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IDENTIFICATION OF THE SPAWNING, REARING, AND MIGRATORY REQUIREMENTS OF FALL CHINOOK SALMON IN THE COLUMBIA RIVER BASIN

Annual Report 1994

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IDENTIFICATION OF THE SPAWNING, REARING, AND MIGRATORY REQUIREMENTS OF FALL CHINOOK SALMON IN THE COLUMBIA RIVER BASIN

ANNUAL REPORT 1994

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EXECUTIVE SUMMARY

This document is the 1994 annual progress report for selected studies of fall chinook salmon *Oncorhynchus tshawytscha* conducted by the National Biological Service (NBS) and the U.S. Fish and Wildlife Service. Activities were funded by the Bonneville Power Administration (BPA) through funding of Project 91-029.

The decline in abundance of fall chinook salmon in the Snake River basin has become a growing concern. In 1992, Snake River fall chinook salmon were listed as "threatened" and in 1994 the stock was listed as "endangered" under the Endangered Species Act. Effective recovery efforts for fall chinook salmon cannot be developed until we increase our knowledge of the factors that are limiting the various life history stages. This study attempts to identify those physical and biological factors which influence spawning of fall chinook salmon in the free-flowing Snake River and their rearing and seaward migration through Columbia River basin reservoirs.

Snake River fall chinook salmon spawning was generally a November event in 1994 as it was in past years. A total of 53 redds were counted by helicopter and ground truthing surveys. A total of 81 deep-water areas were searched for redds resulting in 14 redds being counted. The most concentrated group of redds was at Rkm 289.0 (N=13; 19% of total). Over half of the redds counted in the Snake River in 1994 were above the Salmon River confluence.

Flow releases from Hells Canyon Complex played a significant role in shaping flow and temperature regimes in the Snake River. Releases had the greatest influence on Snake River flows downstream to Rkm 270 during adult immigration, spawning, and egg incubation. The Salmon River begins to contribute a significant portion of flow during spring runoff. Water temperatures in the Snake River were warmer above the Salmon River confluence than below it during most of the 1993 brood year. The consequences of this may be delaying immigration and spawning while accelerating egg incubation and juvenile emigration.

Spawning substrate was examined at four sites in the Snake River in 1994. Overall quality indices of spawning substrate from three of the sites were generally high; the fourth site had gravel too large for spawning. The percent fines in the substrate were usually below 16%. Laboratory experiments conducted on emergence success showed an inverse relationship to the percent fines present in the substrate. Incubation and

emergence success of fall chinook salmon in the Snake River should generally exceed 75% at study locations where suitable spawning gravel is present.

Juvenile fall chinook salmon were seined and tagged with Passive Integrated Transponder (PIT) tags in the Snake and Clearwater rivers to describe rearing patterns, emigration behavior, and emigration timing. A total of 4,831 and 1,023 subyearling chinook salmon were seined in the Snake and Clearwater rivers in 1994. We PIT tagged and released 2,345 and 692 of the above fish in each respective river. Eighty percent of the subyearlings tagged in the Snake River and collected at Lower Granite Dam were fall chinook salmon based on electrophoresis. Fall chinook salmon were tagged in the Snake River from 17 May through 22 June with a median date of 26 May. Mean emigration rate from release sites in the Snake River to Lower Granite Dam was 2.0 km/d with peak and median dates of passage on 11 July. Only one subyearling emigrant was detected at Lower Granite Dam from Clearwater River releases. Of the subyearlings PIT tagged in the Snake and Clearwater rivers in 1994, 3.5% and 3.2% were detected as yearlings in 1995.

Point electroshocking was used to assess the usage of different habitat types by subyearling chinook salmon and predators in McNary Reservoir and the Hanford Reach of the Columbia River. More subyearling chinook salmon were observed in the Hanford Reach while more predatory fishes were observed in McNary Reservoir. Greater numbers of subyearling chinook salmon were found in areas where gradient and velocity were low regardless of substrate. Predators were found primarily in deeper water near large rip-rap substrate.

Fyke nets and underwater video techniques were used in the Hanford Reach to study nearshore movement and feeding behavior of subyearling chinook salmon. In early May, many fish were captured moving downstream, but in early June, most fish captured were moving upstream. Fish were generally observed throughout the water column during the day, but were found near the bottom at night. Upstream movements outnumbered downstream movements and occurred mostly during the day. Feeding was observed only during daylight hours and was highest during midday. Fish always captured food items in front and above them. After capturing a food item, a fish would turn and swim downstream. Competition for food was only occasionally observed.

Subyearling chinook salmon were marked at McNary Dam to estimate travel times of marked groups to John Day Dam and to determine the adult contribution of different groups. A total of 130,019 fish were marked during the early, middle, and late portions of the outmigration. Travel times of coded-wire tag groups to John Day Dam ranged from 8-23 d and were not correlated with ATPase activity, flow, temperature, release date or size. Premigrant subyearling chinook salmon challenged in seawater showed increasing osmoregulatory competence with increasing size and date. Active emigrants at McNary Dam performed adequately, but not as well as in previous years. Salinity preference test results were inconclusive due to similar behavior of test and control fish. Migratory behavior was tested in laboratory experiments and showed that subyearling chinook salmon displayed the most net downstream movement at velocities of 15-45 cm/s early in the season. Fish were generally more active during the day than at night and had higher rates of movement during the day.

ACKNOWLEDGMENTS

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CHAPTER ONE

Fall Chinook Salmon Spawning Ground Surveys in the Snake River, 1994

by

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Introduction

Spawning ground surveys were conducted in 1994 as part of a five year study of Snake River chinook salmon *Oncorhynchus tshawytscha* begun in 1991. Observations of fall chinook salmon spawning in the Snake River were limited to infrequent aerial redd counts in the years prior to 1987 (Haas 1965, Irving and Bjornn 1981, Witty 1988). From 1987-1990, redd counts were made on a limited basis by an interagency team and reported by the Washington Department of Fisheries (Seidel and Bugert 1987, Seidel et al. 1988, Bugert et al. 1989-1991, and Mendel et al. 1992). Starting in 1991, the U. S. Fish and Wildlife Service (USFWS), and other cooperating agencies and organizations, expanded the scope of spawning ground surveys to include: (1) additional aerial surveys to improve redd counts and provide data on the timing of spawning; (2) the validation (ground truthing) of redd counts from aerial surveys to improve count accuracy; (3) underwater searches to locate redds in water too deep to allow detection from the air; and (4) bathymetric mapping of spawning sites for characterizing spawning habitat.

The objectives for spawning ground surveys conducted in 1994 were to describe spawning timing, redd distribution, and extent of fall chinook salmon spawning in the Snake River using redd counts from helicopter surveys, underwater searches, and ground observations. This report includes results from data we collected in the first four years of our study, (1991-1994), and data collected from 1987 to 1990.

Study Area

The study area included the Snake River from Hells Canyon Dam to the mouth (Figure 1). We describe specific locations within the area in terms of river kilometers (Rkm) based on U.S. Army Corps of Engineers (COE) navigation charts of the Snake River (COE 1990) and U.S. Geological Survey topographical maps. Much of our work in 1994 was conducted in the riverine reach of the Snake River between Hells Canyon Dam (Rkm 398) and the head of Lower Granite Reservoir near Asotin, Washington (Rkm 235).

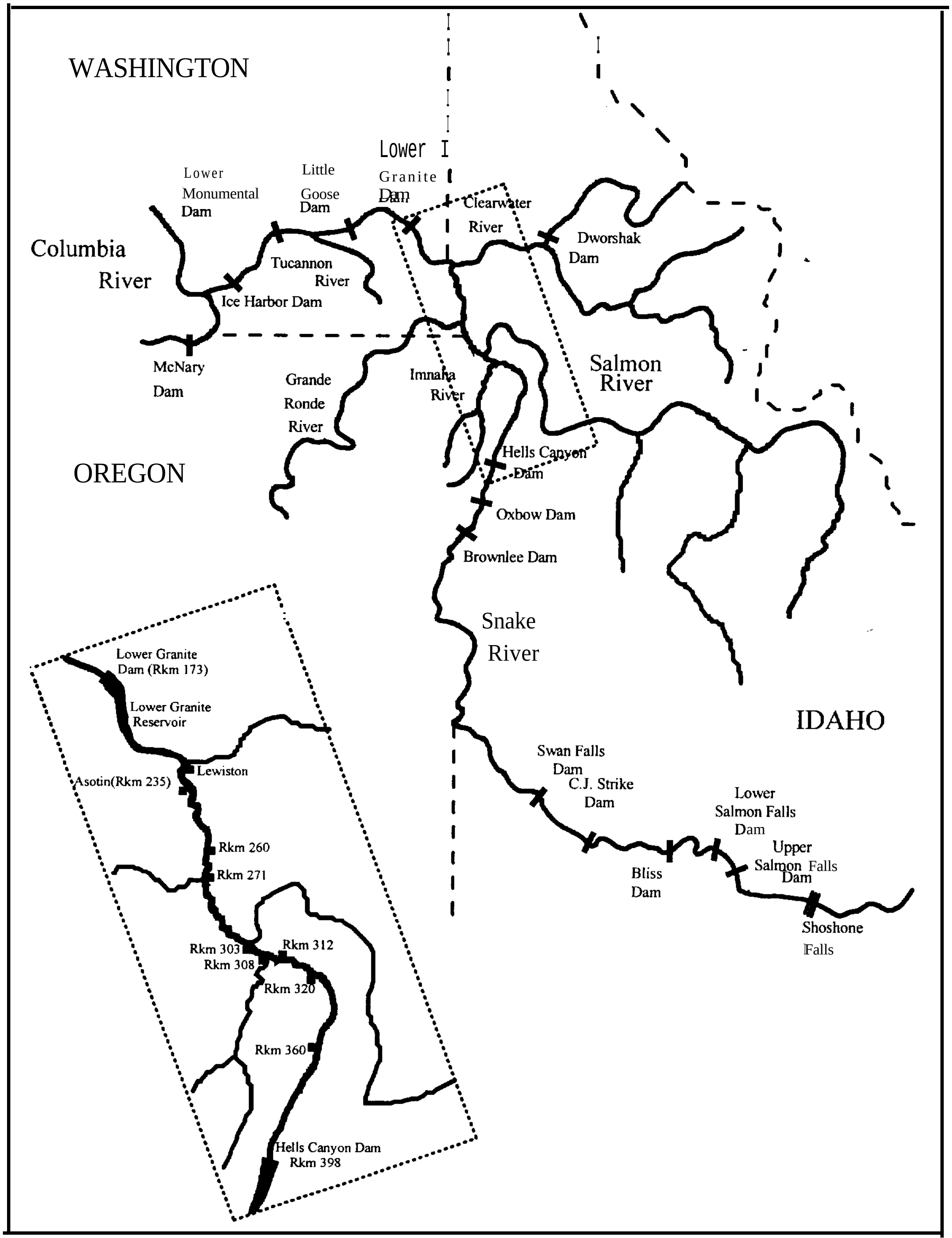

Figure 1.- Map of the Snake River drainage featuring major tributaries, and inset showing river kilometers for reference to spawning areas, the head of Lower Granite Reservoir at Rkm 235, and Hells Canyon Dam at Rkm 398.

Methods

Aerial Surveys

We conducted aerial surveys to count fall chinook salmon redds from 1991 to 1994, using methods similar to those used from 1987-1990 (Seidel and Bugert 1987, Seidel et al. 1988, Bugert et al. 1989-1991). Redd counts were made by two observers in a helicopter as it traveled from Asotin, Washington, to Hells Canyon Dam at an altitude of <200 m. When a potential redd was observed, the helicopter was positioned for optimal viewing and one observer marked the location on a COE navigation chart. Beginning in 1993, a sketch was made of each spawning site when redds were first observed, then updated on subsequent air and ground surveys. River kilometers and site descriptions associated with redds counted from 1987-1994 are given in Appendix 1.

The number and timing of aerial searches has varied between years (Connor et al. 1993; Garcia et al. 1994). Although we scheduled each survey at 7-d intervals, river and weather conditions frequently required us to change flight dates. In 1994, eight redd surveys were conducted at 6-8 d intervals from 24 October to 12 December. Eight redd counts were made at 7-d intervals from 25 October to 13 December 1993. Eight redd counts were made at 6-11 d intervals from 16 October to 12 December 1992, and nine counts were made at 6-8 d intervals from 14 October to 9 December 1991. Only two aerial redd counts were made each year from 1987-1989, and three in 1990. Redd counts in the 1987-1990 reports were referred to as index counts.

Ground Truthing

Potential fall chinook salmon redds observed from the air in 1991-1994 were examined (ground truthed) by boat, wading, or using underwater cameras. Aerial redd counts were then adjusted based on ground truthing observations. In 1991-1992, all redds observed from the air were examined by wading or from a boat. In 1993 and 1994, redds were examined from a boat or using an underwater camera when their authenticity appeared questionable from the air. The locations of most validated redds observed from the air in 1993 and 1994 were recorded using survey instrumentation (Idaho Power Company, unpublished data).

Redd Searches in Deep Water

We conducted underwater searches for redds in areas greater than 3 m deep (deep-water areas), since redds typically could not be observed from a helicopter at that depth range. In 1991 and 1992, we searched deep-water areas using methods developed by Swan (1989) that involved direct observation of the river bottom by SCUBA divers (Connor et al. 1993; Garcia et al. 1994). We used underwater video equipment after 1992 as a result of field tests conducted in cooperation with Groves (1993) and Garcia et al. (1994). In 1993, we conducted "high-intensity" searches of deep-water areas by passing an underwater camera, that faced the river bottom, along a series of equally spaced cross sections (Garcia et al. 1994). Searches in 1994 were conducted in three parts, all with the camera oriented roughly 45" to the river bottom. First, we performed "low-intensity" searches by passing a camera through each deep-water area in a zig-zag pattern. Second, if a redd was encountered, we then searched the site in an "unlimited" search pattern until we felt we covered the area completely. Third, at the sites where redds were located, we then used the same "high-intensity" search method practiced in 1993. Groves (unpublished data) also used low-intensity search methods at some of the sites we searched in 1994.

To improve methods for searching deep-water areas, we increased the number of search areas each year, and varied search technique. The deep-water areas we searched in 1991 and 1992 were limited to recently active spawning sites with suitable spawning substrate (dominant size range, 2.5-15 cm; Connor et al. 1993; Raleigh and Miller 1986) extending into water greater than 3 m deep. In 1993, we searched three new areas where Groves observed redds, as well as areas we searched in 1992. In 1994, we expanded our search effort to include a subsample of 96 potential deep-water spawning areas located by Groves'in 1993.

Results

Aerial Surveys and Ground Truthing

A total of 53 redds were counted on helicopter and ground-truthing surveys in 1994 (Table 1). This compares to 60 redds counted by air and ground surveys in 1993, 47 in 1992, and 4 in 1991 (Table 2, Figure 2). The peak redd counts occurred on 7 November in 1994, 1 November in 1993, 23 November in 1992, and 18 November in 1991.

Deep-water Searches

In 1994, a total of 81 deep-water areas were searched, 44 by USFWS and 37 by Groves (1996; Tables 3 and 4; Appendix 1). This compares to 51 deep-water areas searched in 1993, three in 1992, and one in 1991. The number of redds counted in deep-water areas totaled 14 in 1994, 67 in 1993, zero in 1992, and five in 1991 (Table 5).

Table 1.- River kilometer (Rkm), landmark, and new fall chinook salmon redds counted during air and ground surveys of the Snake River from the Head of Lower Granite Reservoir (Rkm 234.9), to Hells Canyon Dam (Rkm 397.4), 1994.

Rkm	Landmark	New redds counted by flight date								Site
		24-Oct	01-Nov	07-Nov	13-Nov	21-Nov	29-Nov	05-Dec	12-Dec	Totals
245.2	Big Bench Point	-	-	-	1	3	1	-	-	5
265.0	Lower Billy Ck Rapids	-	-	-	-	-	1	-	-	1
265.6	Perkins Gulch (ID side)	-	-	2	-	-	1		-	3
271.4	Grande Ronde River	-	1	-		1	4	-	-	6
286.9	Near Cache Creek Range	-	-	1		-	-		-	1
288.0	Upper Cochran Range	-	-	1	-	-	-	-	-	1
289.0	Cougar Bar Range No. 4	-	-	3	-	2	-	-	-	5
306.4	Knight Creek	-	-	-	-	-		1		1
311.2	Divide Creek		1	1	-	-	-	-	-	2
311.7	Divide to Zig Zag	-	-	1		1	-	-	-	2
311.8	Big Canyon Creek	-	-	-		-	1		-	1
312.1	Big Canyon Range		1	1	-	-	-	-	-	2
315.4	Rapid No. 97	-	-	1	1	-	-		-	2
319.9	Robinson Gulch			4	1	1	-	-	-	6
347.7	Klopton Creek	-	-	-	-	1	-	-	-	1
352.9	Kirby Range No. 5	-	-	2	1	-	-	-	-	3
358.6	Suicide Rock	1	-	-	-	-	-	-	-	1
359.0	Hominy Creek			-	3	-	-	-	-	3
379.2	Hat Creek		-	1	2	1	1	-	-	5
381.3	Lower Dry Gulch	-	1	-	-	-	1	-	-	2
	Totals	1	4	18	9	10	10	1	0	53

Table 2.- Number of fall chinook salmon redds counted in the Snake River, by search method and year, 1987-1994. Data sources and methods can be found in Garcia et al. (1994).

Search Method	1987	1988	1989	1990	1991	1992	1993	1994
Air and Ground	66	57	58	37	41	47	60	53
Underwater	-	-	-		5	0	67	14
Totals	66	57	58	37	46	47	127	67

Table 3.- Number of different deep-water areas searched for fall chinook salmon in the Snake River, by year and investigator, 1991-1994 (Connor et al. 1993, Garcia et al. 1994, Groves 1996).

	Number of deep-water areas searched			
Investigator	1991	1992	1993	1994
USFWS	1	3	6	44
Groves	0	0	45	37
	1	3	51	81

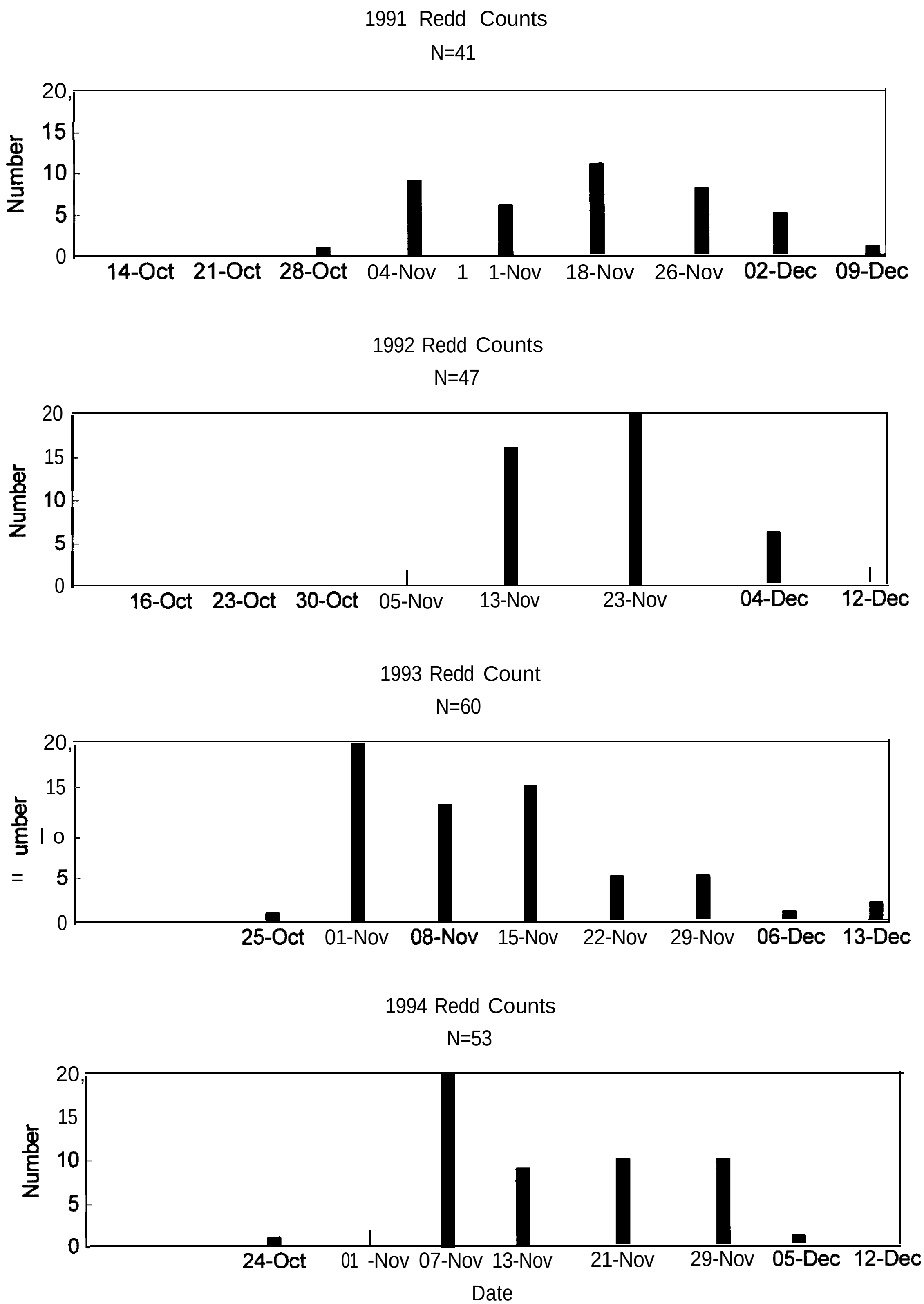

Figure 2.- Number of new fall chinook salmon redds counted on helicopter and ground surveys between Asotin and Hells Canyon Dam on the Snake River, 1991-1994.

Table 4.- River kilometer and dates of low- and high-intensity deep-water (> 3 m) searches for Snake River fall chinook salmon redds, 1994. Landmarks associated with river kilometers where redds were counted between 1987-1994 are given in Appendix 1.

Rkm	Search Date(s)		
	Low intensity		High intensity
238.9	19-Nov		
242.2	17-Nov		
246.5	17-Nov		-
248.3	14-Nov		
250.4	14-Nov		
252.6	14-Nov	14-Dec	
254.2	17-Nov		
259.0	15-Nov		
261.5	15-Nov	15-Dec	
263.4	15-Nov		
264.5	13-Dec		
266.6	18-Nov		
267.4	18-Nov		
268.1	18-Nov	15-Dec	-
274.0	19-Nov	-	-
275.8	16-Nov	-	-
276.6	19 -Nov	-	-
285.8	16-NOV	-	-
286.9	16-Nov		
294.6	16-Nov		
311.3	28-Nov		
311.7	28-Nov		07-Dec
312.3	20-Nov	-	06-Dec
312.8	20-Nov		-
313.1	20-Nov		
318.9	20-Nov		
326.3	02-Dec		
326.8	22-Nov		
328.1	22-Nov		
329.7	29-Nov	-	-
334.7	22-Nov	-	-
335.2	30-Nov	-	-
336.8	21-Nov	-	-
337.7	21-Nov	-	-
338.9	30-Nov	-	-
341.4	22-Nov	-	-
343.2	30-Nov	-	-
350.4	01-Dec	-	-
354.3	29-Nov	-	
357.7	01-Dec		
358.3	29-Nov	14-Dec	
359.9	29-Nov	-	
366.7	01-Dec	14-Dec	
366.9	01-Dec		

Redd Distribution

A total of 67 fall chinook salmon redds were located between Rkm 245.2 and Rkm 381.3 in 1994 (Tables 1 and 5). The most concentrated group of redds was at Rkm 289.0 (N=13; 19% of total). Over half of the redds counted in the Snake River in 1994 were above the Salmon River confluence (N=37; 55% of total). Annual redd counts between 1987-1994, with all search methods combined, ranged from a low of 37 in 1990 to a high of 127 in 1993 (Table 2). A total of 505 redds were observed between Rkm 238.6 and Rkm 396.6 from 1987-1994, with the majority located downstream of the Salmon River confluence (Figure 3).

