Table C2.--Continued.

	Released 28 June (Julian 179)											
	Treatments and tag code (AG D1 D2)[a]											
	Tanner Creek 07 14 17						Midstream Columbia River 07 56 54					
Date of	Purse		Beach		Total		Purse		Beach		Total	
recovery[b]	A[c]	S[d]	A	S	A	S	A	S	A	S	A	S
178 (27 Jun)	0	-	0	-	0	-	0	-	0	-	0	-
179	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0
181	0	0	0	0	0	0	0	0	0	0	0	0
182 (1 Jul)	4	4	0	0	4	4	5	6	0	0	5	6
183	21	21	3	8	24	29	28	28	1	3	29	31
184	49	31	1	3	50	34	47	29	4	10	51	39
185	41	34	NE	6	41	40	42	35	NE	8	42	43
186 (5 Jul)	28	16[e]	9	9	37	25[e]	35	21[e]	6	6	41	27[e]
187	13	12	19	6[e]	32	18	15	14	37	12[e]	52	26
188	8	11	40	12	48	23	12	17	55	16	67	33
189	15	15	19	9	34	24	10	10	19	9	29	19
190	9	7	8	3	17	10	10	8	12	5	22	13
191 (10 Jul)	5	7	0	0	5	7	6	9	1	1	7	10
192	7	9	0	0	7	9	9	11	0	0	9	11
193	3	4	0	0	3	4	4	6	1	1	5	7
194	6	8	0	0	6	8	5	6	1	2	6	8
195	7	7	0	-	7	7	4	4	0	-	4	4
196 (15 Jul)	0	0	0	-	0	0	0	0	0	-	0	0
197	1	1	0	-	1	1	2	3	0	-	2	3
198	1	-	NE	-	1	-	1	-	NE	-	1	-
199	1	-	NE	-	1	-	4	-	NE	-	4	-
200	2	-	NE	-	2	-	1	-	NE	-	1	-
Total	221	187	99	56	320	243	240	207	137	73	377	280
Mvmt rate		22.4		19.6		22.4		22.4		19.6		22.4

[a] AG D1 D2 = Agency code, Data 1 code, Data 2 code.
[b] Julian date; equivalent day and month shown in parentheses.
[c] A = Actual daily purse seine or beach seine catch.
[d] S = Standardized daily catch. Purse seine data standardized to a 10-set-per-day effort Julian dates 179 to 197; beach seine data standardized to a 5-set-per-day effort Julian dates 179 to 194. A "-" indicates recoveries of fish from date outside of the data standardization periods because of minimal catches and low effort.
[e] Day that the median fish was captured (standardized effort).
[f] NE = no sampling effort.
[g] Mvmt. rate = Movement rate (km/day) = distance traveled (RKm 232 to RKm 75) ÷ travel time (days from release to median fish recovery).

APPENDIX D

STATISTICAL ANALYSES OF JUVENILE RECOVERY DATA

APPENDIX D

Statistical Analysis of Juvenile Recovery Data

A. Chi-square goodness of fit analysis was used to evaluate differences among observed recoveries (Appendix Table C2) through time for different treatment groups released on the same day (Sokal and Rohlf 1981). A nonsignificant result indicated that there was equal probability of capture at Jones Beach for each treatment group (i.e., that the groups were adequately mixed). For additional details of this procedure see Appendix D in Dawley et al. (1989).

H_o: There was homogeneity between recovery distributions of treatments.

Release date	Seine type	Chi-square	df	P
24 June	purse	15.025	18	0.6602
28 June	purse	5.349	15	0.9887
24 June	beach	9.331	8	0.3151
28 June	beach	6.721	6	0.3474
24 June	total	17.625	18	0.4806
28 June	total	7.943	15	0.9260

Conclusion: No evidence to suggest there is nonhomogeneity between treatment recovery distributions.

Appendix D.--Continued.

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.

Consider the following notation:

P_{tc1} = true survival to and recovery at Jones Beach of fish released in Tanner Creek before squawfish removal on 24 June

p_{tc1} = estimate of P_{tc1} = recovery proportion at Jones Beach of fish released at Tanner Creek on 24 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 before squawfish removal

2 denotes 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 will assume z (as defined below) follows a standard normal distribution.

1) 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 is as follows:

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

Appendix D.--Continued.

The test statistic is as follows:

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

The relevant statistics for the first release pair are the following:

$p_{mc1} = 344 \div 93679 = 0.003672$

$p_{tc1} = 285 \div 95542 = 0.002983$

Then,

$$z = \frac{(0.003672 - 0.002983)}{\sqrt{\frac{0.003672(0.996328)}{93679} + \frac{0.002983(0.997017)}{95542}}}$$

$$= \frac{0.000689}{0.000265} = 2.6018, \quad p\text{-}value = 0.0093$$

Conclusion: The recovery rate for midstream Columbia River-released fish was significantly higher than for Tanner Creek-released fish; the difference was 23.3%.

2) 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 is the following:

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

Appendix D.--Continued.

The test statistic is as follows:

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

The relevant statistics for second release pair are the following:

$p_{mc2} = 377 \div 96017 = 0.003926$

$p_{tc2} = 320 \div 97666 = 0.003276$

Then,

$$z = \frac{(0.003926 - 0.003276)}{\sqrt{\frac{0.003926(0.996074)}{96017} + \frac{0.003276(0.996724)}{97666}}}$$

$$= \frac{0.000650}{0.000272} = 2.3869, \quad p\text{-}value = 0.0168$$

Conclusion: The recovery rate for midstream Columbia River-released fish was significantly higher than for Tanner Creek-released fish; the difference was 18.2%.

3) The null hypothesis for testing whether squawfish removal had a significant benefit for midstream Columbia River-released fish is the following:

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

Appendix D.--Continued.

The test statistic is as follows:

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

The relevant statistics for the study are the following:

$p_{mc1} = 344 \div 93679 = 0.003672$

$p_{tc1} = 285 \div 95542 = 0.002983$

$p_{mc2} = 377 \div 96017 = 0.003926$

$p_{tc2} = 320 \div 97666 = 0.003276$

Then,

$$z = \frac{(0.003672 - 0.002983) - (0.003926 - 0.003276)}{\sqrt{\frac{0.003672(0.996328)}{93679} + \frac{0.002983(0.997017)}{95542} + \frac{0.003926(0.996074)}{96017} + \frac{0.003276(0.996724)}{97666}}}$$

$$= \frac{0.000039}{0.00038} = 0.1026 \quad p\text{-}value = 0.9182$$

Conclusion: The effect of removing northern squawfish from the migration route of Tanner Creek-released fish was insignificant; the reduction was 21.9% ((23.3% - 18.2% ÷ 23.3) * 100).

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