Comparison of Deep-water Search Methods

Comparisons made in 1993 and 1994 (Table 6) show low-intensity search method consistently detected at least as many redds as the high-intensity method and sometimes more. An "unlimited" search method was tried at one site only, and yielded the same count as the low- and high-intensity searches.

Discussion

Snake River fall chinook salmon spawning is generally a November event with some activity occurring in late October and early December. The date of initial observation of redds has varied by as much as 12 d from 1991-1994 while the date of peak spawning has ranged up to 22 d for the same period.

A disproportionate number of fall chinook salmon redds were counted below the mouth of the Grande Ronde River from 1987-1993 (Garcia et al. 1994). Of the 438 redds counted in the Snake River from 1987-1993, 61.2% were observed below the Grande Ronde River, within the lower 36 km (22%) of the 163 km riverine reach. In 1994, however, only 13.4% of the redds counted were observed downstream of the Grande Ronde River. Similarly, early aerial surveys between Hells Canyon Dam and Lewiston, Idaho, showed fewer redds were counted downstream of the Imnaha River, 18% (33 of 188) in 1967, and 32% (180 of 568) in 1969 (Irving and Bjornn 1981).

Our observations indicate that it is typical for fall chinook salmon to concentrate their spawning in a few areas each year. One area, Rkm 289.0, had a disproportionate number of redds in 1994. Each year from 1991-1993 it was common to have a few spawning areas dominate the total count for the year. Of the most heavily used areas in 1992-1994, most of the redds were located using underwater cameras, indicating the importance of deepwater redd surveys in the Snake River.

Table 5.- Number of fall chinook salmon redds counted in deep-water areas of the Snake River, by river kilometer, landmark, and year, 1991-1994 (Connor et al. 1993, Groves, unpublished data).

Rkm	Landmark	Redds counted in deep-water areas			
		1991	1992	1993	1994
261.3	Captain Johns Creek	5	0	0	0
266.5	Billy Creek			28	0
267.4	Fisher Range			11	0
267.7	Lower Lewis Rapids			21	0
289.1	Cougar Bar	-		2	8
311.8	Big Canyon Creek	-	-	1	0
312.3	Zig Zag Creek	-	-	-	5
320.8	Trail Gulch			1	0
358.5	Suicide Point	-	-	3	0
381.3	Lower Dry Gulch				1
		5	0	67	14

Table 6.- River kilometer, year, number of fall chinook salmon redds counted using low-intensity, high-intensity, and unlimited search methods, and total number of redds counted by all methods, 1993 and 1994. Total counts were determined by summing separate redds counted by each method.

Rkm	Year	Search Method			Total Count (all methods)
		Low Intensity	High Intensity	Unlimited	
266.5	1993	28[a]	19[b]	-	28
267.4	1993	9[a]	3[b]	-	11
267.7	1993	18[a]	16[b]	-	21
289.1	1993	2[a]	0[a]	-	2
312.3	1994	5[b]	5[b]	5[c]	5
320.8	1993	1[a]	1[a]		1

[a] Search conducted by Groves (unpublished data).
[b] Search conducted by USFWS.
[c] Searched separately by USFWS and Groves.

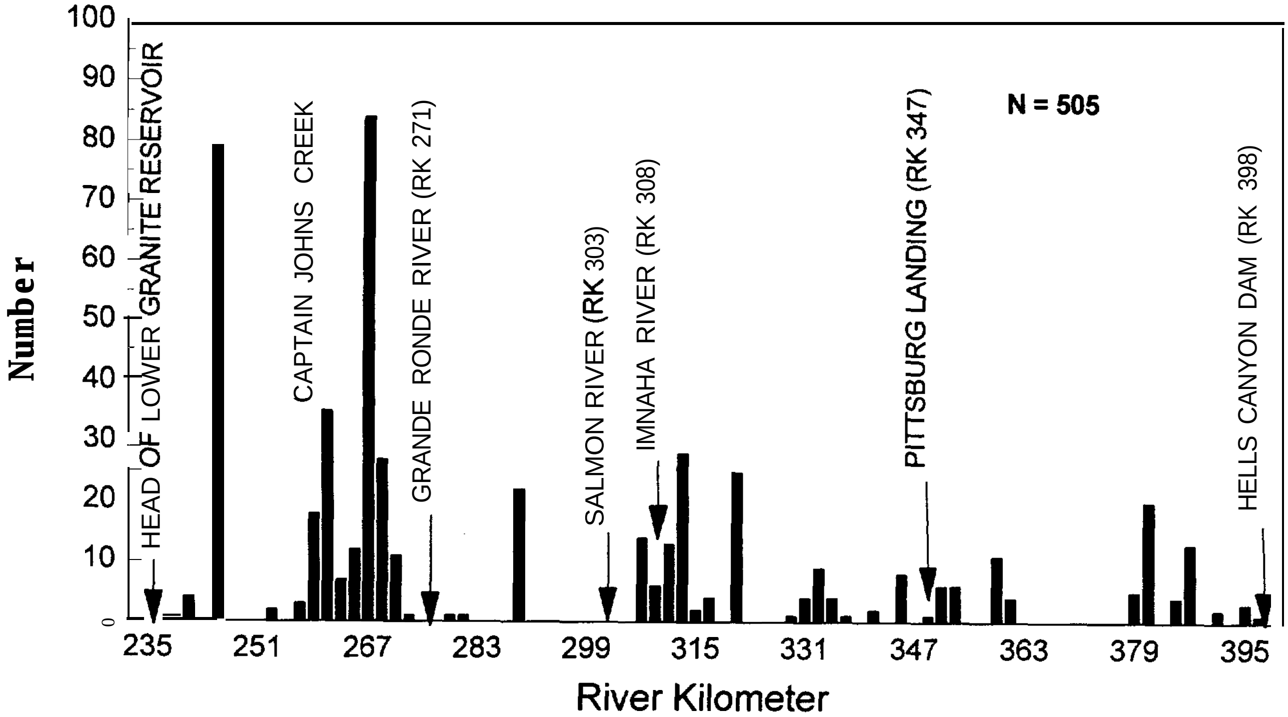

Figure 3.-River kilometer, and numbe: of fall chinook salmon redds counted in the Snake River by helicopter, diving, cam .. and ground observation from 1987-1994.

We have varied the methods and intensity of deep-water redd searches throughout the course of this study. Data collected in 1993 and 1994 indicate a combination of the low-intensity search method may provide the most effective method to search for fall chinook salmon redds in deep-water areas of the Snake River.

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CHAPTER Two

Snake River Flows And Temperatures During the 1993 Snake River Fall Chinook Salmon Brood Year

by

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Introduction

In 1992, Snake River fall chinook salmon *Oncorhynchus tshawytscha* were listed as threatened under the Endangered Species Act (National Marine Fisheries Service 1992). At that time, information on the effects of Snake River flows and water temperatures on the spawning, egg incubation, and rearing requirements of Snake River fall chinook salmon was minimal. Releases from Hells Canyon Dam can shape downstream flow and thermal regimes and may influence the timing of life history events. We have collected flow and water temperature data since 1991 to examine their influences on Snake River fall chinook salmon life history periods. The study objectives for 1994 were to describe Snake River discharge and water temperatures during fall chinook salmon immigration, spawning, and egg incubation periods from August 1993 to June 1994 (fall chinook salmon brood year 1993; BY 93).

Study Area

The study area encompassed the Snake River from Hells Canyon Dam to its mouth (Figure 1). Locations described within this area are in river kilometers (Rkm) based on the navigation charts of the Snake River produced by the United States Army Corps of Engineers. The focus in BY 93 was on the free-flowing reach of the Snake River from Hells Canyon Dam (Rkm 398) to the head of Lower Granite Reservoir near Asotin, Washington (Rkm 235).

Methods

Data Collection

Discharge data for the Snake, Imnaha, Salmon, and Grande Ronde rivers were furnished by the United States Geological Survey (USGS; Appendix 2). Water discharge data are reported in thousands of cubic feet per second (KCFS) based on USGS standards. Snake River water temperature data were collected during BY 93 by thermograph at Pittsburg Landing (Rkm 347) and Billy Creek, Idaho (Rkm 265; Appendix 3).

Data Analysis

We used data collected from 1991 to 1994 (Connor et al, 1993; Connor et al. 1994; Garcia et al. 1994; Connor et al. in this report) to approximate the timing of fall chinook salmon life stages (August immigration through June fry emergence) for BY 93. Snake River flows and temperatures were then

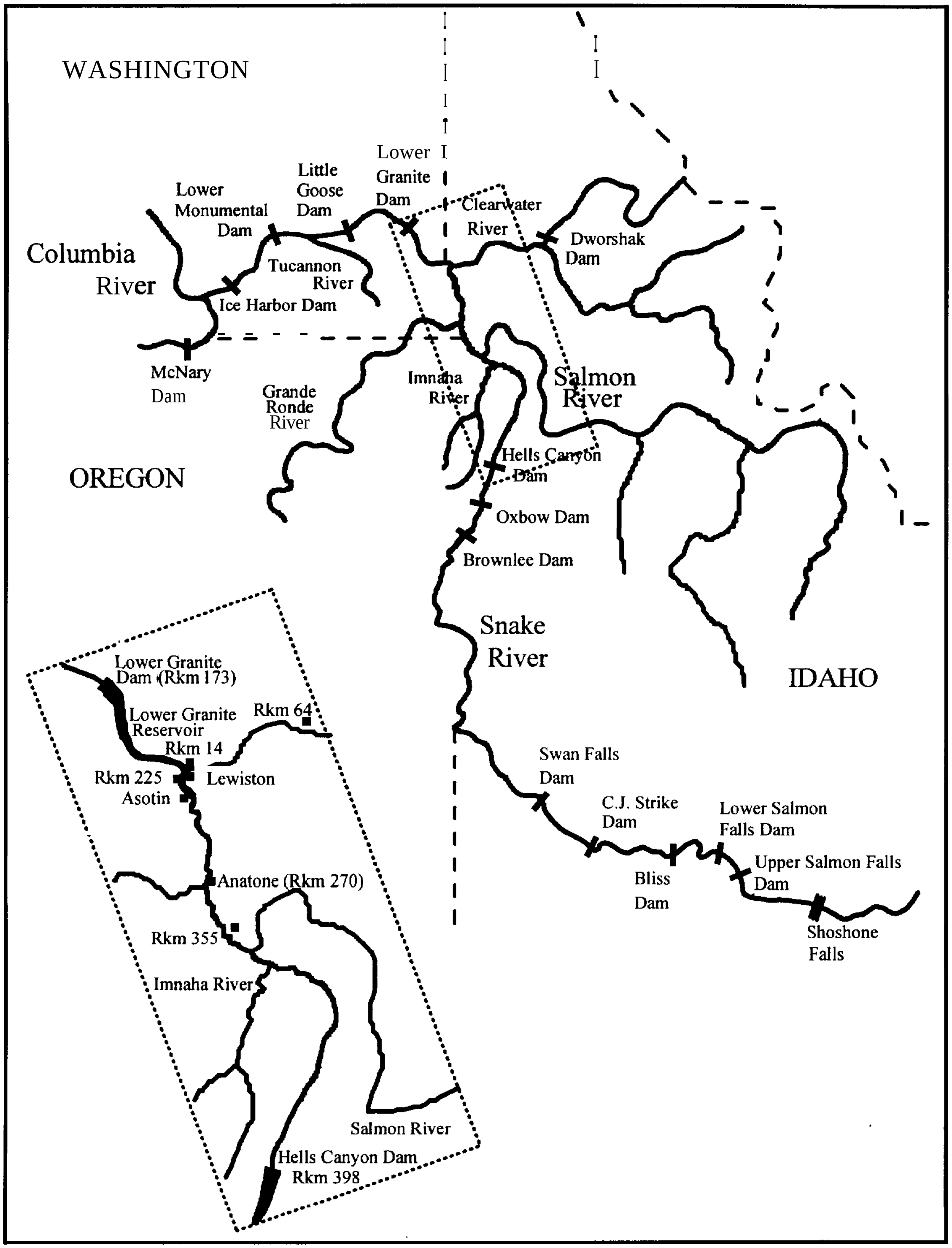

Figure 1. Map of the Snake River drainage with an insert to show the 1994 Snake River seining area boundaries of Rkm 225 and Rkm 290 and Clearwater River boundaries of Rkm 14 and Rkm 64.

characterized for each fall chinook salmon life history stage for BY 93.

Results

Discharge

During fall chinook salmon immigration, Hells Canyon Dam (Rkm 398) releases comprised 70% of the Snake River's discharge recorded at Anatone Gage (Rkm 270; Table 1). The Imnaha, Salmon, and Grande Ronde rivers contributed the remaining 30% of the discharge. Average discharge at Anatone Gage during immigration was 19.9 KCFS with a range of 11.3-31.8 KCFS. Two major water fluctuation events occurred during immigration. Over a 15-d period, releases at Hells Canyon Dam dropped from 16.3 KCFS on 9 September to 5.9 KCFS on 13 September and returned to high of 18.7 KCFS by 23 September. The second fluctuation occurred over a 9-d period initiating lower stable spawning flows when discharge dropped from 22.1 KCFS on 15 October to 9.5 KCFS on 23 October. Both events were reflected in the readings at Anatone Gage (Figure 2).

During the fall chinook salmon spawning period, flows were primarily stable. Hells Canyon Dam releases made up 66% of the flow at Anatone Gage during the spawning period (Table l), and averaged 14.5 KCFS with a range of 12.5-15.3 KCFS. The only fluctuation at the Anatone Gage during this period was due to a small decrease in flow from the Salmon River around 27 November.

Throughout early egg incubation, Hells Canyon Dam contributed 70% of the flow recorded at the Anatone Gage (Table 1)I and averaged 15.9 KCFS with a range of 24.2-12.5 KCFS. The first part of the early incubation period was governed by stable discharge at Hells Canyon Dam (Figure 2). On 12 December, Hells Canyon Dam began an erratic release scenario, termed power peaking, which continued throughout the remainder of the early incubation period.

Hells Canyon Dam flows comprised less than 50% of the discharge at Anatone Gage during late egg incubation (Table 1). Average discharge for this period was 30.4 KCFS with a range of 15.1-64.3 KCFS. Hells Canyon Dam discharge had the greatest influence on readings at Anatone Gage, until spring runoff started on 18 April, which coincided with an increase of discharge from the Salmon River (Figure 2). Flows at Anatone Gage increased from 23.7 KCFS on 17 April to 50.0 KCFS by 24 April. A second surge of water from the Salmon River on 7 May contributed to a peak discharge of 64.3 KCFS on 11 May.

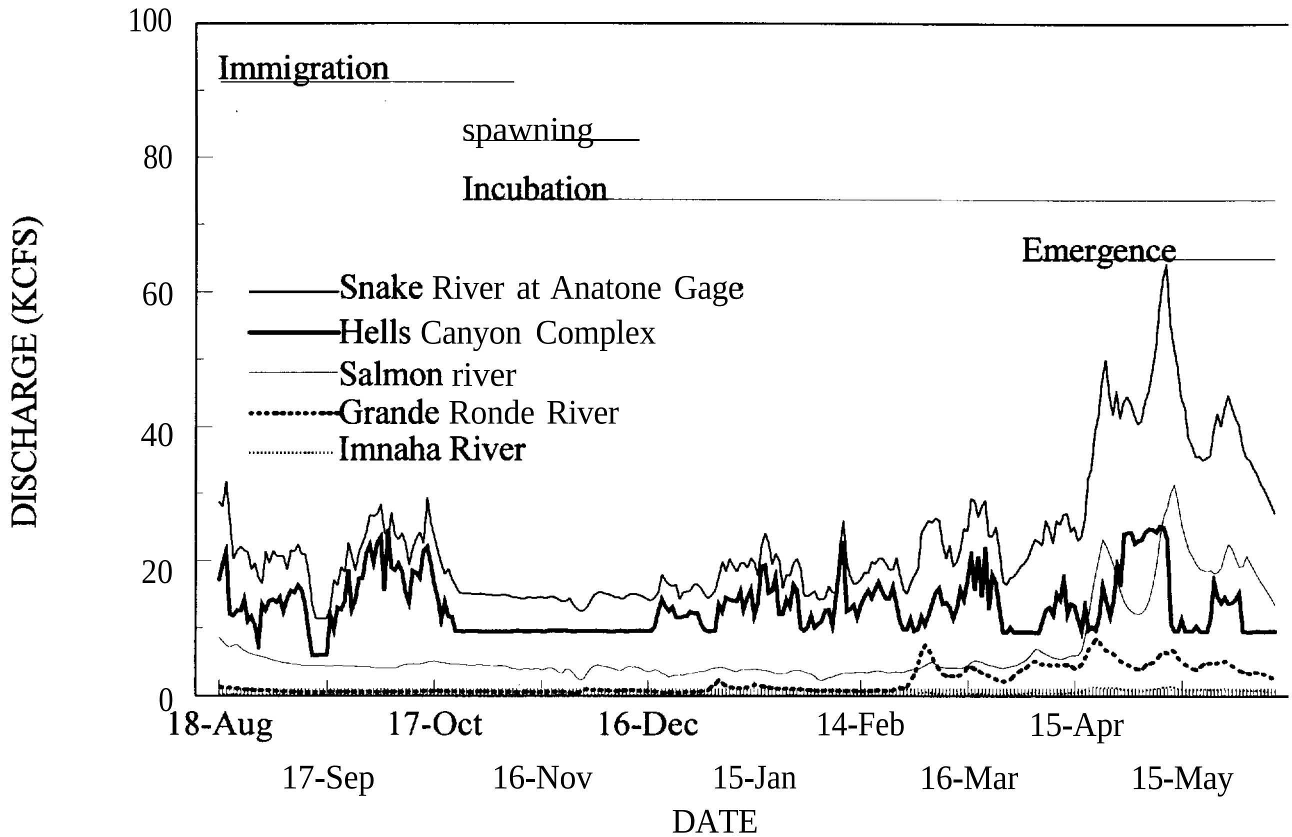

Figure 2.-Average daily discharge at Snake River at Anatone Gage, Hells Canyon Dam, Salmon River, Grande Ronde River, the Imnaha River during the 1993 fall chinook salmon brood year. Discharge data provided by United States Geological Survey.

Table l.-Discharge contributed by Hells Canyon Dam, and Imnaha, Salmon, and Grande Ronde rivers to the mainstem Snake River at Anatone Gage, Washington during the 1993 fall chinook salmon brood year. Total flow does not always add to 100% because the stations are not synchronized.

		Percent of Snake River discharge contributed by source			
Life stage	Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River
Immigration	18 Aug - 11 Nov	69	1	25	4
Spawning	25 Oct - 13 Dec	66	1	28	5
Early Incubation	25 Oct - 07 Feb	70	1	23	5
Late Incubation	08 Feb - 10 Jun	46	2	36	13

Table 2.-Average Snake River water temperatures (°C) above the Salmon River at Rkm 347 (Pittsburg Landing) and below at Rkm 265 (Billy Creek) during different life stages of the 1993 brood year. Temperature ranges are shown in parentheses.

Life Stage	Rkm 265	Rkm 347
Immigration	16.7 (9.5-20.8)	17.7 (12.1-21.1)
Spawning	7.8 (4.5-12.9)	10.0 (6.0-14.6)
Early Incubation	5.7 (2.2-15.6)	6.9 (2.6-14.6)
Late Incubation	9.0 (2.2-15.6)	9.0 (2.5-16.7)

Water Temperature

Water temperatures in the Snake River followed a typical seasonal pattern of decreasing from fall to mid winter then increasing again with the onset of spring (Figure **3**). Average Snake River water temperatures during immigration, spawning, and early incubation were warmer above the Salmon River at Rkm **347** than they were below it at Rkm **265** (Table 2). Average water temperatures became more similar during late incubation at both sites.

Discussion

Fall chinook salmon habitat in the remaining free-flowing Snake River is affected by the operation of Hells Canyon Dam. Hells Canyon Dam discharge governed the flow regime of the Snake River at the Anatone Gage until the late incubation period when spring runoff began from the Salmon River drainage. The dominant influence of Hells Canyon Dam operation on the Snake River's flow regime during BY 93 is consistent with findings from past years and emphasizes the need for the completion of our ongoing instream flow studies.

The Snake River was warmer above the Salmon River confluence than below it during most of BY 93 as was observed in past brood years. Warmer water temperatures may delay immigration and spawning, while accelerating egg incubation and juvenile emigration. Low redd counts in the upper river have prevented the collection of empirical data to confirm these theories. Completing the water temperature modeling component of our study, combined with the collection of juveniles above the Salmon River, will increase our understanding of Hells Canyon Dam's influence on Snake River fall chinook salmon early life history.

In conclusion, our findings during BY 93 indicate: (1) under drought conditions, Hells Canyon complex dominated the Snake River flow pattern downstream to Rkm **270** during BY 93 through late incubation, and (2) the Snake River has two distinct thermal regimes above and below the Salmon River until late incubation. The information we have presented in this chapter will be modified upon the analysis of additional data.

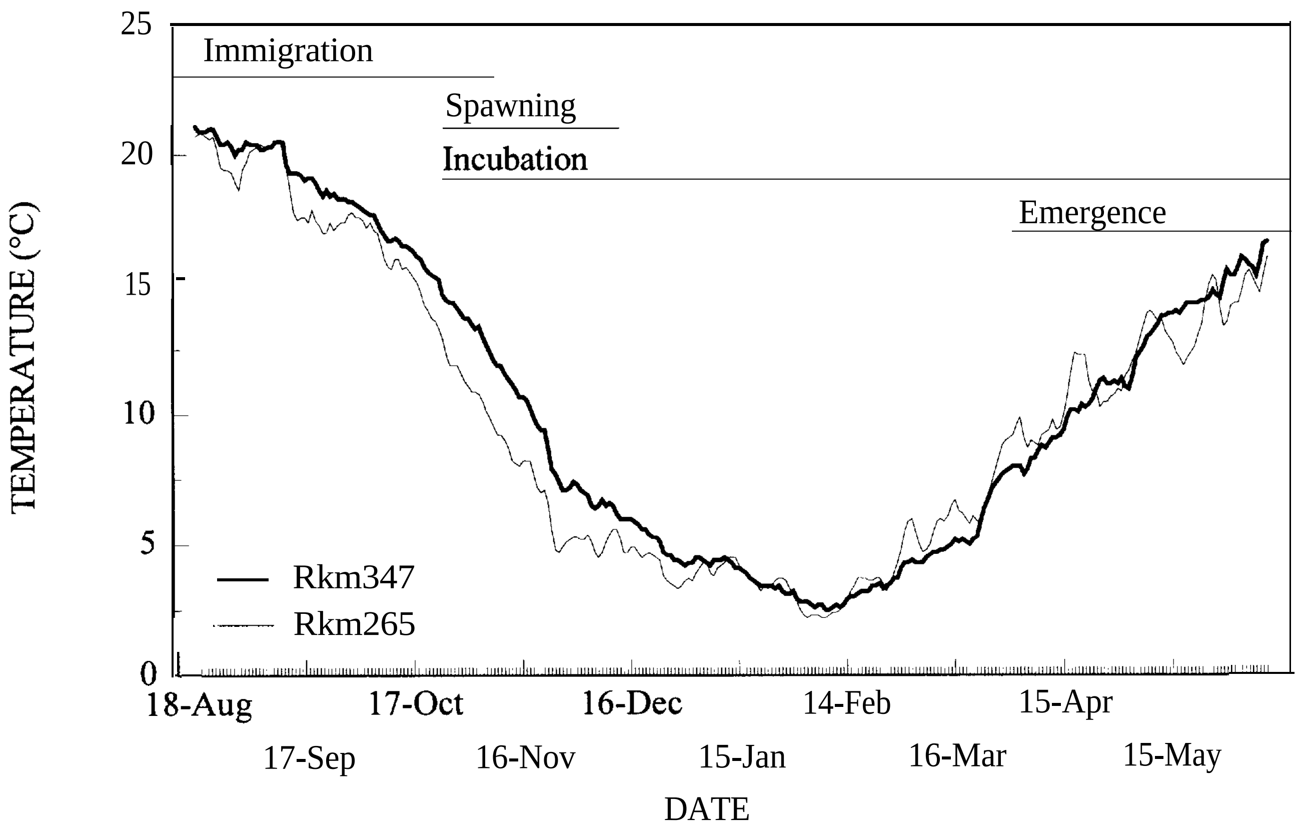

Figure 3.-Average daily Snake River water temperatures at Rkm 347 and Rkm 265 for the 1993 fall chinook salmon brood year.

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CHAPTERTHREE

Evaluation of Substrate Quality for Embryo Incubation of Fall Chinook Salmon in the Snake River

by

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Introduction

The National Marine Fisheries Service was petitioned in 1991 to list Snake River fall chinook salmon *Oncorhynchus tshawytscha* under the 1973 Endangered Species Act (National Marine Fisheries Service 1992). Effective recovery efforts for fall chinook salmon can only be developed after factors limiting the various life history stages are known. The potential for successful natural reproduction of Snake River fall chinook salmon is based largely on the quality of gravel in spawning areas. Fall chinook salmon are known to spawn in the free-flowing reach of the Snake River between river kilometers (Rkm) 235 and 398.

Underwater video techniques have been used to describe the surface substrate of fall chinook salmon spawning areas throughout the free-flowing reach of the Snake River (Garcia et al. 1994). Underwater video and ground surveys can only estimate the quantity and quality of available spawning gravels by visual appearance of the substrate surface. However, visual appearance is an inadequate and often misleading indicator of gravel quality because textural composition can change with substrate depth, and cannot be visually assessed at the 10 to 30 cm depth where spawning salmonids usually deposit their eggs without disturbing the redd (Everest et al. 1982). Excessive amounts of fine sediment in the spawning gravel decrease permeability and water flow to incubating salmonid embryos (Lotspeich and Everest 1981). Decreased flow through the gravel reduces oxygen availability and removal of metabolic wastes that are potentially toxic to embryos (Iwamoto et al. 1978). Furthermore, entrapment of fry occurs when fine material lodged in gravel interstices prevents emergence (Phillips 1975). The purpose of this study was to describe the quality of available spawning gravel and its effect on the incubation success of fall chinook salmon. Our objectives included: (1) reviewing the literature on quality of spawning substrate of Pacific salmon and substrate sampling techniques with emphasis on chinook salmon; (2) characterizing the spawning substrate of 12 previously identified fall chinook salmon spawning locations; and (3) estimating incubation success of fall chinook salmon embryos in artificial redds using substrate representative of the 12 study locations.

Study Area

The free-flowing reach of the Snake River extends from Hells Canyon Dam (Rkm 398) to the upstream end of Lower Granite Reservoir (Rkm 2351, near Asotin, Washington. Twelve spawning sites within the free-flowing reach, previously identified from redd counts (Connor et al. 19931, were chosen for study based on habitat type (Figure 1). Riffles, glides, lateral gravel bars,

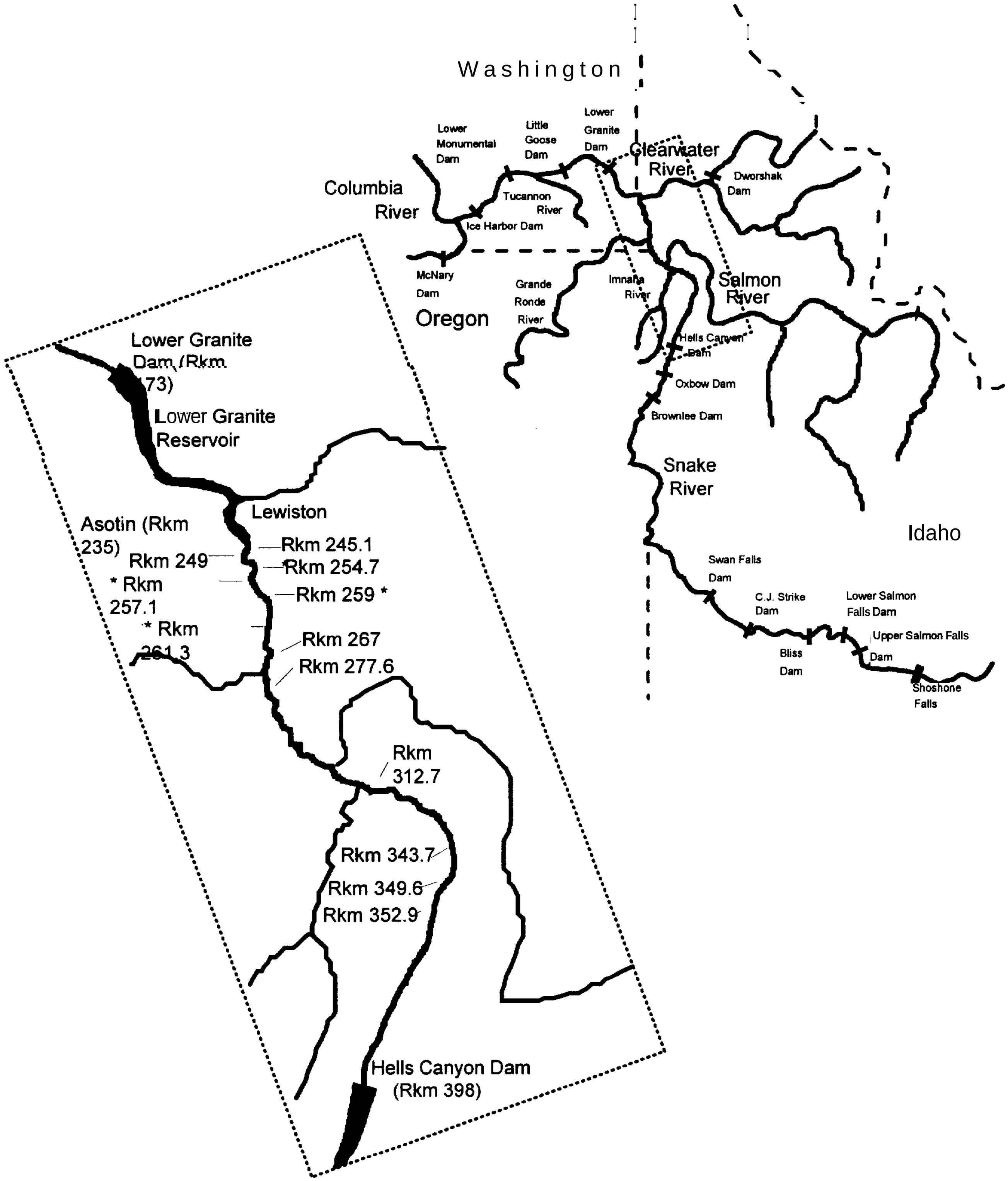

Figure 1. Map of fall chinook salmon spawning sites from river kilometer (Rkm) 398 to 235 in the free-flowing reach of the Snake River. Astrisks indicate locations sampled during 1994.

and runs, all within deep and shallow locations, were associated with the 12 sites. Four of the 12 locations, Rkms 245.1, 257.1, 259, and 261.3, were sampled during 1994 to assess gravel composition.

Methods

Data Collection

Substrate composition.- Ten random substrate samples were taken during 1994 at each of four (Rkms 245.1, 257.1, 259, and 261.3) of the 12 previously identified spawning sites (Connor et al. 1994). In deep-water locations, SCUBA divers extended lead lines marked at 10 m intervals perpendicular to the current. A modified, suction dome sampler was used to sample substrate in water > 1.2 m deep (Gale and Thompson 1975). The sampler was positioned into the substrate by a diver, and the substrate was removed and placed into an attached collection bag. Fine sediments were then removed with a bilge pump into a separate collection bag.

A modified, tri-tube freeze core sampler was used to sample substrate in water < 1.2 m deep (Arnsberg et al. 1992). A diamond-shaped, galvanized deflector (0.5 x 0.9 x 1.4 m high) was placed around the sampler to divert water flow and enhance freezing of the substrate. Plastic tarps were placed around the deflector's bottom edge to prevent upwelling around the freeze core probes. Liquid CO, was used in the core probes to freeze the substrate. Cores were extracted using an adjustable, aluminum tripod and a chain winch. Extracted cores were placed on a subsampler, heated, stratified into three 10.2 cm depth strata (stratum 1 = 0 - 10.2 cm, stratum 2 = 10.2 - 20.3 cm, stratum **3** = 20.3 - 30.5 cm; Everest et al. 1980), and placed into labeled collection bags. Substrate samples were subsequently dried for 2 days at 101°C then were shaken through USGS standard sieves with mesh sizes of 75, 50, 20, 12.5, 9.5, 6.35, 4.75, 3.35, 2.0, 0.85, 0.5, and 0.25 **mm.** Dry weight from each sieve was used to calculate the mean particle size distribution of each sample.

Emergence experiments.- Forty-eight troughs (121.9 cm length x 30.5 cm wide **x** 30.5 cm deep) were filled to **a** depth of 25 cm with eight gravel-sand mixtures (Figure 2). Gravel and sand were weighed and mixed by hand to obtain the eight compositions (Table 1). Six replicates of each mixture were randomly placed in the troughs.

A total of 150 eyed fall chinook salmon embryos from Bonneville State Fish Hatchery, Bonneville, Oregon, were randomly placed near the bottom in each trough. Also, 100 embryos, which

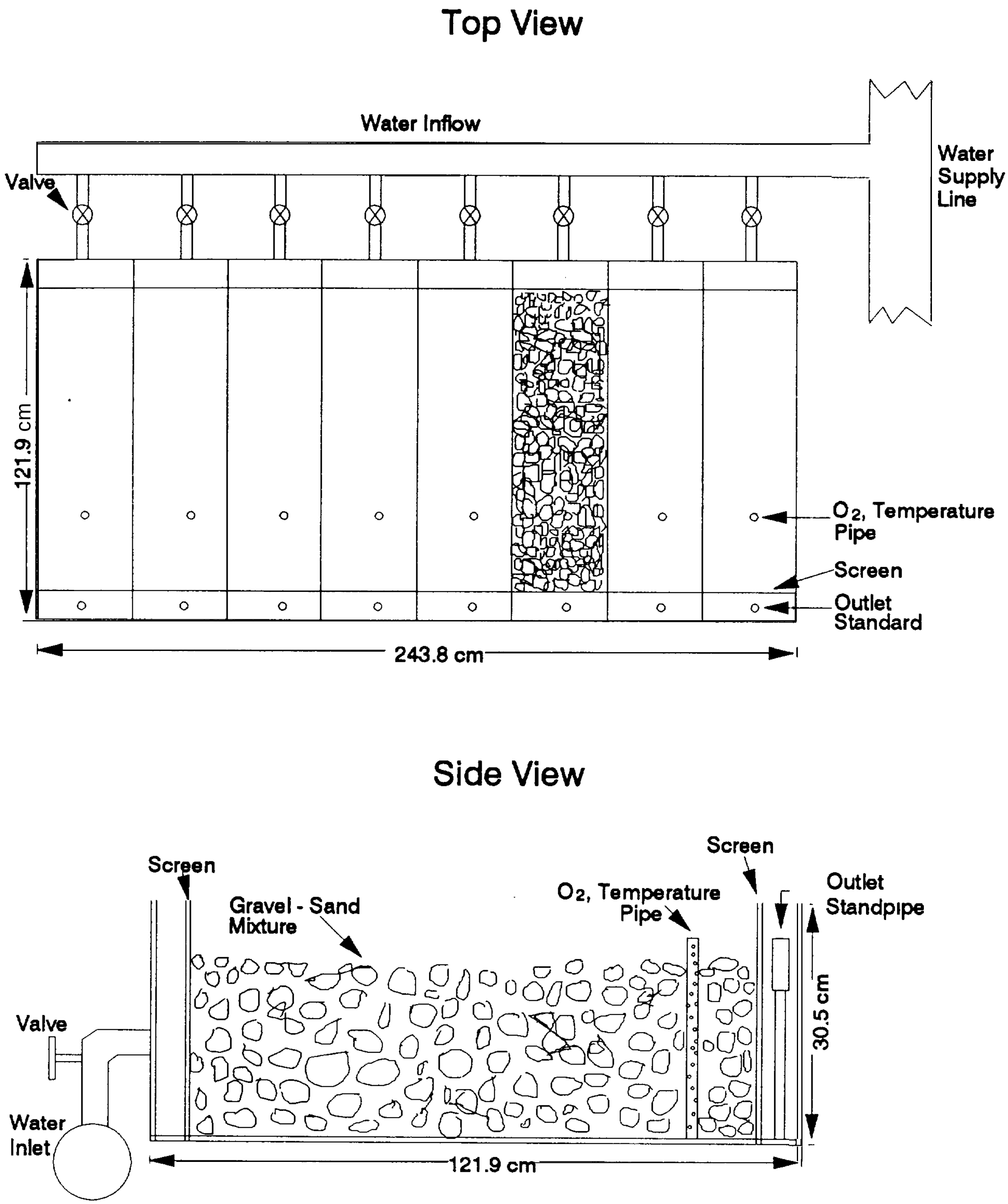

Figure 2. Diagram of test troughs used to estimate emergence success of fall chinook salmon embryos in various substrate compositions during 1995.

Table 1.-Substrate composition (%) used to assess embryo incubation success of fall chinook salmon in the laboratory during 1994.

Composition number	Category	(<6.4 mm)		(>6.4 <25 mm)		(>25 mm)	
		planned	actual	planned	actual	planned	actual
1	A	0	2	75	72	25	26
2	B	8	11	70	72	22	17
3	C	12	26	81	68	7	6
4	C	16	23	75	73	9	4
5	D	20	29	65	66	15	5
6	D	26	28	70	69	4	3
7	D	30	32	54	60	16	8
8	D	35	36	65	62	0	2

served as controls, were placed in Heath Tray incubators to quantify spawning success of the embryos.

Chilled, unchlorinated recycled tap water flowed laterally through the troughs. Approximately 60 L of water entered the system per minute and about 30 L were discarded. A perforated PVC pipe (20 cm long x 1.8 cm diameter) was placed in the middle of each egg pocket nearest the outflow where dissolved oxygen and temperature from each trough were measured. Water temperatures were recorded hourly. Flows through the troughs were determined by gradient differences between the inflow and outflow sources. A 2% gradient was maintained where possible.

As fry emerged, they were removed from the troughs, placed in sample bags, and preserved in 10% formalin. After 21 days, fry were blotted dry, weighed to the nearest 0.1 mg, and total length measured to the nearest 0.5 mm (Rombough 1985). Substrate samples from the inflow, middle, and outflow of each trough were taken with a 15.24 cm McNeil sampler (McNeil and Ahnell 1964) after all fry emerged.

Data Analysis

Substrate composition. -Two methods were used to determine substrate composition. For the first method, we calculated the proportion of gravel particles less than a given sieve size (< 0.85 mm and < 6.4 mm) of the total weight of the sample (McNeil and Ahnell 1964; Bjornn 1969; McCuddin 1977; Tappel and Bjornn 1983; Young et al. 1991). Data were normalized by arcsine transformation for analysis of variance (Ott 1984). We examined mean particle size distribution at each location by plotting the data on a logarithmic scale. Substrate samples from fluvial systems have particle size distributions close to lognormal (Shirazi and Seim 1979; Tappel and Bjornn 1983).

For the second method, aspects of the central tendency of the entire particle distribution were calculated. Geometric mean and fredle index were used as indices. The geometric mean (dg) describes the permeability and porosity of sediments (Platts et al. 1979). Sediments with small dg values are less permeable than those with large values. Geometric mean (dg) is calculated by:

$$dg = (d1^{w1} \times d2^{w2} \times \ldots dn^{wn});$$

where: d = mean particle diameter captured by *a* sieve
w = decimal fraction by weight of particles retained by a given sieve.

The fredle index (fi; Lotspeich and Everest 1981), which uses the size distribution (So) of sediment particles and the geometric mean in a sample, was also calculated as an index of embryo survival potential. Permeability and pore size, which control movement of water and fry through gravel, are determined largely by the size distribution of grains in a sample. Pore size and relative permeability increase as fredle index increases. The fredle index is calculated by:

$$fi = dg/So;$$

where: dg = geometric mean,
So = d84/d16 is the sorting coefficient
d84 and d16 = particle size diameter at which 84% or 16% (one standard deviation) of the sample is finer on a weight basis (Kondolf 1988).

We log transformed the data (ft = (fi + 0.373)0.5) for normality (Ott 1984) to statistically compare ($P < 0.05$) vertical stratification within and between each freeze-core sample using the general linear model (GLM) procedure of analysis of variance (SAS Institute 1989).

Emergence experiments. -Apparent water velocity in the forty-eight troughs was calculated as: V = Q/A;

where: V = apparent velocity (cm/s),
Q = volume of flow per unit time
A = total cross-sectional area (Terhune 1958).

Survival was calculated as the proportion of the 150 fry that emerged. Emergence success (%) was transformed by arcsine (Ott 1984) and compared among substrate compositions by polynomial regression analysis (SAS Institute 1989).

Substrate samples from the forty-eight troughs were dried and shaken through USGS standard sieves and weighed. Percent fines (< 6.4 mm), geometric mean diameter, and fredle index were calculated. Least squares means (SAS 1989; $P < 0.05$) were used to determine if differences in fine (< 0.85 mm) particle size distribution occurred.

Results

Substrate Composition

Differences in particle size distribution of substrate sampled in > 1.2 m of water were observed at Rkm 245.1, Rkm 259, and Rkm 261.3 (Figure 3). ***No*** significant difference ($P > 0.05$) in particle size composition was found at Rkm 245.1 and Rkm

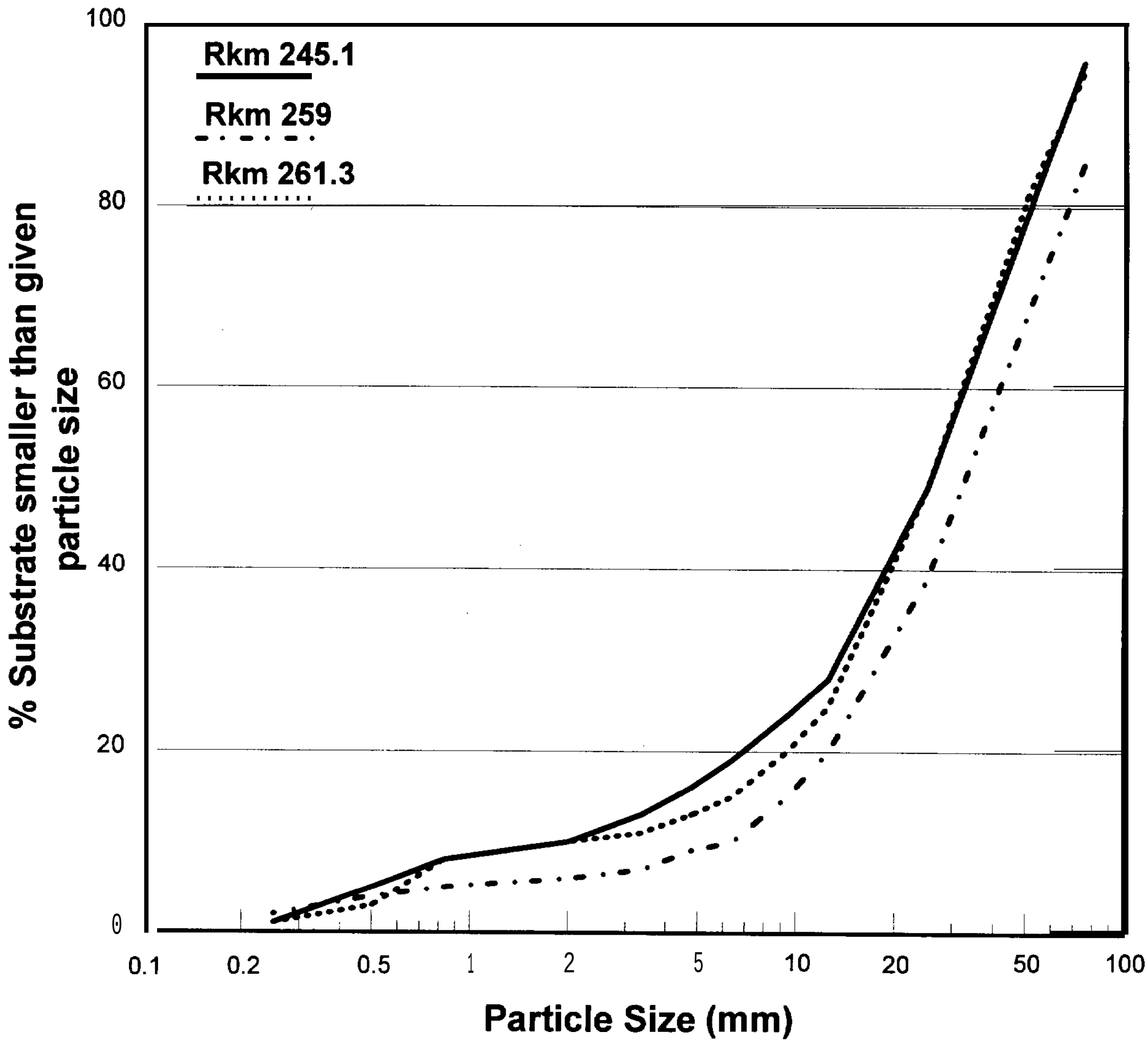

Figure 3. Mean particle size distribution (log 10) of substrate from fall chinook salmon spawning locations at river kilometers (Rkm) 245.1, 259, and 261.3 in the Snake River during 1994.

261.3. These locations contained the highest percentage of small (< 2.0 mm) particles, while Rkm 259 contained the highest percentage of large (> 9.35 mm) particles. Gravel sampled at Rkm 257.1 was > 15.24 cm and considered too large for spawning. Therefore, this location was omitted from our analyses. Mean percent fine substrate particles < 0.85 mm was highest at Rkm 245.1 (8.5%) and lowest at Rkm 259 (5.0%; Table 2). Fines < 6.4 mm showed a similar relationship with 18.8% at Rkm 245.1 and 10.5% at Rkm 259. The geometric mean and mean fredle index values were highest at Rkm 259 (dg=26.9 and fi=11.28) and lowest at Rkm 245.1 (dg=17.7 and fi=5.89).

Percent fines (< 0.85 mm) at Rkm 245.1 sampled in < 1.2 m of water were lowest in stratum 1 (10.7%) and gradually increased with depth (Table 3). We found a significant difference ($P <$ 0.05) in fines at Rkm 245.1 between stratum 1 and strata 2 and 3 whereas fines between strata 2 and 3 showed no significant difference. No significant difference in percent fines (< 0.85 mm) was found at Rkm 261.3 among strata. Geometric mean and mean fredle index decreased with depth at Rkm 245.1 and remained similar at Rkm 261.1.

Emergence Experiments

Analysis of substrate from the troughs after fry emergence indicated four discrete compositions could be used to evaluate incubation success (Table 1). Substrate compositions 3 and 4, and 5, 6, 7 and 8 were combined and identified as categories C and D, respectively, because there were no statistical differences ($P > 0.05$) in composition among the categories.

Ninety-eight percent of the fall chinook salmon in the Heath trays (controls) survived to the swim-up stage of development. An inverse relationship between percent fines (< 6.4 mm) and survival to emergence was obtained in the gravel-sand mixtures. The mean percent survival to emergence in test troughs with 2% fines (category A) < 6.4 mm was 78.5% (Table 4). Survival declined with increased fine sediment in the substrate. The model that best described the relationship between survival (y) to emergence of fall chinook salmon and the geometric mean substrate particle size was:

$$y = 0.0379x3 - 1.7541x2 + 27.128x - 78.393, R^2 = 0.6236.$$

Survival in substrates with geometric mean < 5 mm was zero, increased rapidly to a mean size of 10 mm, and remained similar at larger mean sizes (Figure 4). Mean length and weight of emerging, fall chinook salmon fry were not affected by the amount of sediment in the substrate (Table 4). No significant differences in mean weight ($P > 0.42$) and length ($P > 0.65$) were found among the four substrate compositions.

Table 2.-Mean quality indices of substrate sampled in > 1.2 m of water during 1994 at river kilometers (Rkm) 245.1, 259, and 261.3 in the Snake River.

Location	N	Percent fines < 0.85 mm	Percent fines < 6.4 mm	Geometric mean diameter (mm)	Fredle index
245.1	10	8.5	18.8	17.7	5.89
259.0	9	5.0	10.5	26.9	11.28
261.3	10	7.8	15.4	18.6	6.57

Table 3.-Mean quality indices of substrate sampled in < 1.2 m of water during 1994 at river kilometers (Rkm) 245.1 and 261.3 in the Snake River.

Site	N	Percent fines < 0.85 mm strata			Geometric mean diameter (mm) strata			Fredle index strata		
		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
245.1	4	10.7	16.0	17.1	15.0	10.9	8.3	4.13	1.58	1.18
261.3	3	10.7	9.7	7.1	12.6	13.7	17.2	4.01	3.19	3.94

Table $.-Mean survival to emergence, length, weight, and number of fall chinook salmon from four substrate compositions in experimental troughs during 1995.

Category	% Fines < 6.4 mm	N	Percent survival	Length (mm)	Weight (mg)
A	2	470	78.5	32.8	391
B	11	459	76.5	31.6	377
C	25	615	55.0	32.1	375
D	31	1002	41.5	31.2	359

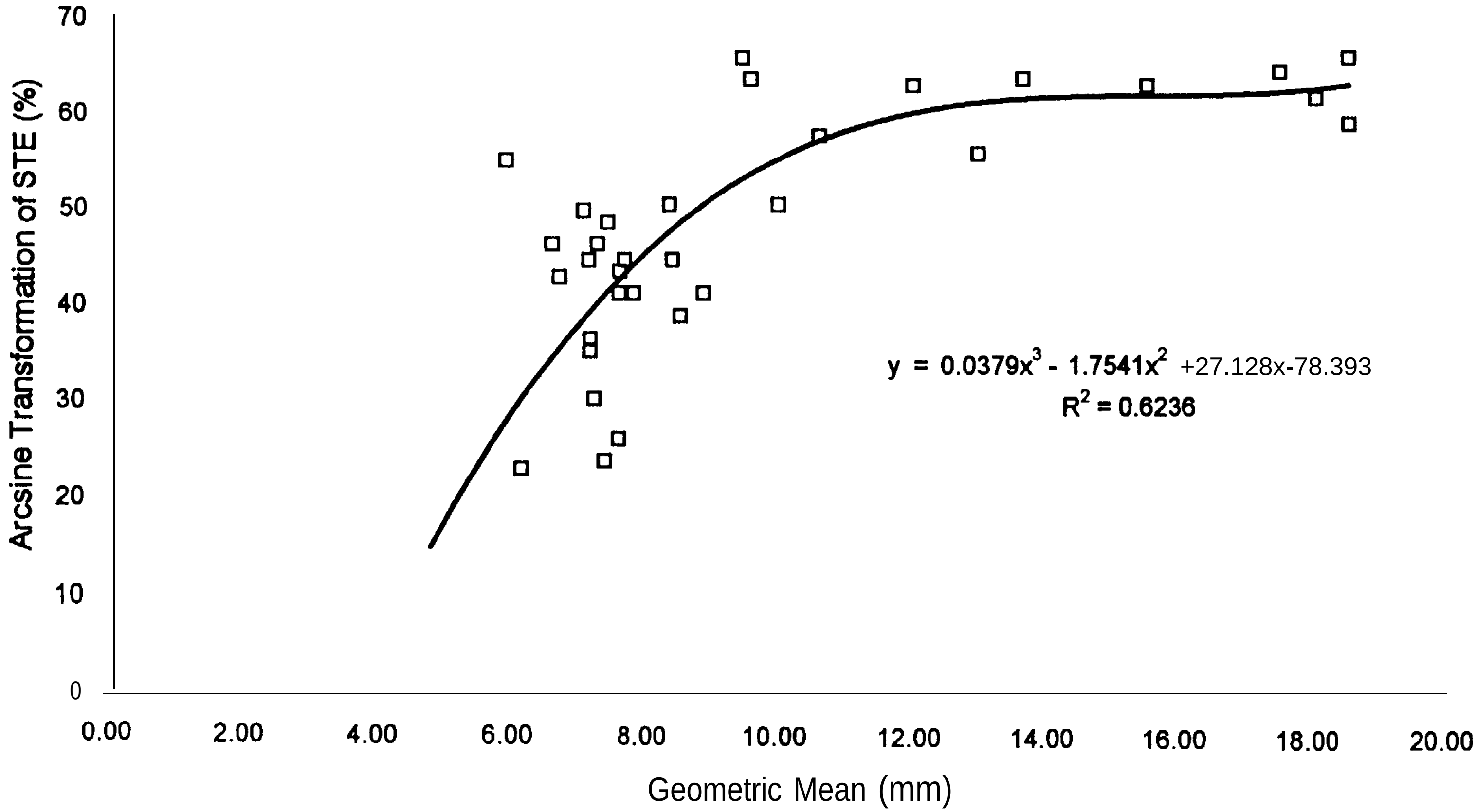

Figure **4.** Relationship **between survival to emergence (STE) of fall chinook salmon and the geometric mean** substrate **particle size in experimental troughs during 1995.**

Dissolved oxygen concentrations were > 9 mg/L (92% saturated) in all test troughs throughout the study and did not decrease as the amount of fine sediments increased. The average water temperature in the troughs was 11.2°C and ranged from 7.9 to 16.6°C. The average apparent velocity was 0.71 cm/s.

Discussion

Researchers have used various sized particles to qualify spawning gravel (Bjornn 1969; McCuddin 1977; Shirazi and Seim 1979; Tappel and Bjornn 1983). Young et al. (1991) found substrate particles < 0.85 mm could be used to detect changes more frequently than other measures of percent fines. Bjornn (1969) and McCuddin (1979), in experiments similar to ours, used substrate fines < 6.4 mm. We chose both of these measures (< 0.85 mm and < 6.4 mm) for comparison in our work.

Overall quality indices of spawning substrate from Rkm 245.1, Rkm 259, and Rkm 261.3 were generally high. The percent fines < 0.85 at Rkm 245.1 and Rkm 261.3 sampled by the freeze-core sampler (15.2 and 9.2%, respectively) compared well to those found at these locations (15.6 and 7.2%) by Arnsberg et al. (1992). Our strata profile showed a decrease in substrate quality indices with depth at Rkm 245.1 and uniform quality at Rkm 261.3. Arnsberg et al. (1992) found uniform quality of all three strata from Rkm 245.1. Site Rkm 259 was not freeze-core sampled because fast water current precluded obtaining a solid gravel core. Therefore, this location was sampled with a dome suction sampler, although most of the spawning gravel at Rkm 259 was in water > 1.2 m deep.

Incubation and emergence success from our experimental troughs were similar to those of others who found an inverse relationship between survival to emergence and fine sediments (Bjornn 1969; McCuddin 1977; Tappel and Bjornn 1983). Bjornn (1969) and McCuddin (1977) demonstrated that survival and emergence of chinook salmon and steelhead *O.* mykiss embryos were reduced when sediments < 6.4 mm in diameter made up 20 to 25% of the substrate composition. Our results also show a reduction in emergence when more than 25% of the composition is made up of fines.

Eyed eggs were placed into experimental troughs on December 23, 1994 and began emerging as sac fry on 4 January 1995. Alderdice et al. (1958) found that low oxygen concentrations during the latter stages of egg development may stimulate premature hatching. Dissolved oxygen concentrations in the troughs were never < 9.2 mg/L and concentrations in most of the troughs were 10.0 mg/L. The lowest apparent velocity of water in the troughs was 0.51 cm/s. Cooper (1965) found that sockeye *O. nerka* emergence did not show any deleterious effects until apparent velocities were 0.03 cm/s. Dissolved oxygen is not available to embryos at this low velocity, and metabolic wastes cannot be removed. Therefore, dissolved oxygen and removal of metabolic waste probably were not factors in early emergence for our experiments, while warm water temperatures were.

Laboratory results have often been compared to field conditions (Phillips et al. 1975; Shirazi and Seim 1979). Our emergence results and others (Bjornn 1969; McCuddin 1977) show fine sediments (< 6.4 mm) that comprise 20 to 25% of the substrate composition will have a deleterious effect on incubation success. Shirazi and Seim (1979) showed a strong relationship between survival to emergence and the geometric mean diameter of spawning gravel for coho salmon *O. kisutch*, sockeye salmon, cutthroat trout *O. clarki*, and steelhead trout. They predicted survival to emergence of 70 to 80% at a geometric mean > 15 mm. Results from our trough experiments concur with their prediction. Tappel and Bjornn (1983) reported the relationship between fredle index number and embryo survival was about 90% when the fredle index was > 5; embryo survival decreased when the fredle index was < 5. Our indices for the quality of spawning gravel using both 0.85 and 6.4 mm and results from our trough experiments indicate incubation and emergence success of fall chinook should generally exceed 75% at study locations Rkm 254.1, 259, and 261.3 in the Snake River

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CHAPTER FOUR

Rearing and Emigration of Naturally Produced
Juvenile Snake River Fall Chinook Salmon

by

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Introduction

Our understanding of Snake River fall chinook salmon *Oncorhynchus tshawytscha* rearing and emigration has steadily increased over the past four years. When Snake River fall chinook salmon were listed as a threatened species under the Endangered Species Act (ESA; National Marine Fisheries Service 1992), much of the contemporary information on these subyearling emigrants was based on our 1991 and 1992 research (Connor et al. 1993, 1994a, 1994b). The purpose of our study is to increase the information on naturally produced Snake River fall chinook salmon juveniles for ESA recovery efforts. Our objective in this 1994 annual report is to describe subyearling chinook salmon rearing and emigration on the Snake and Clearwater rivers.

Study Area

The study area in 1994 included the Snake and Clearwater rivers (Figure 1). Data were collected on the Snake River from Rkm 225 to Rkm 290, and on the Clearwater River from Rkm 14 to Rkm 64.

Methods

Data Collection

Systematic samples. - There were originally 19 Snake River systematic sites, however, low redd counts made it impractical to sample sites above Rkm 290 on a regular basis. The 15 systematic sites below Rkm 290 were beach seined from 6 April until 13 July. There were a total of 8 systematic sites on the Clearwater River which were sampled from 5 April to 6 July. Each site was visited about once a week and normally seined three times in an upriver direction; each consecutive set started where the previous one ended. The beach seine had a weighted multistranded mudline, 0.48 cm mesh and was 30.5 m x 1.8 m with a 3.9 m^3 bag. Each end of the seine was fitted with a bottom weighted brail, equal in length to net depth, and attached to 15.2 m lead ropes. The seine was set parallel to shore from the stern platform of a 6.7 m jet boat. The net was then hauled straight into shore by both lead ropes. The net sampled approximately 465 m^2 to a depth of 1.8 m.

Supplemental samples.-Seine hauls made at locations other than the 15 and 8 systematic sampling sites in the Snake and Clearwater rivers were classified as supplemental. Supplemental samples functioned to increase the number of tagged chinook salmon for emigration analyses. There were a total of about 45 supplemental

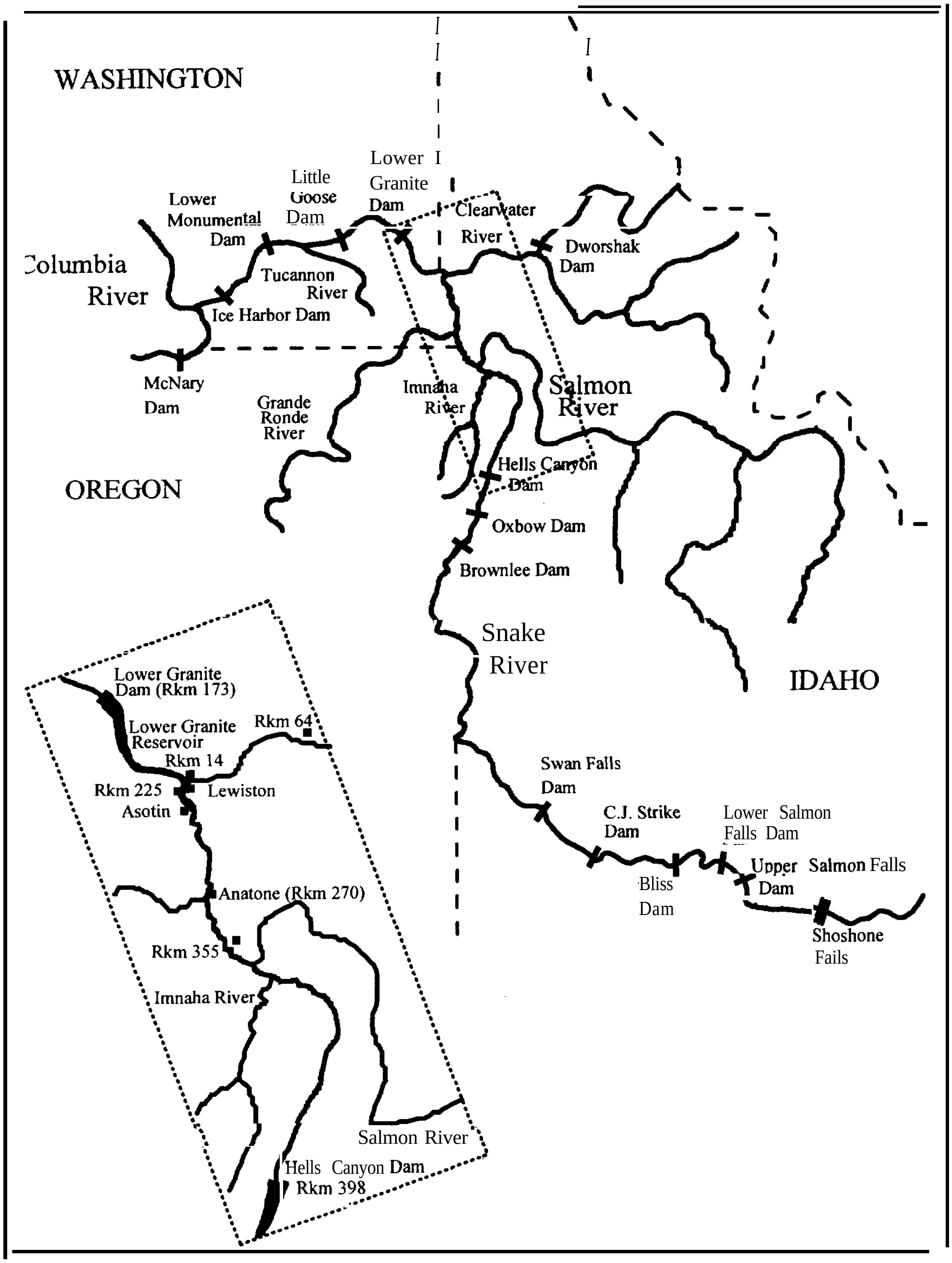

Figure 1. Map of the Snake River drainage with an insert to show the 1994 Snake River seining area boundaries of Rkm 225 and Rkm 290 and Clearwater River boundaries of Rkm 14 and Rkm 64.

sites including about 24 in the Snake River and 21 in the Clearwater River. Supplemental sites were selected based upon habitat features that were similar to our systematic seining sites. These sites are characterized by low velocity and sloping shore with minimal obstructions for landing a beach seine. Supplemental sampling effort was highest about one week before, during, and one week after the systematic catch peaked.

Anesthetic.-once seined, chinook salmon were transferred to a 94.6 L oxygenated live-well supplied with water at river temperature, 100 g of NaCl, and 12.5 mL of Polyaqua. All chinook salmon were anesthetized in a dilute tricane methane sulfonate (MS-2223 solution of 2-5 mL of concentrated MS-222 to 18.9 L of water, which was buffered with 0.5 gm of $NaHCO_3$. The concentrate was prepared by mixing 100 gm of powdered MS-222 in a 100 mL of water. The MS-222 concentrate was kept refrigerated and was stored in a dark plastic bottle. Chinook salmon were anesthetized in groups of 6-10 fish.

In-season age identification.-Fork length (FL) of anesthetized chinook salmon was measured to the nearest millimeter. We calculated a size limit to separate the smaller subyearling chinook salmon juveniles "in-season" from larger yearling chinook salmon. The size limit was calculated based on water temperature, projected fry emergence dates, and projected growth rate. Water temperature data for the Snake River size limit were collected at Chalk Creek (Rkm 303) and Billy Creek (Rkm 265) and for the Clearwater River at Cherry Lane Bridge (Rkm 34). These temperature data were used to project the beginning of fry emergence at 895 Celsius temperature units after the first redds were counted in 1993. For the size limit calculation, emergent fry were estimated to be 38 mm FL (Arnsberg et al. 1992), and estimated to have a growth rate of 1.0 mm/d. Snake River fall chinook salmon fry emergence timing had to be projected separately for chinook salmon juveniles collected above and below the Salmon River confluence because of differences in water temperature. We calculated the upper fall chinook salmon size limit in Table 1 using water temperatures from Rkm 303. The lower fall chinook salmon size limit in Table 1 was calculated using a 60 mm minimum tagging size and water temperatures from Rkm 265. The upper and lower size limits on the Clearwater River (Table 2) were calculated using the technique described above and water temperature data from Rkm 34.

PIT tagging.-Chinook salmon were Passive Integrated Transponder (PIT) tagged (Prentice et al. 1990a) if they fit within the size limits of Tables 1 or 2, or had the sharper body features and smaller eyes we noted in fall chinook salmon during 1991. The minimum size limit for PIT tagging chinook salmon was 60 mm FL based on laboratory data by colleagues (McCann et al. 1993). A

Table 1.-Upper and lower size limits (fork length in mm) calculated for in-season age identification of chinook salmon seined in the Snake River, 1994.

Limit	Estimated fall chinook salmon size by date							
	26-Apr	03-May	10-May	17-May	24-May	31-May	07-Jun	14-Jun
Upper	64	71	78	85	92	99	106	113
Lower	60	60	60	60	60	60	60	60

Table 2.-Upper and lower size limits (fork length in mm) calculated for in-season age identification of chinook salmon seined in the Clearwater River, 1994.

Limit	Estimated fall chinook salmon size by date						
	31-May	07-Jun	14-Jun	21-Jun	28-Jun	05-Jul	12-Jul
Upper	63	70	77	84	91	98	105
Lower	60	60	60	60	60	60	60

70% ethyl alcohol treatment was used to disinfect the tags. The disinfected tags were blotted dry prior to insertion into the fish. Chinook salmon juveniles were immobilized by placing them in a cool, wet, notched foam pad. Tags were manually implanted with a 12 gauge needle affixed to a syringe. After tagging, we transferred the fish to an oxygenated 18.9 L recovery bucket filled with saline water (20 gm NaCl) and 12.5 mL of polyaqua. The salmon were held in the recovery bucket for 15 min prior to release after tagging.

PIT-tag data.-The data collected from the PIT-tagged chinook salmon juveniles were recorded in computer files (PIT Tag Work Group 1994). These tagging files were uploaded to the PIT Tag Information System (PITAGIS). Emigrating chinook salmon juveniles that bypass Lower Granite Dam turbines via the submersible traveling screen were monitored for PIT tags (Prentice et al. 1990b). Both PIT-tagging and PIT-tag detection data are available to interested parties through PITAGIS.

Electrophoresis.-A subsample of the PIT-tagged chinook salmon detected at Lower Granite Dam were diverted by a hydraulic slide gate. Diverted chinook salmon were scanned for tag codes and measured by Smolt Monitoring Program personnel. When our tag codes were detected in chinook salmon a scale sample was taken for aging (Jerald 1983) and the fish was labeled and frozen. The Washington Department of Fisheries (WDF) estimated the race of the frozen chinook salmon using tissue extracts and horizontal starch-gel electrophoresis (Abbersold et al. 1987) and Maximum Liklihood Estimation (MLE; Anne Marshall, WDF, unpublished protocol).

Data Analysis

Subyearling collection and tagging.- Data from the systematic and supplemental samples were combined (combined sample), separately for the Snake and Clearwater rivers, to describe subyearling chinook salmon catch by date. The number of subyearling chinook salmon we PIT-tagged during combined samples was also presented by date for each river. We tested for differences in average FL at tagging between Snake River and Clearwater River chinook salmon using an independent two-sample t-test ($P = 0.05$; Zar 1984, Systat 1990). Differences in Snake and Clearwater river temperatures measured at the time fish were released after tagging were also tested using a t-test at the 95% level of significance.

Subyearling emigration and race.-Data from all PIT-tagged subyearling chinook salmon that were detected and collected at Lower Granite Dam were tabulated. Electrophoresis separated the sample of juvenile chinook salmon diverted at Lower Granite Dam into MLE-estimated fall chinook salmon and MLE-estimated spring/summer chinook salmon. Subyearling chinook salmon which were detected, but not diverted, are considered mixed race in origin. We tested for differences in average fork length at tagging between the MLE-estimated races using a t-test (P = 0.05; Zar 1984, Systat 1990). There were too few PIT-tagged subyearlings detected from the Clearwater River releases for a meaningful analysis.

Yearling emigration.-Each summer a portion of the subyearling chinook salmon we PIT tag in the Snake and Clearwater rivers residualize in the Snake or Columbia river reservoirs rather than emigrating to the Columbia River estuary. Some of these residuals, survive over the summer and winter, to emigrate as yearlings the following spring. Data from the above residuals, which were detected as yearlings emigrants, were tabulated for 1991-1994 and graphed for 1994.

Results

Subyearling Collection and Tagging

We beach seined 4,831 and 1,023 subyearling chinook salmon juveniles in the Snake and Clearwater rivers, respectively (Table 3; Figure 2). The catch in the Snake River began on 6 April and ended on 13 July with a median date of collection of 31 May. The catch in the Clearwater River began on 5 April and ended on 6 July with a median date of 21 June. The fork length at capture of Snake River subyearling chinook salmon was significantly smaller than the fork length of Clearwater River subyearling chinook salmon ($P \leq 0.000$). The water temperature at the time of capture and release was significantly warmer in the Clearwater River than in the Snake River ($P \leq 0.000$). Subyearling chinook salmon were captured earlier in the Snake River than in the Clearwater River (Figure 2).

Totals of 2,345 and 692 subyearling chinook salmon were PIT tagged in the Snake and Clearwater rivers (Table 3; Figure 3). PIT tagging in the Snake River began on 6 April and ended on 22 June with a median date of collection of 2 June. PIT tagging in the Clearwater River began on 5 April and ended on 6 July with a median date of 21 June. Mean fork length of fish tagged in the Snake River was 2 mm longer than the mean fork length of fish tagged in the Clearwater River ($P < 0.001$). The water temperature at the time of tagging was 0.2°C warmer in the Snake River than in the Clearwater River ($P = 0.023$). Subyearling chinook salmon were tagged earlier in the Snake River than in the Clearwater River (Figure 3).

Table 3.-Capture and PIT-tagging statistics for subyearling chinook salmon in the Snake and Clearwater rivers, 1994. Differences in fork lengths and water temperatures between rivers were tested using a t-test at the 95% level of significance and are indicated by an asterisk.

River	Capture statistics			Tagging statistics		
	Number	Mean FL (mm; ± SD)	Mean water (°C ± SD)	Number	Mean FL (mm; ± SD)	Mean water (°C ± SD)
Snake River	4,831	65±16	14.9±2	2,345	74±12	15.5±2
		*	*		*	*
Clearwater River	1,023	67±11	15.4±3	692	72±8	15.7±3

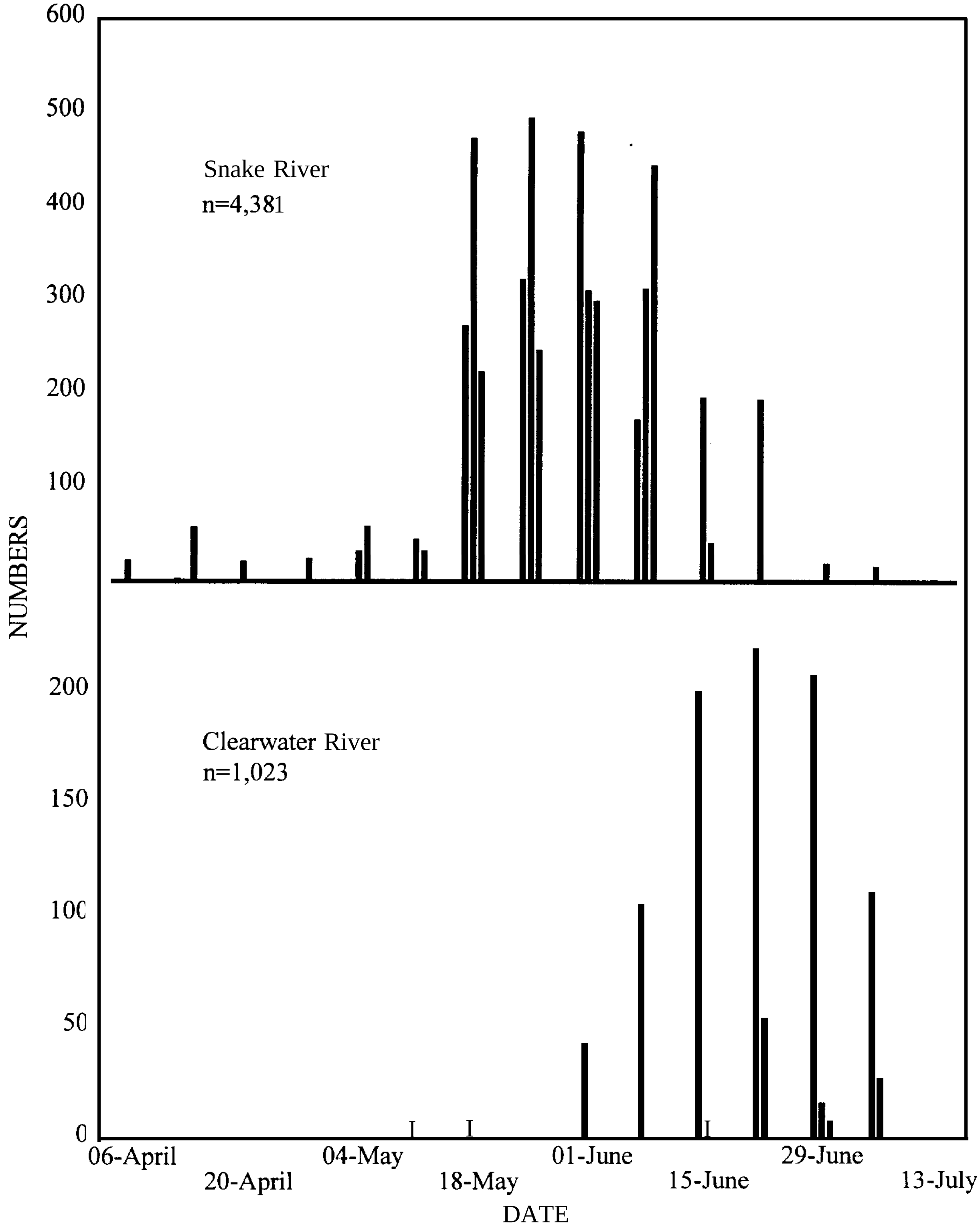

Figure 2.–Numbers of subyearling chinook salmon beach seined by date in the Snake and Clearwater rivers, 1994.

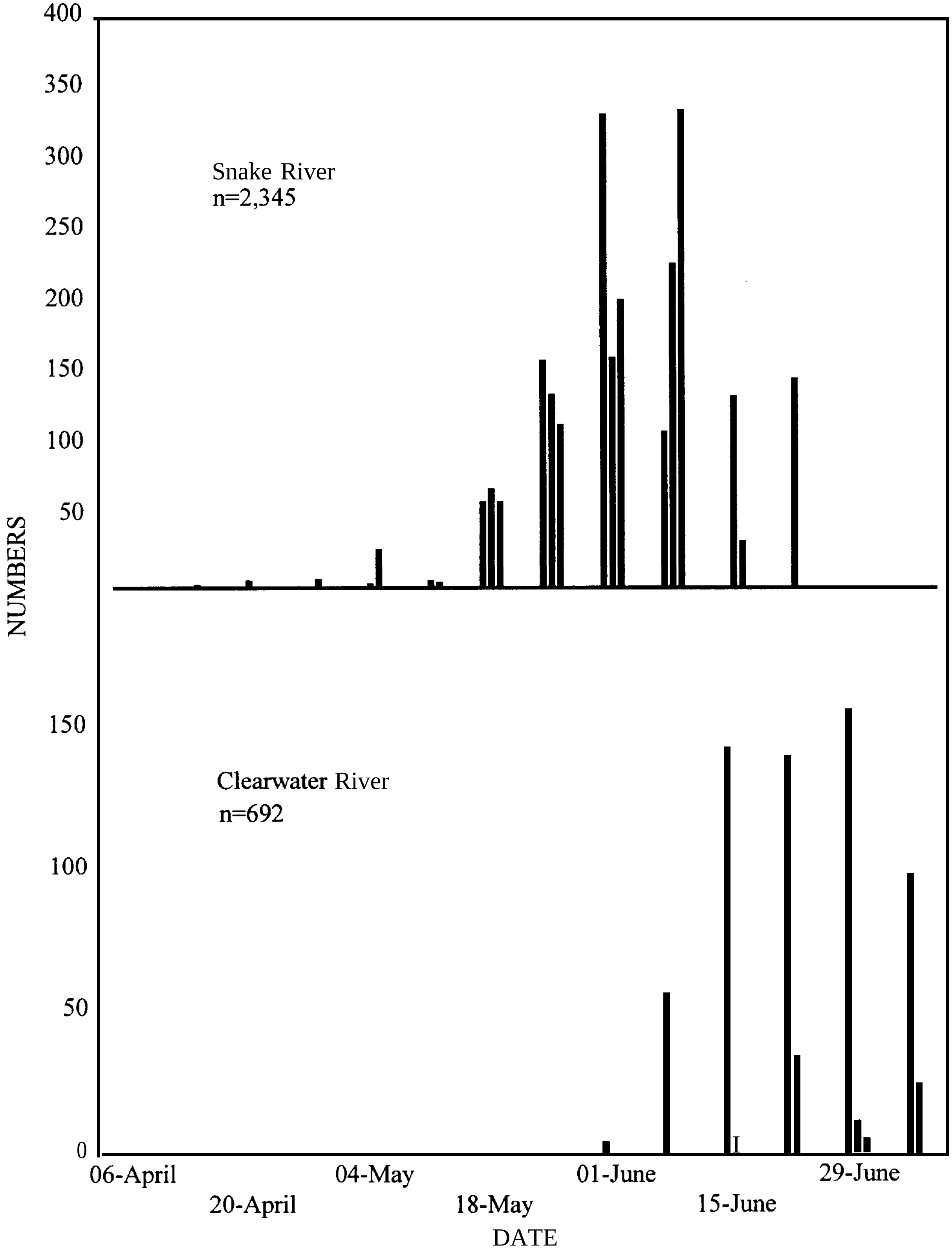

Figure 3.- Numbers of subyearling chinook salmon PIT tagged by date in the Snake and Clearwater rivers, 1994.

Subyearling Emigration and Race

Totals of 193 and 1 of the subyearling chinook salmon juveniles we PIT tagged in the Snake and Clearwater rivers were detected at Lower Granite Dam as subyearling emigrants (Table 4; Figure 4). Detections of PIT-tagged subyearling chinook salmon from the Snake River began on 23 May and ended on 1 November with a median date of detection of 17 July. The pattern of detection for Snake River fish was bimodal with peaks on 7 July and 9 August. The Clearwater River fish was detected on 14 August, 1994.

Totals of 115 and 1 of the Snake and Clearwater river fish were diverted by the sliding gate and collected at Lower Granite Dam. Electrophoresis and MLE estimated that 92 (80%) of the 115 fish from the Snake River sample were fall chinook salmon and the remaining 23 (20%) were spring/summer chinook salmon (Table 4). There was no significant difference between the tagging dates of estimated fall and spring/summer chinook salmon. Conversely, mean fork length of MLE estimated fall chinook salmon was significantly smaller (11 mm difference; $P \leq 0.000$) at tagging than mean fork length of spring/summer chinook salmon. The subyearling chinook salmon from the Clearwater River was a fall chinook salmon.

The 92 MLE-estimated fall chinook salmon from the Snake River took from 16.4 to 115.7 d to be detected at Lower Granite Dam after they were last seined (average = 42.6 ± 19.7 d; Table 5). They were detected at Lower Granite Dam between 24 June and 24 September (Figure 5). The median and peak detection date of MLE-estimated fall chinook salmon at Lower Granite Dam was 11 July. PIT-tagged fall chinook salmon emigrated to Lower Granite Dam at an average rate of 2.0 km/d (SD = ± 0.8 km/d; range = 0.6-4.5 km/d; Table 5).

Residualism and Yearling Emigration

A total of 83 (3.5%) subyearling chinook salmon PIT tagged in the Snake River were detected as yearlings (Table 6). Detection numbers and percentages of Snake River fish increased in a downriver direction with roughly half occurring at McNary Dam. Twenty-two (3.2%) subyearling chinook salmon tagged in the Clearwater were detected as yearlings. Detection numbers and percentages of Clearwater River fish decreased in a downriver direction with most detections occurring at Lower Granite Dam. The median dates of detection by dam for Snake River fish were similar, ranging from 12 April to 16 April (Figure 6). Conversely, the median dates of detection by dam for Clearwater River fish progressed from 12 April at Lower Granite to 25 April at McNary (Figure 6).

Table 4.-Statistics on subyearling chinook salmon juveniles that were PIT tagged in the Snake and Clearwater rivers prior to diversion at Lower Granite Dam for measurement', aging, and electrophoresis, 1994. Data for each individual chinook salmon can be found in Appendix 1. Differences in fork lengths at release were tested using a t-test at the 95% level of significance. Differences in release date were tested using a KS test at the 95% level of significance. Significant differences are indicated by an asterisk

River	Race	N	Percent of sample	Release date min	Release date median	Release date max	Mean FL at release (mm; ± SD)
Snake	Fall	92	80.0	17-May	26-May	22-Jun	78±10 *
	Spring	23	20.0	5 -May	1-Jun	15-Jun	89±11
	Mixed	78	-----	------	------	------	-----
Clearwater	Fall	1	-----	------	------	------	-----

Table 5.-Emigration statistics for MLE estimated fall chinook salmon PIT tagged in the Snake River and collected after detection at Lower Granite Dam, 1994.

Days at large			Detection dates			Emigration rate (km/d)		
min	mean±SD	max	min	median	max	min	mean±SD	max
16.4	42.6±19.6	115.7	24-Jun	11-July	24-Sep	0.6	2.0±0.8	4.5

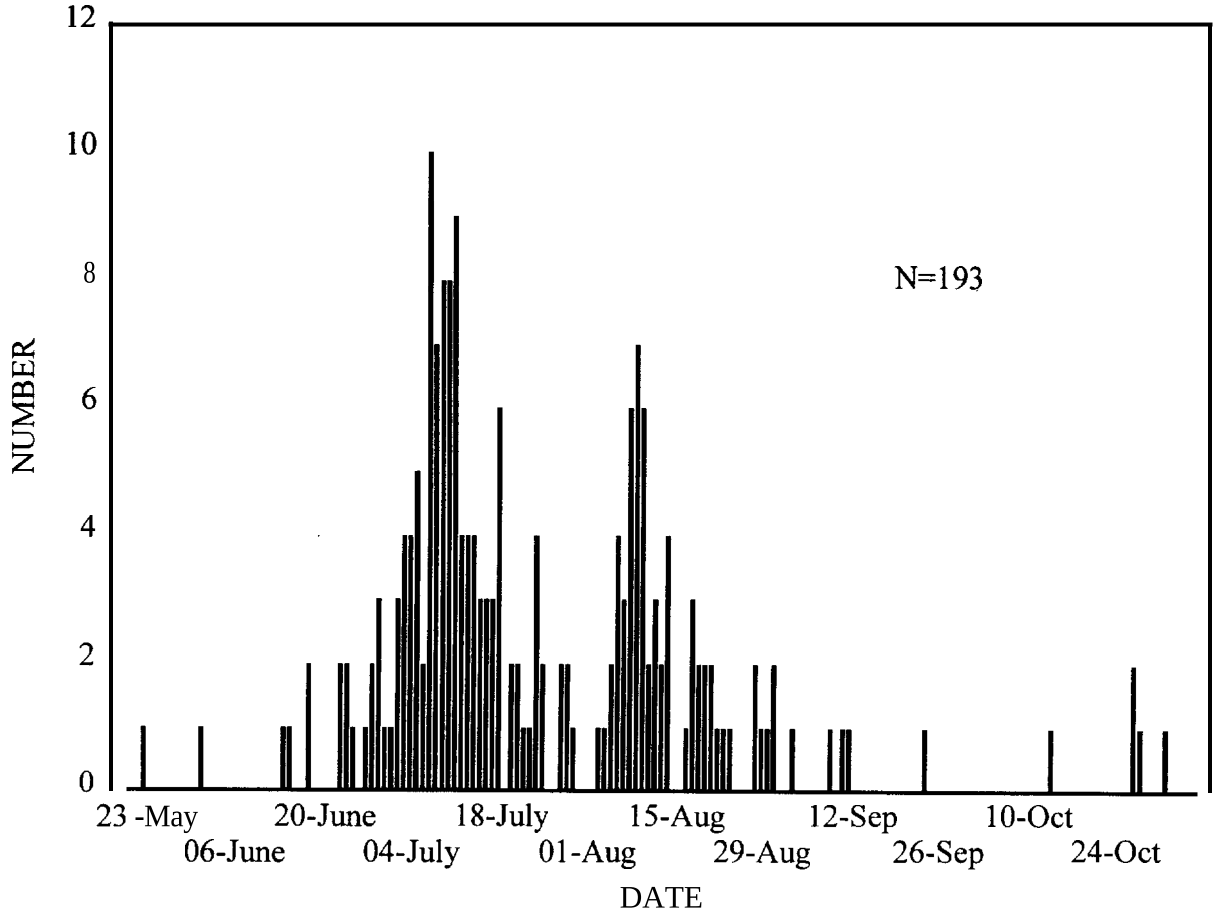

Figure 4.-Detection dates at Lower Granite Dam for PIT-tagged subyearling chinook salmon from the Snake River, 1994.

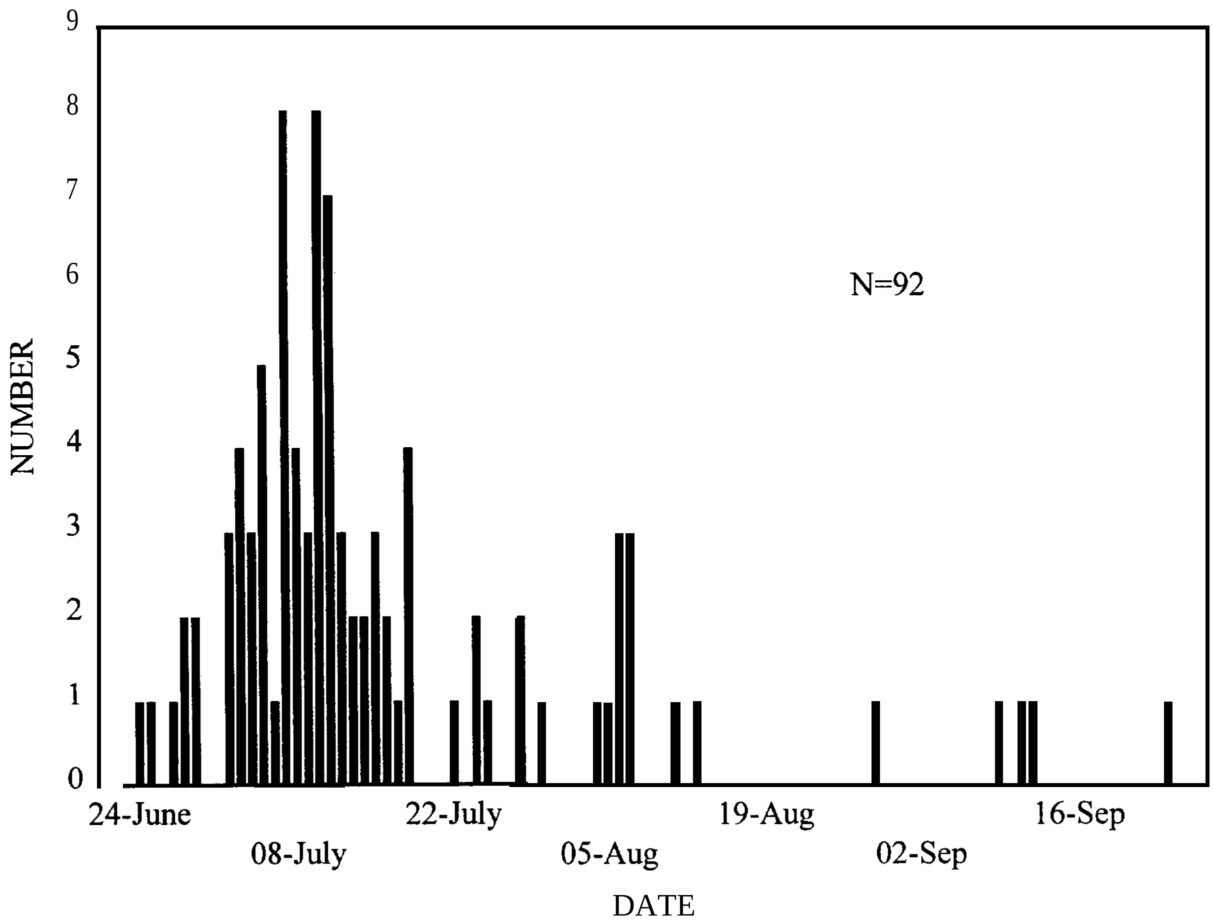

Figure 5.-Detection dates at Lower Granite Dam for PIT-tagged MLE-estimated fall chinook salmon from the Snake River, 1994.

Table 6.-First detections by dam of chinook salmon juveniles PIT tagged in the Snake and Clearwater rivers as subyearlings, but which emigrated as yearlings, 1994. Data from each PIT-tagged chinook salmon can be found in Appendix 2.

	First detection by dam				
River	Lower Granite N (%)	Little Goose N (%)	Lower Monumental N (%)	McNary N (%)	Total N (%)
Snake	7 (0.3)	12 (0.5)	24 (1.0)	40 (1.7)	83 (3.5)
Clearwater	8 (1.2)	5 (0.7)	4 (0.6)	5 (0.7)	22 (3.2)

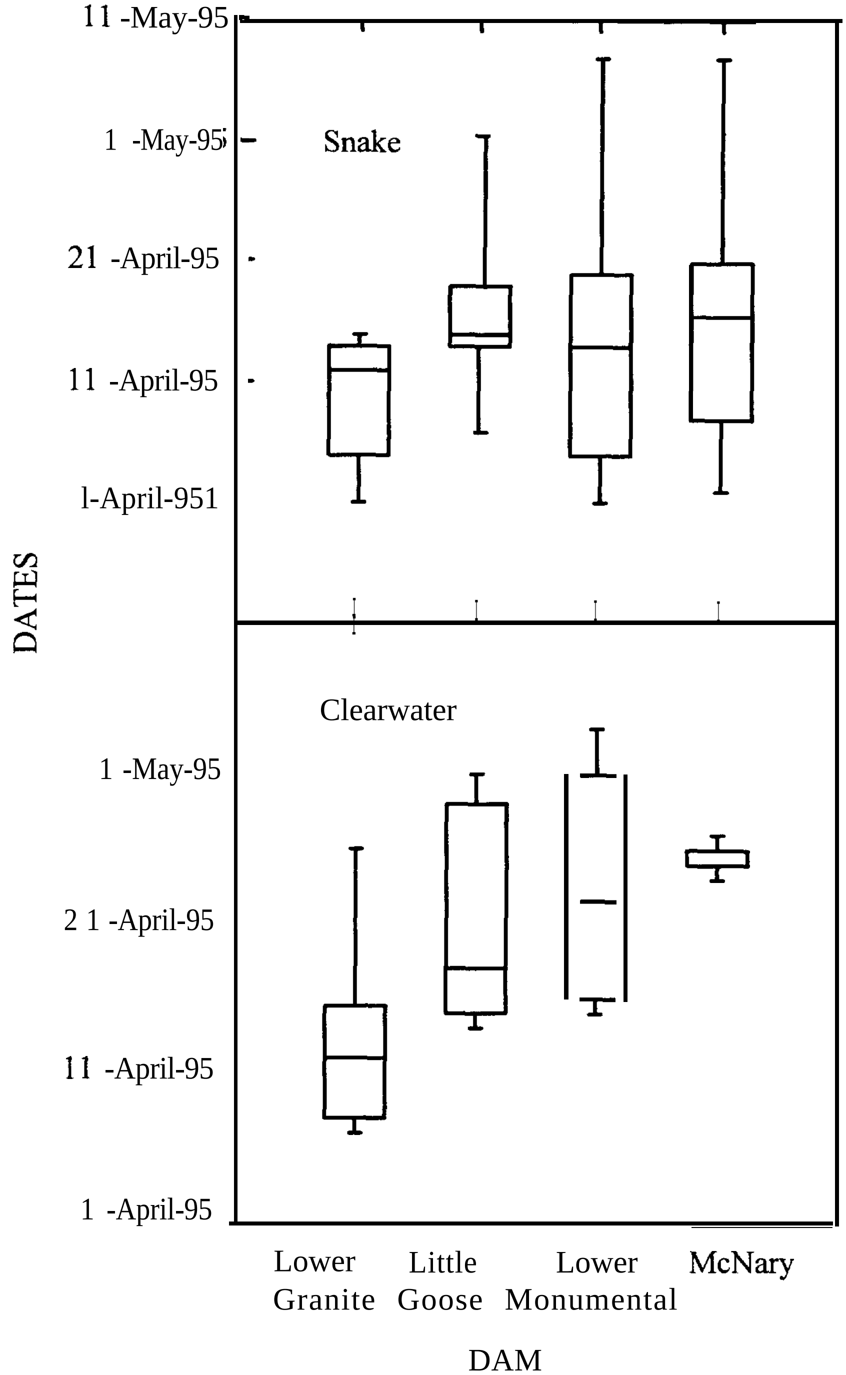

Figure 6.-Detection dates of yearling chinook salmon tagged as subyearlings in the Snake and Clear-water rivers, 1994. The horizontal line in each box is the median, the top and bottom of each box are the 25th and 75th percentiles, and the vertical lines extending from the top and bottom of each box represents the range of dates.

Discussion

Mixed-race and MLE-estimated fall chinook salmon were seined and PIT-tagged in the Snake River in April through June of 1994 similar to 1991-1993 (Connor et al. 1993, 1994a, 1994b). Likewise, emigration timing of tagged fish was consistent with past years occurring mainly during the summer months. In 1994, the detection pattern at Lower Granite Dam was more protracted than in 1992, a similar low-flow year. The 95th percentile of tagged fish was detected the first week of September and the overall detection rate was 8.2%. The detection pattern may have been due to more favorable flow conditions in 1994.

The 1994 detection pattern of both mixed-race and MLE-estimated-fall chinook salmon was bi-modal. The first peak occurred during flow augmentation from Dworshak Reservoir. The second peak occurred 9 d after stopping summer flow augmentation on 31 July. The second peak in detections at Lower Granite Dam may have been the result of tagging subyearling-fall chinook salmon originating from the Grande Ronde River. The fall chinook salmon life cycle in the Grande Ronde lags behind that of the Snake River, because of colder water temperatures and a later emigration pattern (USFWS and ODFW, unpublished data).

We documented three differences between the mixed-race-subyearling chinook salmon samples of the Snake and Clearwater rivers in 1994. First, the pattern of capture of mixed-race-subyearling chinook salmon in the Snake River was three weeks ahead of the Clearwater River pattern. The above difference is due in part to the timing of supplemental sampling, but mostly to differences in life stage timing between the rivers. Second, Snake River chinook salmon averaged 2 mm longer at tagging than their Clearwater River counterparts. Third, the Snake River averaged 0.2°C cooler than the Clearwater River during tagging. The most biologically significant difference between the two rivers is the delayed life cycle of fall chinook salmon in the Clearwater River, which stems from cooler water temperatures during spawning (Arnsberg et al. 1992) and summer releases from Dworshak Reservoir.

Residualized yearlings from the Snake and Clearwater rivers were predominately April emigrants. Most residualized PIT-tagged Snake River fish were detected at Lower Monumental Dam followed by Lower Granite Dam, with little difference in the median dates of detection, indicating that fish were dispersed widely. In contrast, most yearling residuals from the Clearwater River were detected as yearlings at Lower Granite Dam followed by progressively decreasing detection percentages at downstream dams. Median dates of detection were spread out and were later at each downstream dam indicating that fish were not widely dispersed. Since the race of residualized yearling emigrants is unknown, the implication of residualism on survival and adult contribution remains poorly understood.

In summary, we seined 4,831 and 1,023 subyearling chinook salmon in the Snake and Clearwater rivers in 1994. We PIT tagged and released 2,345 and 692 of the above fish in each respective river. Eighty percent of the subyearlings tagged in the Snake River and collected at Lower Granite Dam were fall chinook salmon based on electrophoresis. We tagged fall chinook salmon in the Snake River from 17 May through 22 June with a median date of 26 May. Mean emigration rate from release sites in the Snake River to Lower Granite Dam was 2.0 km/d with peak and median dates of passage on 11 July. Only one subyearling emigrant was detected at Lower Granite Dam from Clearwater River releases. Of the subyearlings PIT tagged in the Snake and Clearwater rivers in 1994, 3.5% and 3.2% were detected as yearlings in 1995. It is important to realize that the low population level of Snake River fall chinook salmon dictated small sample sizes for analyses.

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CHAPTER FIVE

Nearshore Habitat Use by Subyearling Chinook Salmon and Non-Native Piscivores in the Columbia River

by

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Introduction

Little published information exists on habitat requirements for subyearling fall chinook salmon *Oncorhynchus tshawytscha* rearing in the Columbia and Snake rivers. The goal of this study is to identify and describe the characteristics of rearing habitats used by naturally produced subyearling chinook salmon in riverine reaches and in mainstem reservoirs. Such information is necessary to protect important rearing habitats from proposed actions to modify reservoir and riverine habitats by dredging, filling, bank stabilization, flow management, and water diversion. The results described in this report are preliminary findings from data collected in 1994 and 1995.

Study Area

The 1994 and 1995 study area included two reaches in the Columbia River from river kilometer (Rkm) 505 to Rkm 538 in McNary Reservoir and from Rkm 563 to Rkm 596 in the Hanford Reach (Figure 1). River kilometer information was obtained from the National Oceanic and Atmospheric Administration maps for McNary Reservoir and from the United States Geological Survey 7.5 minute topographic maps for the Hanford Reach.

Methods

Reaches were sampled once in 1994 between 16 May and 27 May and twice in 1995 from 24 April to 4 May and from 22 May to 1 June. All samples were collected during daylight hours when subyearling chinook salmon are believed to be active in nearshore areas (Key et al. 1994).

Point Abundance Sampling

Point abundance sampling (Persat and Copp 1990) was used to collect fish in shoreline habitats. Reaches were sampled with a 5.5 m Smith-Root electrofishing boat set to fish at 2 amps,.60 pulses per second DC, and using a 1.02 m umbrella anode array. The boat was driven directly towards the shoreline until the arrays were about 4-5 m from the shoreline or when the water became too shallow for the boat to progress further. At this point, the electricity was turned on and the outboard motor reversed to stop forward motion. This allowed a small area to be shocked with minimal forewarning to fish. Shock duration for most samples was 8 s. Immediately following each point shock, a buoy was set to mark the location for habitat measures, even if no fish were seen. Two additional points were shocked directly upstream from the first point at each site.

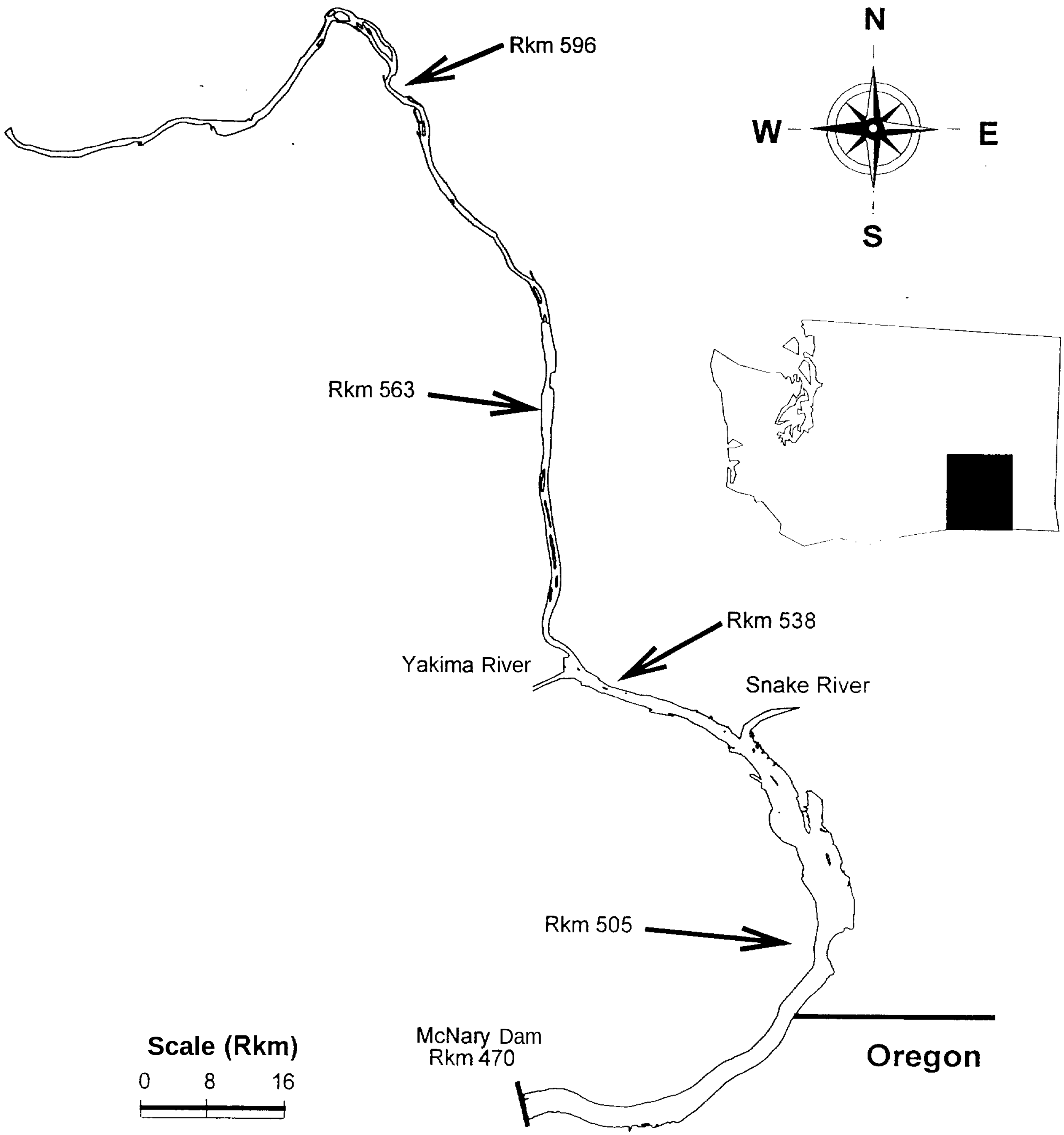

Figure 1.-Map showing the location of McNary Reservoir and Hanford Reach habitat sampling reaches. The McNary Reservoir reach extends from Rkm 505 upstream to Rkm 538 and the Hanford Reach from Rkm 563 to Rkm 596.

Site Selection

Point abundance sampling requires a random selection of sites. A simple random design would have resulted in not sampling some of the rare shoreline habitats. Logistically, a stratified random sampling design would not have been possible within time and personnel constraints. Because habitat variables such as depth, velocity, substrate, and vegetation are dependent on the river elevation, which is dependent on discharge fluctuations at Priest Rapids Dam and McNary Dam, habitat mapping and stratification would have been multi-dimensional.

A method of site selection was used that included some of the more uncommon habitat combinations, avoided unnecessary duplication, and minimized sample bias. Three matrices were constructed to create different habitat combinations to guide sampling efforts, and included 1) velocity x depth, 2) velocity x substrate, and 3)depth x substrate. Sites were selected and sampled to collect information for each matrix cell. Effort was expended to sample the habitat combination in each cell at least once, with three or more samples being preferred. Sampling in a reach was completed when no new sites could be found to fill empty or partially filled cells in the three matrices.

Catch

All electroshocked fish were collected with dipnets, except for large fish, which could have potentially injured subyearling chinook salmon in the nets. Fish which could not be netted were visually identified to species when possible, counted, and recorded as "seen". When large schools of fish were shocked, species were recorded and numbers were estimated.

Catches from each of the three point samples at a given site were held in separate buckets for processing immediately following the last of the three shocks. Collected fish were anesthetized with 26 mg/L of tricaine methanesulfonate (MS-222), measured to the nearest 1 mm fork length, weighed to the nearest 0.1 g, and released when recovered from the anesthetic. The total observed number of a given species was computed by adding together the catch, number "seen", and estimated school size. Non-native potential piscivore numbers were computed by totaling the observed catch of introduced fish species which had the potential of consuming subyearling chinook salmon. These predators included smallmouth bass *Micropterus dolomieui*, largemouth bass *Micropterus salmoides*, walleye *Stizostedion vitreum*, yellow perch *Perca flavescens*, and crappie *Pomoxis* spp., which are all documented piscivores in the Columbia River (Wydoski and Whitney 1979, Poe et al. 1994).

Habitat

Habitat

Various habitat measures were made at each point abundance sample site. Water temperature was measured to the nearest 0.1°C at 1 m, at the point of shock, and 15 m from shore. Water velocity was measured at the point of shock and at 15 m from the shoreline using a current meter. Depth of water was measured concurrently with velocity. Distance of the point of shock from the shore was measured to. the nearest 1 cm. At the point of shock, substrate was visually assessed and assigned a code according to a Wentworth classification modified from Orth (1983; Table 1). Descriptions for visually evaluating substrate embeddedness were obtained from Platts et al. (1983). Presence of inundated vegetation, aquatic macrophytes, and presence of overhanging cover was recorded. Light and turbidity were measured once for each set of three point abundance samples since the samples were generally all collected within a five minute time period. Light was measured to the nearest millilumen above the water surface and 0.5 m below the water surface using a light meter. Turbidity of water collected 15 cm below the surface was measured in Nephelometric Turbidity Units (NTU).

Analysis

The number of point samples, subyearling chinook salmon, and piscivores collected was totaled for each reach. The total number of a given species was computed by adding together the catch, "seen", and estimated school size. The total number of subyearling chinook salmon and piscivores over different substrates, gradients, and velocities, along with the level of effort expended in each habitat, were compared graphically.

Results

A total of 278 points were sampled in McNary Reservoir resulting in counts of 1,541 subyearling chinook salmon, 105 piscivores, and 284 other fish. A total of 294 points were sampled in the Hanford Reach resulting in counts of 6,613 subyearling chinook salmon, 22 piscivores, and 495 other fish. Average fork length of juvenile salmon was 47 mm (SD=8 mm) in McNary Reservoir and 46 mm (SD=6 mm) in the Hanford Reach. Incidental fish caught in McNary Reservoir and the Hanford Reach are reported in Appendix 6.

Subyearling chinook salmon were most abundant at sites wit coarse gravel substrates and piscivores were most abundant at sites with boulder substrates. In McNary Reservoir, effort was highest over boulders (code 9) and lowest over coarse gravel (code 5; Figure 2). Highest mean number of subyearling chinook salmon occurred over coarse gravel (code 5) and was lowest over

Table 1.-Substrate codes, particle size intervals, and descriptions used to classify dominant substrate.

Code	Particle Size (mm)	Description
1	<0.0039-1.0	Fines to coarse sand
2	>1-2	Very coarse sand
3	>2-4	Fine gravel
4	>4-8	Medium gravel
5	>8-16	Coarse gravel
6	>16-32	Small pebble
7	>32-64	Large pebble
8	>64-256	Cobble or rubble
9	>256	Boulder

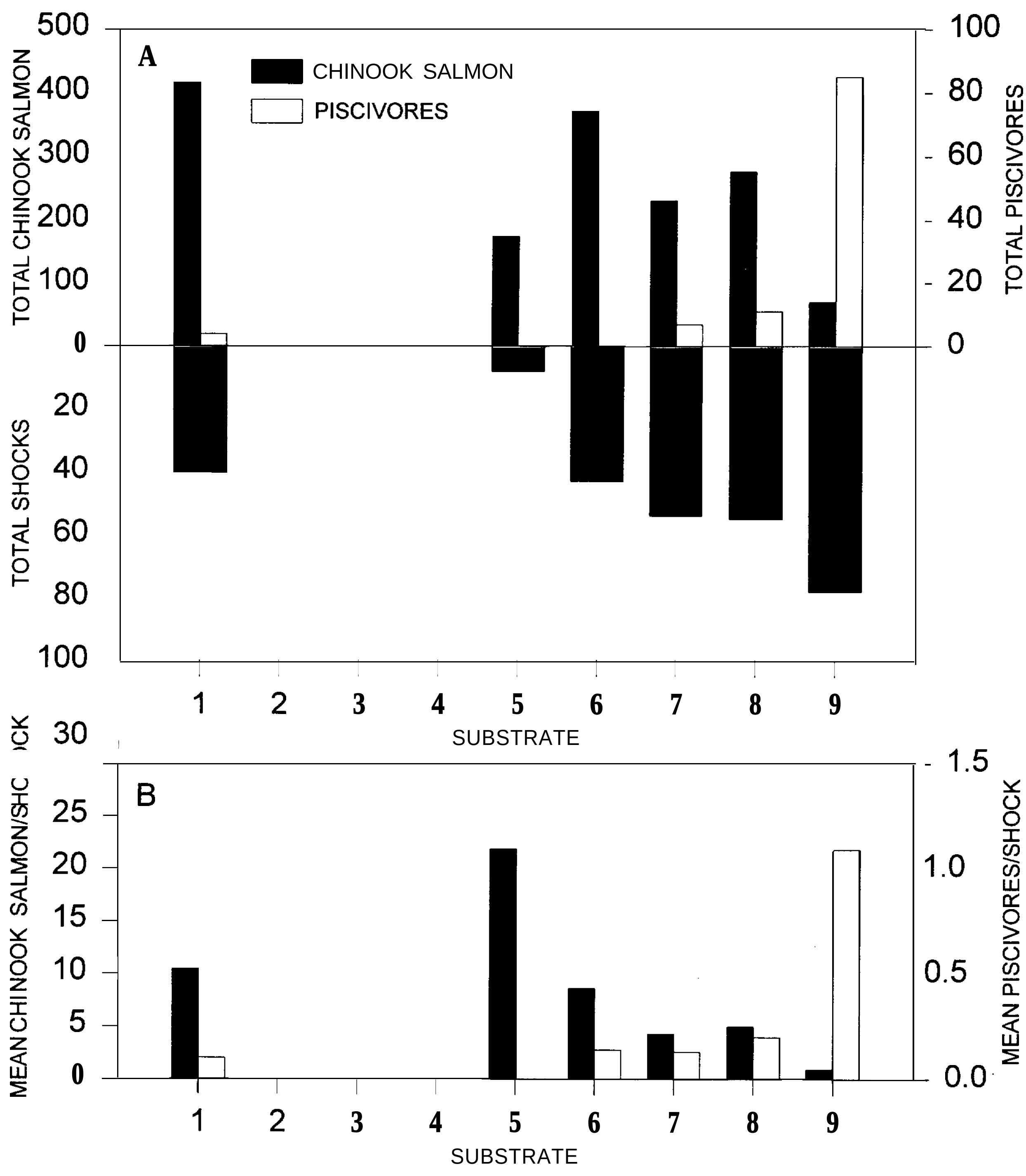

Figure 2.-Comparison of subyearling chinook salmon observed, non-native piscivores observed, and electrofishing point abundance samples collected over substrates in McNary Reservoir, WA, 1994-95. Comparisons were made by total numbers (A) and mean number (B) of fish observed per point abundance shock.

boulders (code 9). Highest mean number of piscivores occurred over boulders (code 9) and none were found over coarse gravel (code 5). In the Hanford Reach, effort was highest over fines (code 1) and lowest over coarse gravel (code 5; Figure 3). Highest mean number of subyearling chinook salmon occurred over coarse gravel (code 5) and was lowest over large pebble (code 7). Highest mean number of piscivores occurred over boulders (code 9) and none were found over coarse gravel and small pebble (code 5-6). Substrates of very coarse sand to medium gravel (codes 2-4) were not found as dominant substrates in McNary Reservoir or the Hanford Reach.

Gradient also appeared to influence the relative abundance of subyearling chinook salmon and piscivores. In McNary Reservoir, effort was highest where the gradient was >5-10% and no samples were collected where the gradient exceeded 75% (Figure 4). The highest mean number of subyearling chinook salmon occurred where gradient was >20-25%, and none were observed in gradients >60%. Piscivores were observed over all gradients sampled with the highest mean number of piscivores occurring where the gradient **was** >45-50%. In the Hanford Reach, effort was highest where the gradient was >15-20 and no samples were collected where the gradient exceeded 65% (Figure 5). The highest mean number of subyearling chinook salmon occurred where the gradient was >35-40%, while the highest mean number of piscivores occurred where the gradient was >55-60%.

Water velocity appears to be another environmental factor segregating subyearling chinook salmon and piscivores in McNary Reservoir although it does not seem to have the same effect in the Hanford Reach. In McNary Reservoir, effort was highest where average velocity was 0.00-0.04 m/s, and no samples were collected at velocities over 0.72 m/s (Figure 6). Subyearling chinook salmon were not observed where velocity exceeded 0.48 m/s, and piscivores were not observed where velocity exceeded 0.56 m/s. The highest mean number of juvenile salmon occurred where velocity was 0.05-0.08 m/s while the highest mean number of piscivores occurred where velocity was 0.53-0.56 m/s. In the Hanford Reach, effort was highest where velocity was 0.00-0.04 m/s and no samples were collected in water over 1.24 m/s (Figure 7). Subyearling chinook salmon were not observed where velocity exceeded 0.80 m/s and piscivores were not observed where velocity exceeded 0.20 m/s. The highest mean number of subyearling chinook salmon and piscivores occurred where velocity was 0.09-0.12 m/s.

Discussion

The total observed number of subyearling chinook salmon was higher in the Hanford Reach than in McNary Reservoir during each of the years sampled. The sample locations in the Hanford Reach were nearer to fall chinook salmon spawning areas and juvenile

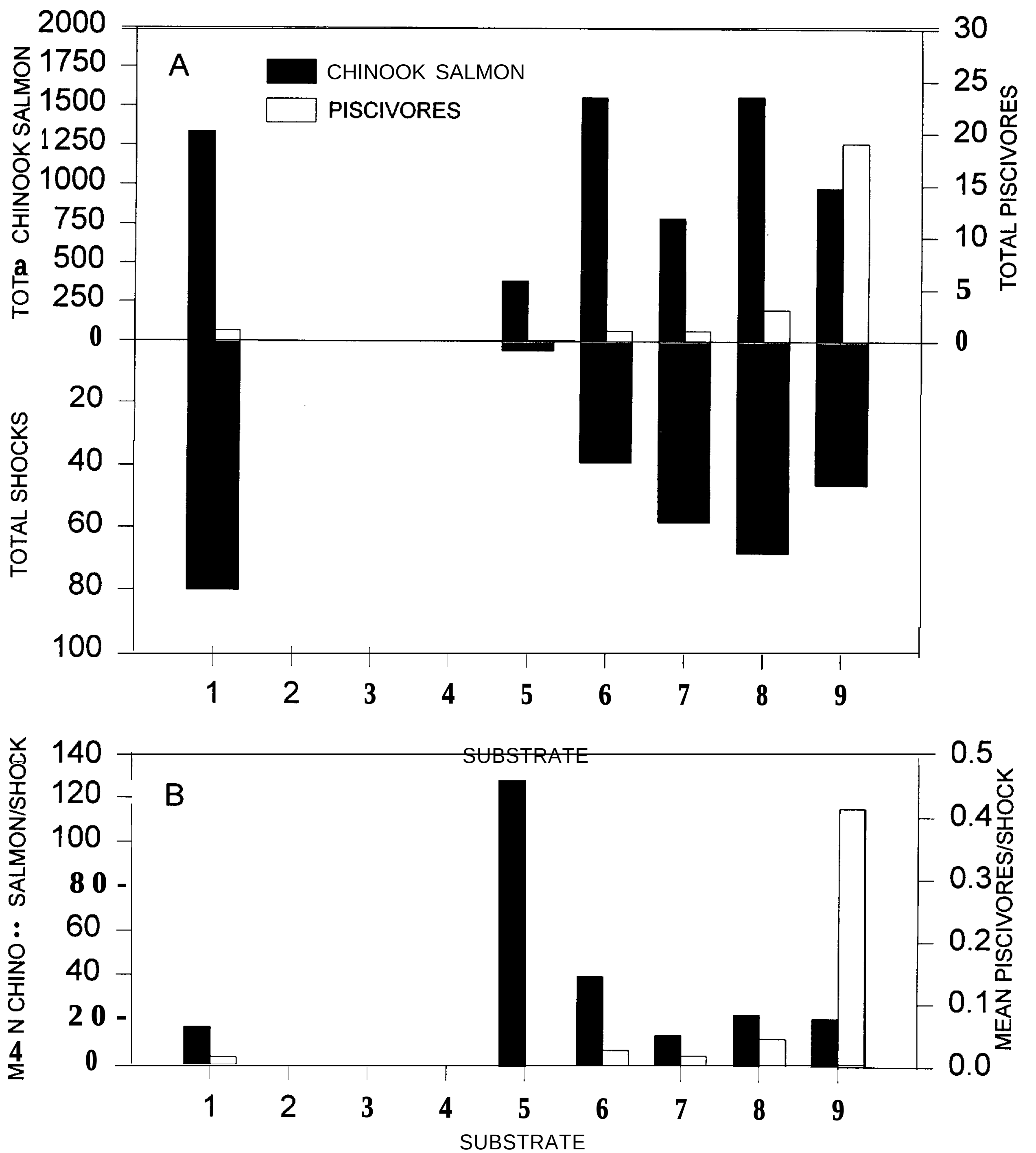

Figure 3.-Comparison of subyearling chinook salmon observed, non-native piscivores observed, and electrofishing point abundance samples collected over substrates in the Hanford Reach, WA, 1994-95. Comparisons were made by total numbers (A) and mean number (B) of fish observed per point abundance shock.

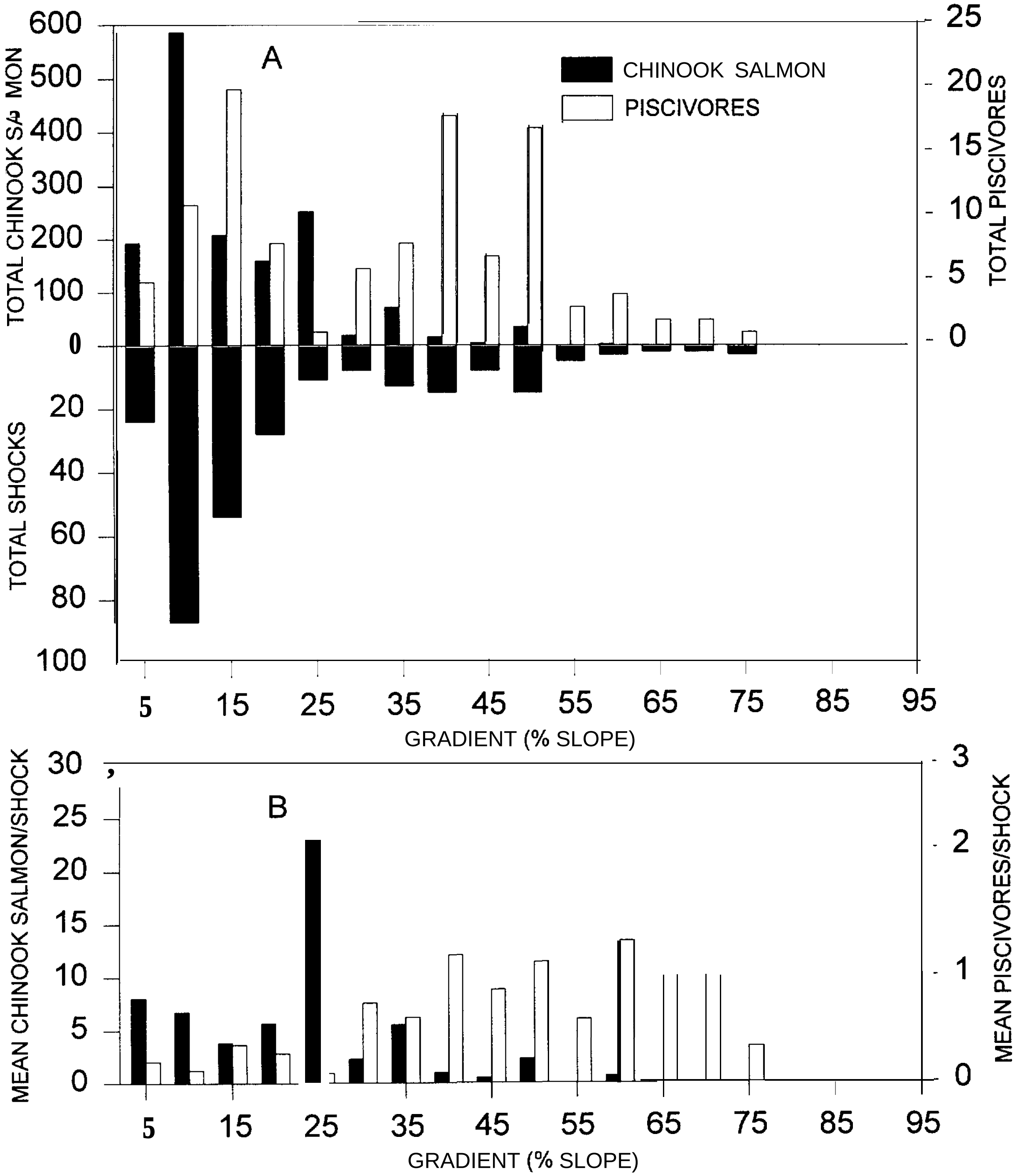

Figure 4.-Comparison of subyearling chinook salmon observed, non-native piscivores observed, and electrofishing point abundance samples collected over various gradient intervals in McNary Reservoir, WA, 1994-95. Comparisons were made by total numbers (A) and mean number (B) of fish observed per point abundance shock.

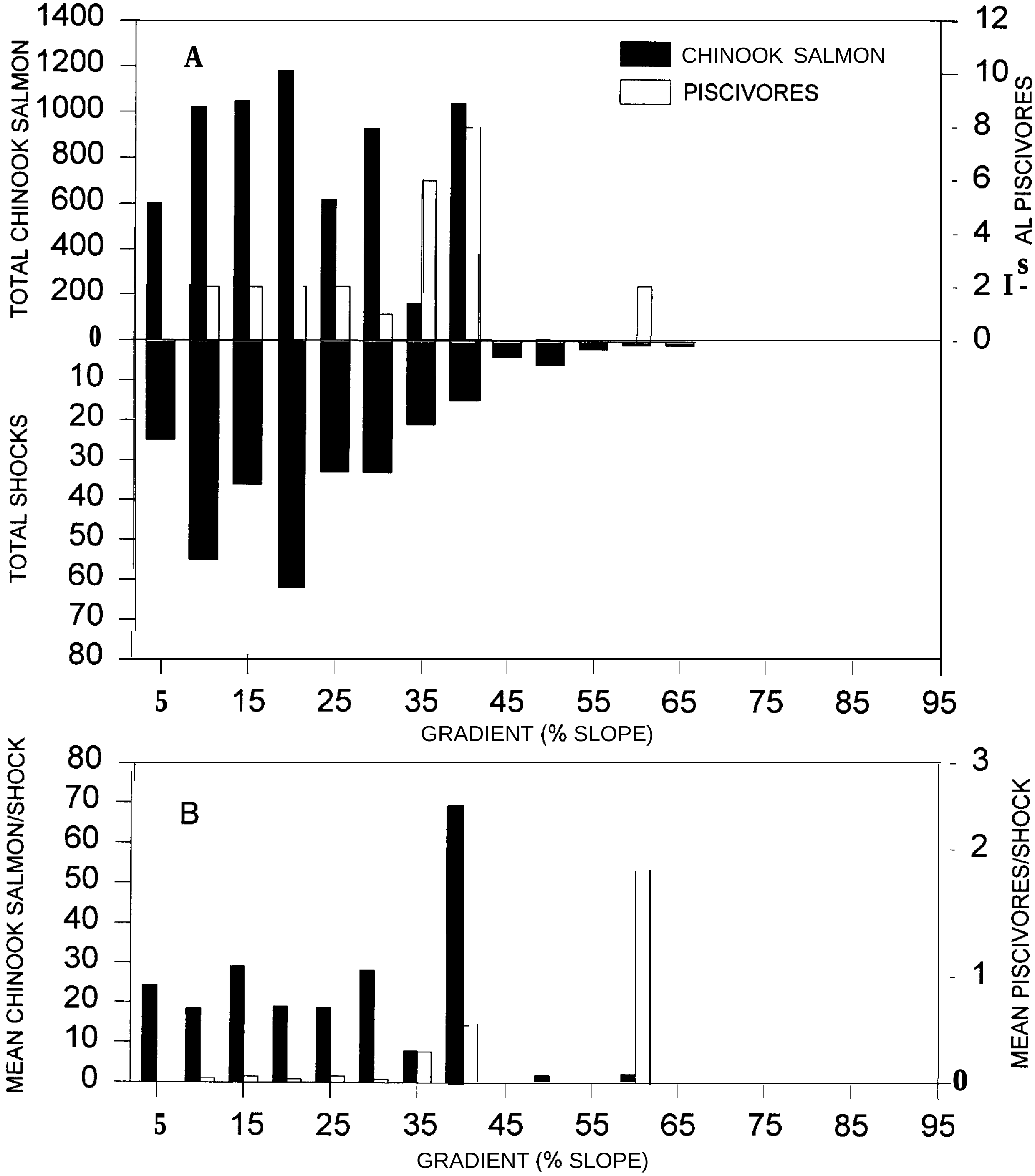

Figure 5 .-Comparison of subyearling chinook salmon observed, non-native piscivores observed, and electrofishing point abundance samples collected over various gradient intervals in the Hanford Reach, WA, 1994-95. Comparisons were made by total numbers (A) and mean number (B) of fish observed per point abundance shock.

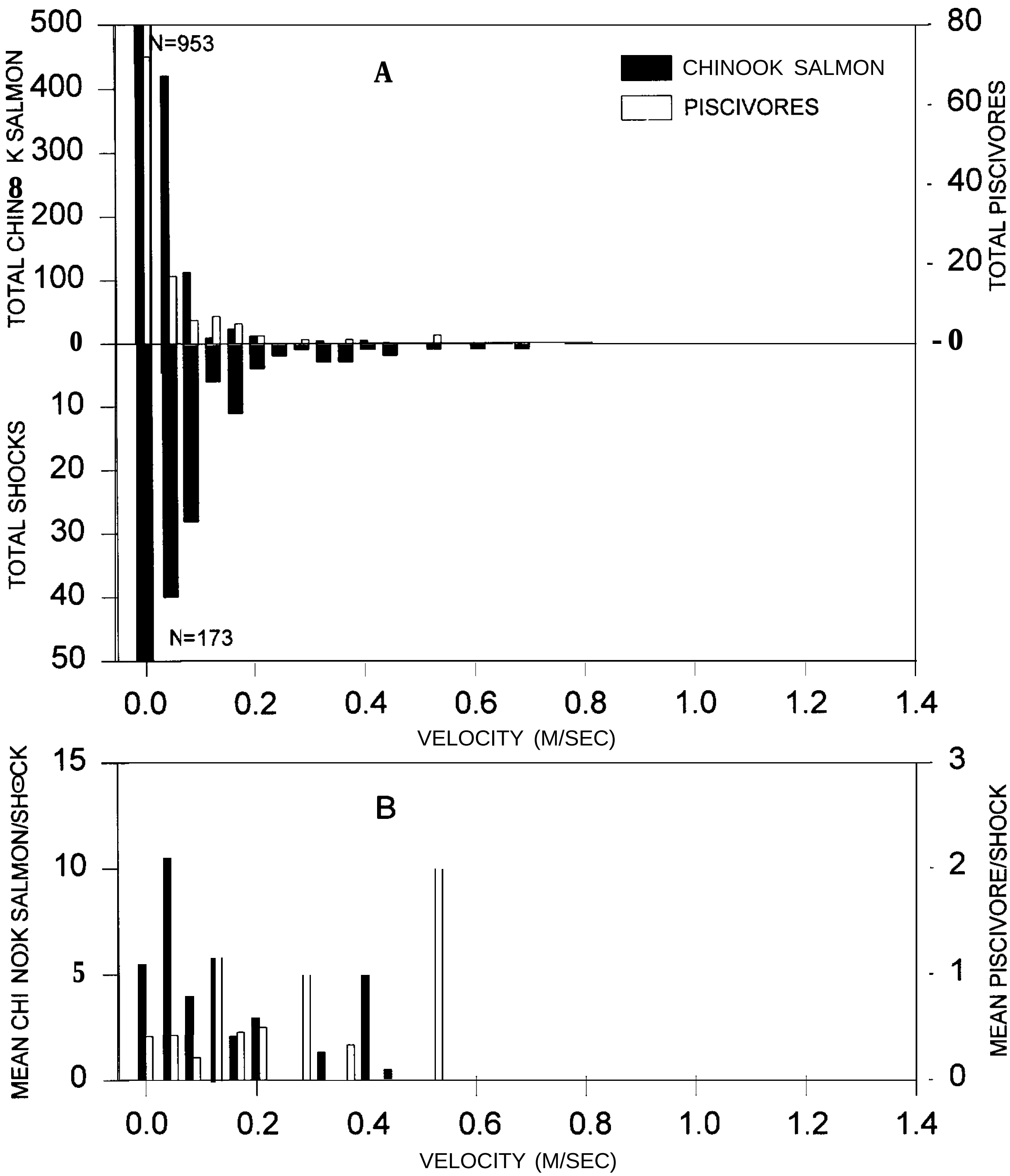

Figure 6.-Comparison of subyearling chinook salmon observed, non-native piscivores observed, and electrofishing point abundance samples collected over velocity intervals in McNary Reservoir, WA, 1994-95. Comparisons were made by total numbers (A) and mean number (B) of fish observed per point abundance shock.

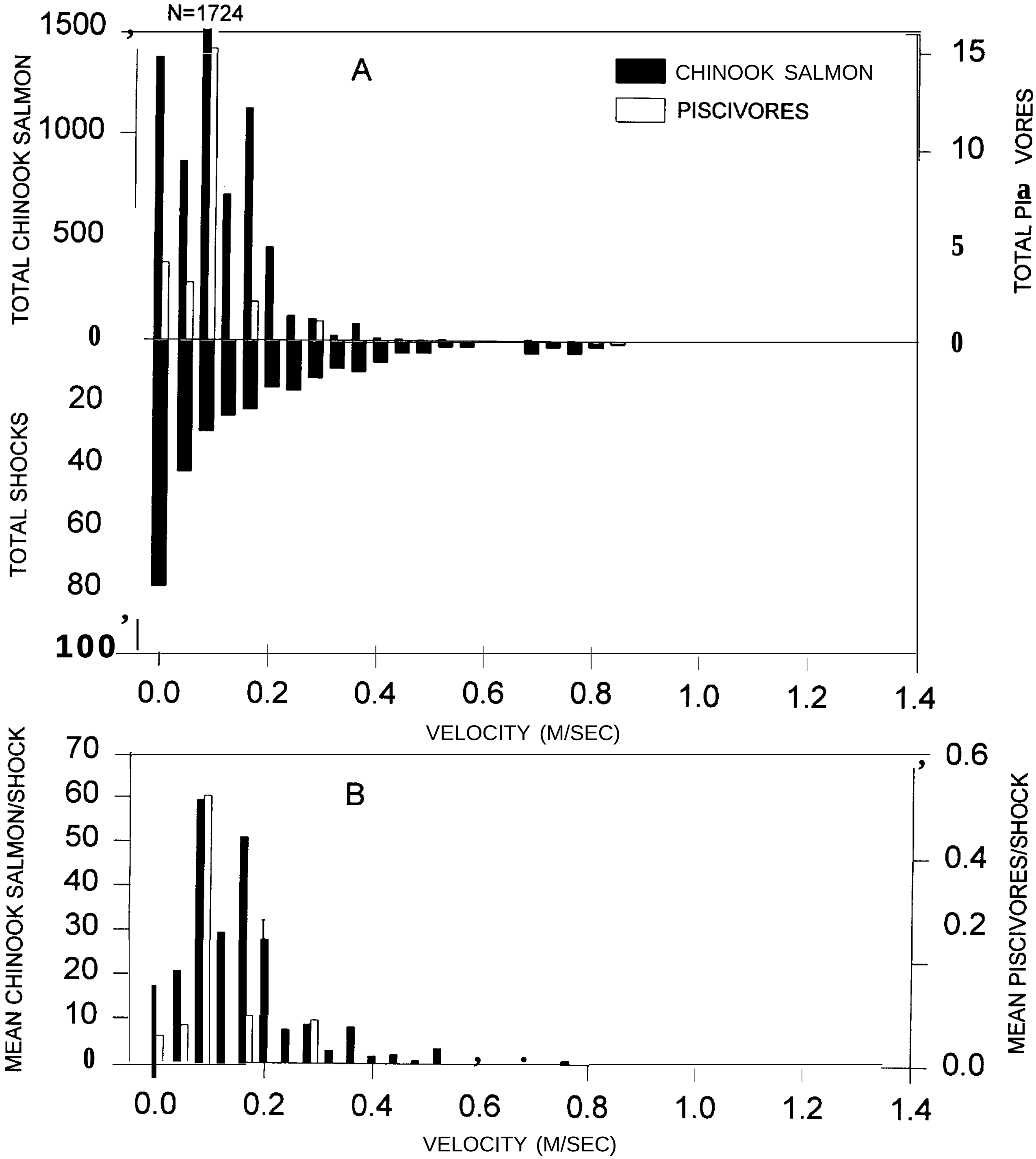

Figure 7.-Comparison of subyearling chinook salmon observed, non-native piscivores observed, and electrofishing point abundance samples collected over velocity intervals in the Hanford Reach, WA, 1994-95. Comparisons were made by total numbers (A) and mean number (B) of fish observed per point abundance shock.

fish were less dispersed. In contrast, the total observed number of piscivores was greater in McNary Reservoir than in the Hanford Reach. The overall water velocity was lower, water temperatures higher, and more cover was available in McNary Reservoir providing more suitable conditions for non-native predators.

In both reaches, mean observed numbers revealed that subyearling chinook salmon were located over all substrates sampled; whereas most piscivores were observed over large substrate. In McNary Reservoir, the smallest number of juvenile salmon were observed over boulders where piscivore numbers were highest. Much of the boulder substrate sampled in McNary Reservoir was riprap, which consists of boulders placed by man for erosion control. The relatively high number of subyearling chinook salmon and absence of piscivores over coarse gravel (code 5) may be an artifact of low sample size.

Even though subyearling chinook salmon do not appear to use riprap as rearing habitat, they may still be at considerable risk to predation when moving through these areas. In 1993, we observed many aggregates of juvenile salmon moving downstream near the shoreline during an increase in river flow in the Hanford Reach. Dauble et al. (1989) found higher abundances of juvenile fall chinook salmon per cubic meter near shore than in midchannel. Predation on subyearling chinook salmon can be significant in nearshore areas (Tabor et. al 1993). This is particularly true considering that much of the shoreline of McNary Reservoir is riprap, which predators such as smallmouth bass prefer.

Gradient also appeared to play a role in defining subyearling chinook salmon and piscivore habitat in McNary Reservoir. Most juvenile salmon in McNary Reservoir were observed in areas of lower gradient; whereas piscivores were more commonly observed in higher gradient areas. It is difficult to separate gradient from substrate in McNary Reservoir as causes of distribution because the two variables are related. Most high gradient sites were riprap shorelines. In the Hanford Reach, gradient and substrate were less interdependent and may explain why gradient was less influential in defining fish distribution in this reach.

Velocity may have influenced subyearling chinook salmon distribution in the nearshore habitats in both reaches. Greater numbers of juvenile salmon were observed in areas where water velocity was lower. Fish may be avoiding higher water velocity where net energy gains may be low. In contrast, velocity did not appear to influence piscivore distribution in McNary Reservoir. Many of the higher velocity sites in McNary Reservoir were characterized by riprap shorelines, which provide velocity breaks that allow piscivores to exist there.

The preliminary findings of this study suggest that subyearling chinook salmon can be found over nearly all substrates, gradients, and velocities. The relative numbers that were observed using selected habitats in the nearshore areas differed. Future analysis will attempt to explain how substrate, gradient, and velocity interact with other habitat measures to influence habitat usage by subyearling chinook salmon and other species in the nearshore areas. The findings contained in this report do provide a strong argument against the creation of additional riprap shoreline as this habitat appears to harbor higher numbers of non-native predators of the subyearling chinook salmon than do other areas.

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CHAPTER SIX

Nearshore Movement and Feeding Behaviors of Juvenile Fall Chinook Salmon in the Columbia River

by

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Introduction

Our knowledge of juvenile fall chinook salmon *Oncorhynchus tshawytscha* behavior in nearshore rearing areas has increased in recent years. Connor et al. (1993, 1994a, 1994b) used the recapture of PIT-tagged juvenile chinook salmon in the free-flowing Snake River and at Lower Granite Dam to examine fidelity to rearing sites and to estimate movement rates. Key et al. (1994a, 1994b) conducted beach seining and electrofishing studies in the Columbia River to identify preferred nearshore habitats. We attempted to build upon these studies by focusing more closely on nearshore movements, behavior and habitat use. Studies reported here were conducted in the Hanford Reach of the Columbia River to use available fall chinook salmon as surrogate experimental animals rather than the endangered Snake River fall chinook salmon. Our objectives were to: 1) document and compare rate and direction of juvenile fall chinook salmon diel movements in nearshore habitats throughout the rearing season; 2) describe the use and avoidance of various microhabitats found in nearshore areas by juvenile fall chinook salmon; and 3) identify the peak times of juvenile fall chinook salmon feeding, resting, and movement in nearshore areas.

Study Area

The 1994 study area was located between river kilometer (Rkm) 508 and Rkm 595 on the Columbia River (Figure 1). Paired fyke nets were fished and underwater video was collected between Rkm 550.5 and Rkm 552.0. River kilometer information was obtained from United States Geological Survey (USGS) 7.5 minute topographic maps.

Methods

Field Procedures

Movement Timing and Direction. -Fish were sampled during two periods, referred to as "runs", in 1994. The early run lasted from 27 April to 30 April and from 3 May to 6 May. The late run lasted from 6 June to 11 June. Fish were collected in fyke nets set to capture fish moving parallel to shore and were set in pairs to keep nearshore and offshore catches separated (Figure 2a and 2b). Net trap frames measured 1.2 m deep by 1.2 m wide, leads were 7.6 m long by 1.2 m deep, and mesh size was 3.2 mm. Only fish moving in a downstream direction were collected in the early run (Figure 2a). The addition of a second, upstream net allowed us to collect fish moving in either direction during the late run (Figure 2b).

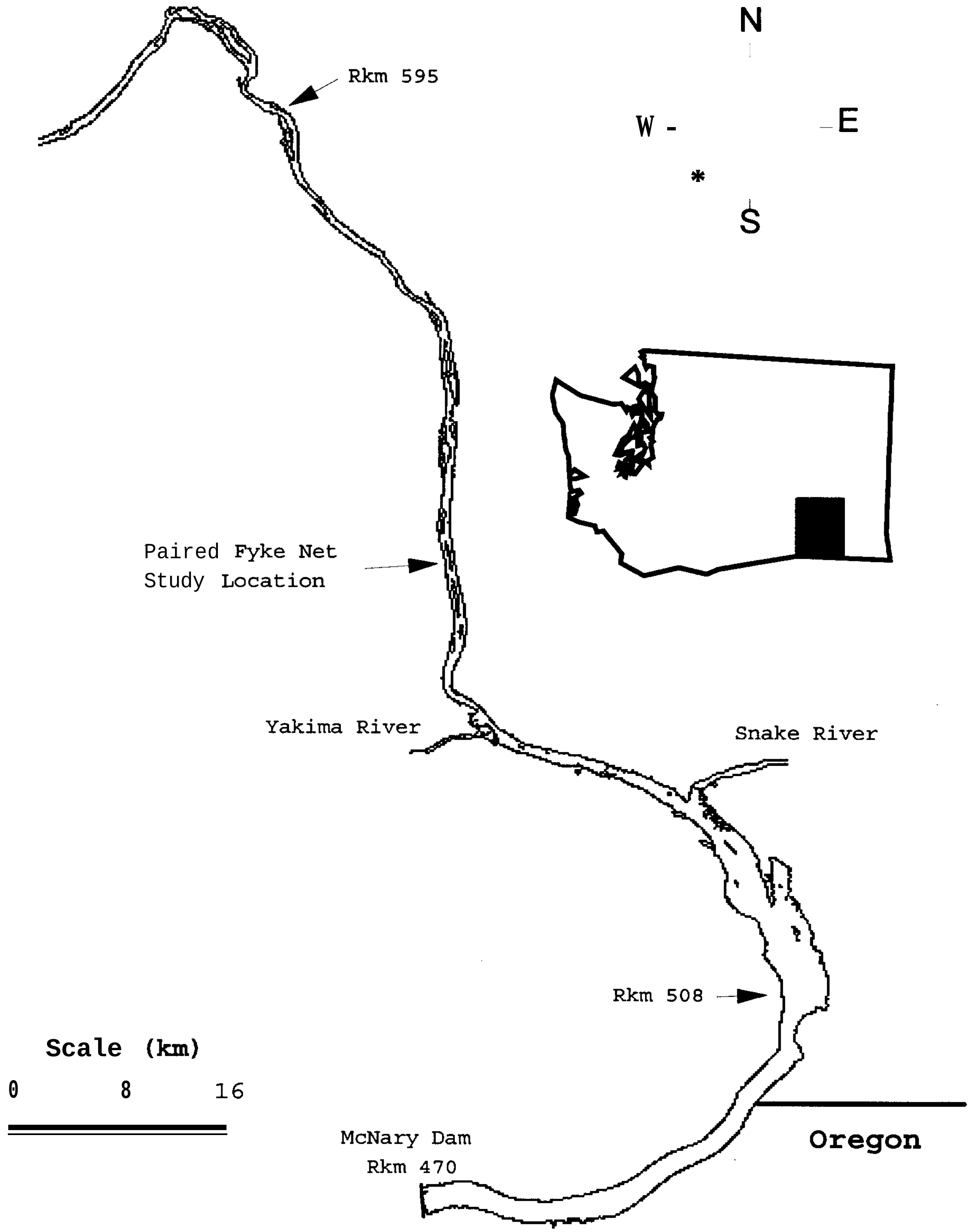

Figure 1.-Map of the area sampled with paired fyke nets and underwater video in the Columbia River, April - June, 1994.

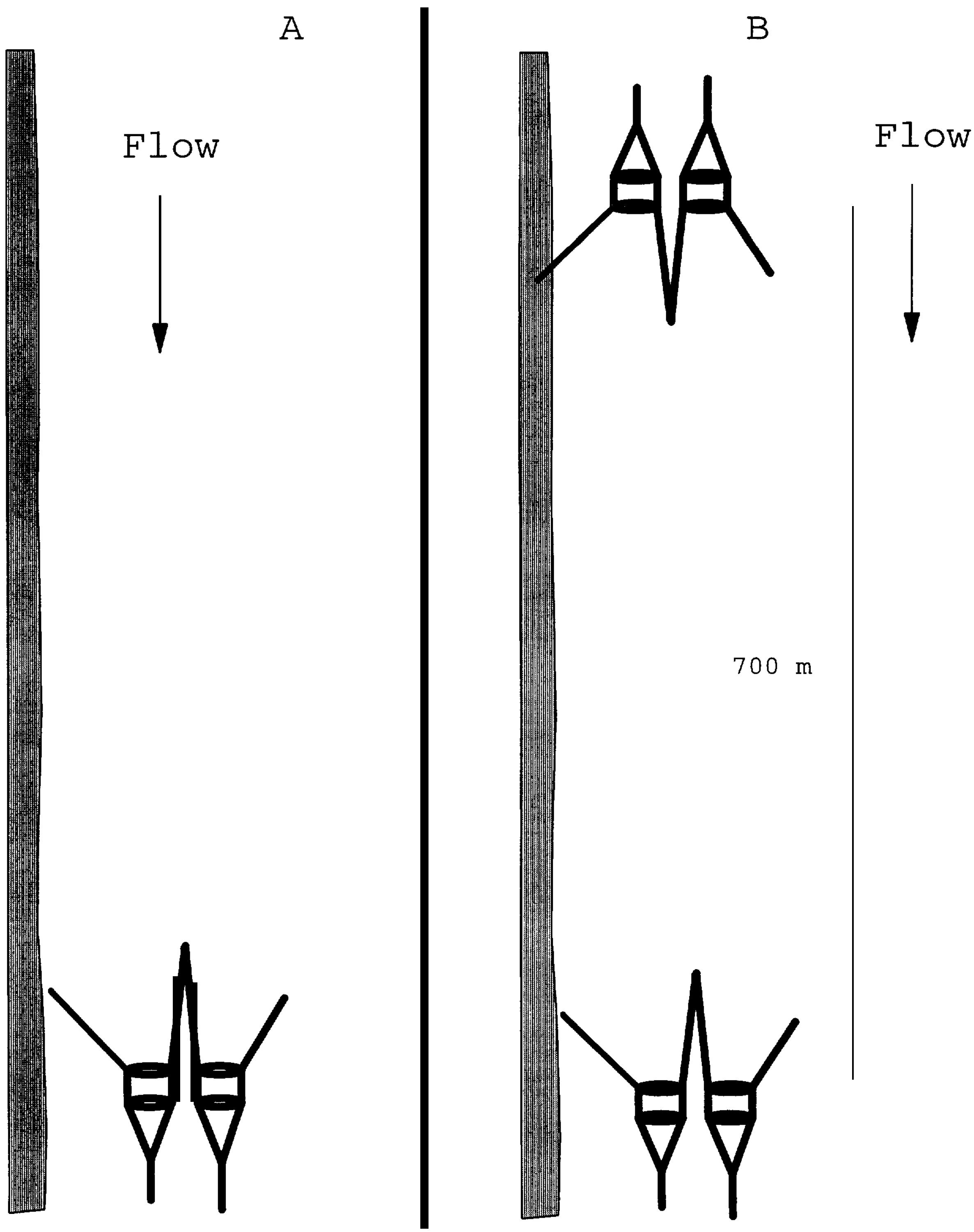

Figure 2.-Fyke net configurations in the early (A) and late (B) runs of the movement and migration, and movement rate study, in the Columbia River, April - June, 1994.

Nets were placed in an area known to contain high numbers of subyearling fall chinook salmon. Nets were fished continuously for the duration of each run, and fish were removed every 2-3 h depending on the number of fish and amount of debris in the nets. We also collected water temperature and light intensity each time the nets were emptied.

Fish from the nearshore and offshore traps were placed in separate buckets, lightly anesthetized with MS-222, identified to species, and enumerated. Twenty individuals of each species collected from each trap were also measured to the nearest 1 mm fork length (FL). After handling, fish were allowed to recover in fresh river water prior to release.

Underwater Video. -Fish behavior data were collected using an underwater video system. The system consisted of a Hi 8 mm camcorder with "video in" capability encased in a weatherproof housing, a remote underwater camera, a 12 V power supply, and a field monitor. Power was supplied to the camera and the video image transmitted to the camcorder and monitor through a common cable.

Videotape recordings were approximately 2 h in duration and were collected throughout the day and night. During daylight hours, ambient light was sufficient for data collection, but night samples required the use of supplemental illumination. Early in the season, incandescent light was used, but later, we switched to infrared light, which is believed to be invisible to fish (Lythgoe 1988). Whenever possible, the underwater camera was positioned so the entire water column was in the field of view. The following environmental data were also collected immediately before and after filming: light intensity, water temperature, dissolved oxygen concentration, turbidity, visibility, depth, and water velocity at the camera and at the limit of visibility. Water velocity was measured at the surface, 0.6 depth, and at the bottom. Visibility was determined by moving an aluminum rod away from the underwater camera until it was no longer visible. The rod was then moved back towards the camera until it became visible again and its distance from the camera was then measured.

Data Analysis

Movement Timing and Direction. -Catch rates were compared between nets to evaluate the timing and direction of subyearling chinook salmon movements. Catch per hour (CPH) was calculated by dividing the number of fish collected by the number of hours the net fished. Separate CPH estimates were made for nearshore, offshore, and both traps combined for both the upstream and downstream nets. Catch rates were calculated for the following 6-h time blocks:

nighttime (2101-0300 h), dawn (0301-0900 h), daytime (0901-1500 h), and dusk (1501-2100 h).

Differences between catch rates were compared using analysis of variance (ANOVA) and a Tukey multiple comparison test (Statgraphics 1992). One-way ANOVA was used to examine the effect of time period and trap depth on catch rates during the early run. Multifactor ANOVA was used to examine the effect of time period, trap depth, and net location (upstream versus downstream) in the late run. Catch rates were normalized using the transformation CPH_n = Log,, (CPH_r + 1); where CPH_n is the normalized catch rate and CPH_r is the raw catch rate. The constant 1 was added to all CPH_r estimates to provide a definition for the expression where $CPH_r = 0$. Statistical significance was assumed at $P \leq 0.05$.

Underwater Video.-Videotapes were analyzed using the following system. Tapes were played on an 8 mm VCR with frame-by-frame and freeze-frame capabilities. The video image was displayed on a monochrome monitor which had two horizontal lines on the screen to divide the image into equal thirds. The image was also sent to a personal computer (PC) equipped with a frame grabber and video analysis software. A time/date generator in the VCR provided a continuous time (HH:MM:SS) readout on the videotape.

Due to the large amount of information contained on these videotapes, we limited our analyses of fish behavior to three major activities including microhabitat associations, movement, and feeding behaviors. These activities were then further subdivided into specific activities or events. Microhabitat associations were limited to the surface, open water, submerged vegetation, and bottom substrate. A fish was considered associated with the surface or bottom substrate areas if they were within 0.5 body length of these areas. Movement variables included whether the fish was holding position in the current or moving unidirectionally through the field of view. Movement rate (body lengths per second, BL/s) was estimated for moving fish. Feeding events were analyzed for feeding rate, location in the water column, competition for individual food items, and distance moved (body lengths) to capture a food item.

When a fish entered the field of view its position in the water column, microhabitat association, direction of travel, and orientation were recorded. Fish that failed to pass through the entire field of view were recorded as "milling". Those that did pass through the entire field of view were labeled as "actively moving", and if possible their movement rate was recorded. Results pertaining to the number of active and milling fish are reported as the number observed per hour of tape analyzed for each time period.

Movement rates were determined through the use of the PC and frame grabber. When an actively moving fish was encountered, initial head and tail coordinates and time were recorded using the video analysis software and the time on the videotape. The tape was then advanced until just before the fish left the field of view, and a second set of coordinates and time were recorded. Two body lengths (BL) measurements were calculated (in arbitrary units) using the two sets of coordinates and the distance formula;

$$BL = [(X_2-X_1)^2+(Y_2-Y_1)^2]^{0.5} \qquad (1)$$

where X_1,Y_1 and X_2,Y_2 refer to head and tail coordinates at the beginning and ending positions on the monitor. If these two body lengths differed by < 10% it was assumed the fish passed through the field of view in a single X-Y plane, making movement rate estimation possible. Movement along the Z axis would result in an apparent change in body length, and preclude movement rate estimation. The two body length measurements were then averaged and the distance between the head coordinates (H_M) was calculated using Formula 1. Movement rate (BL/s) was then estimated as

$$(H_M/BL_{mean})/s \qquad (2)$$

where H_M is the distance between the two head coordinates; BL_{mean} is the average of the two calculated body lengths; and s is the number of seconds between measurements.

Feeding events were comprised of two parts. We use the term "initiation" to describe the first detectable change in behavior when a fish began moving toward a food item. The capture of a food item is termed the "strike". When a feeding event was observed, the position of the fish in the water column at initiation and the strike were recorded. We also noted the number of fish attempting to capture the same food item and the number of fish on the screen as a measure of competition. Due to the rapidity of feeding events, it was not possible to measure initiation to strike time, and therefore feeding movement rates. Feeding behavior data were analyzed over the same four time blocks described previously. Results were interpreted graphically.

Results

Movement Timing and Direction

In the early run, 4,567 juvenile fall chinook salmon were collected (mean FL = 44.0 mm, SD = 3.91, range 36-69 mm, N = 2,188). The nearshore trap collected 3,462 chinook, and 1,105 were captured in the offshore trap.

Catch rates in the early run were highest during daytime (66.5 fish/h), lowest during nighttime (9.4 fish/h), and intermediate and similar during dawn and dusk (37.4 and 34.2 fish/h, respectively; Figure 3). Catch rates were significantly different between time periods in both the nearshore and offshore traps, $P = 0.0395$ (nearshore) and $P = 0.0021$ (offshore). Multiple range comparison showed nighttime and daytime catches were significantly different in both analyses. Dawn and dusk catches were not significantly different from each other.

Catch rates also differed between the nearshore and offshore traps (Figure 4). Catches in both traps followed the same daily pattern described above, but catches in the nearshore trap were consistently higher than in the offshore trap.

In the late run, 358 juvenile fall chinook salmon were collected (mean FL = 59.1 mm, SD = 7.74, range = 37-92 mm, N = 355). One hundred forty-five were collected in the downstream net (mean FL = 59.1 mm, SD = 9.23, range 37-92 mm, N = 144); 98 in the nearshore trap and 47 in the offshore trap. The upstream net captured 213 chinook salmon (mean FL = 58.4 mm, SD = 6.92, range 43-84 mm, N = 211); 169 in the nearshore trap and 44 in the offshore trap.

Catch rates in the late run differed when compared over the four time periods. In the late run, catches were highest during the nighttime (5.28 fish/h), lowest during the daytime (0.61 fish/h), and intermediate and similar during dawn and dusk (1.74 and 1.29 fish/h respectively; Figure 5). Except for two instances of unusually high catches in the upstream net, up and downstream catches were similar (Figure 6) so the data were pooled to increase sample size. Catch rates differed significantly between time periods in both the nearshore and offshore traps, $P = 0.0008$ (nearshore) and $P = 0.0329$ (offshhore), regardless of up or downstream direction. Multiple comparisons tests identified nearshore trap catch rates as differing between daytime, nighttime, and dusk. Offshore trap catch rates differed only between nighttime and daytime.

Catch rate plots from nearshore and offshore traps in both nets showed the distinct daily patterns described above (Figures 7 and 8). In the downstream net, catches between the two traps were similar (Figure 7), but in the upstream net, however, the nearshore trap consistently collected higher numbers of fish (Figure 8).

Underwater Video

Juvenile fall chinook salmon were observed utilizing several microhabitats throughout the day. They were most commonly

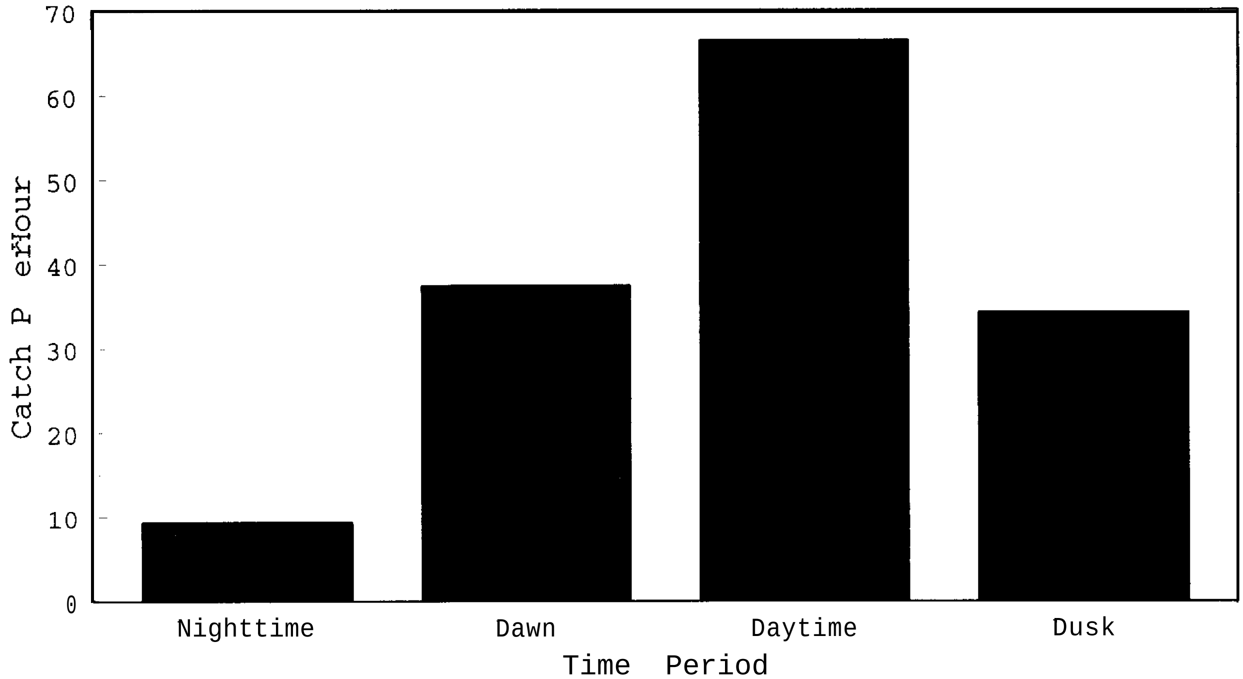

Figure 3.-Mean catch per hour of juvenile fall chinook salmon collected from nearshore and offshore traps during four time periods from the Columbia River, 27 April to 30 April, 1994.

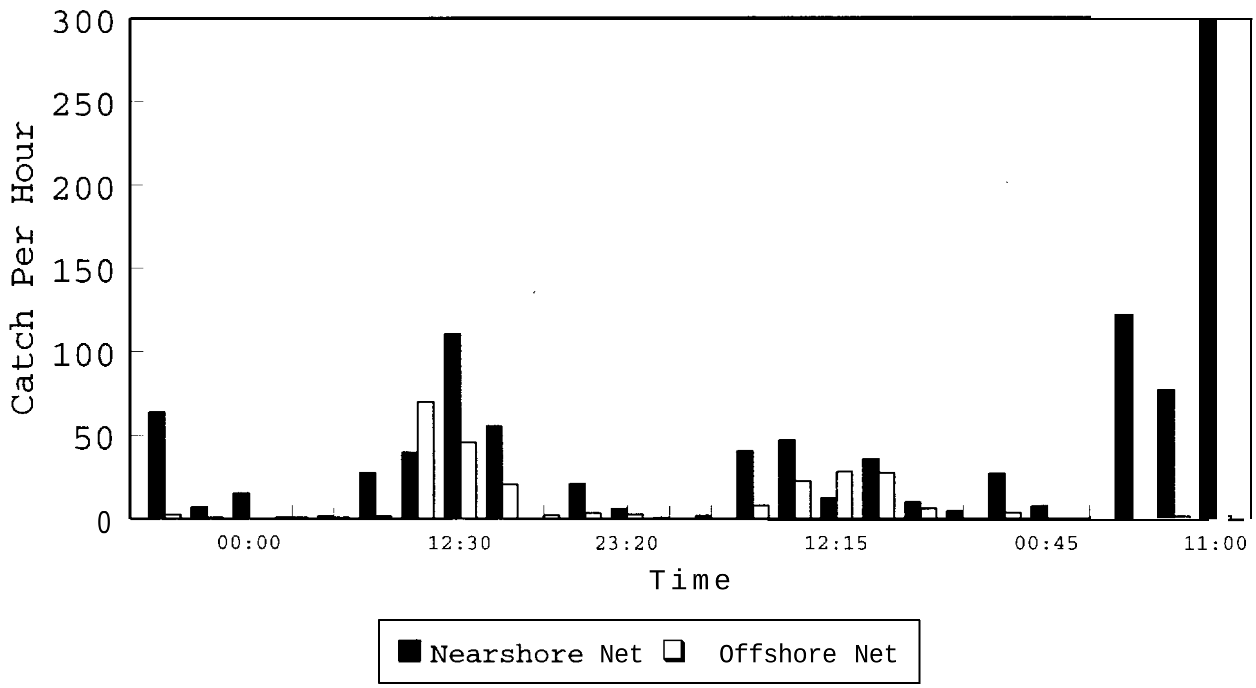

Figure 4.-Daily catches of juvenile fall chinook salmon in the nearshore and offshore traps from fyke nets in the Columbia River, April 27 - 30, 1994.

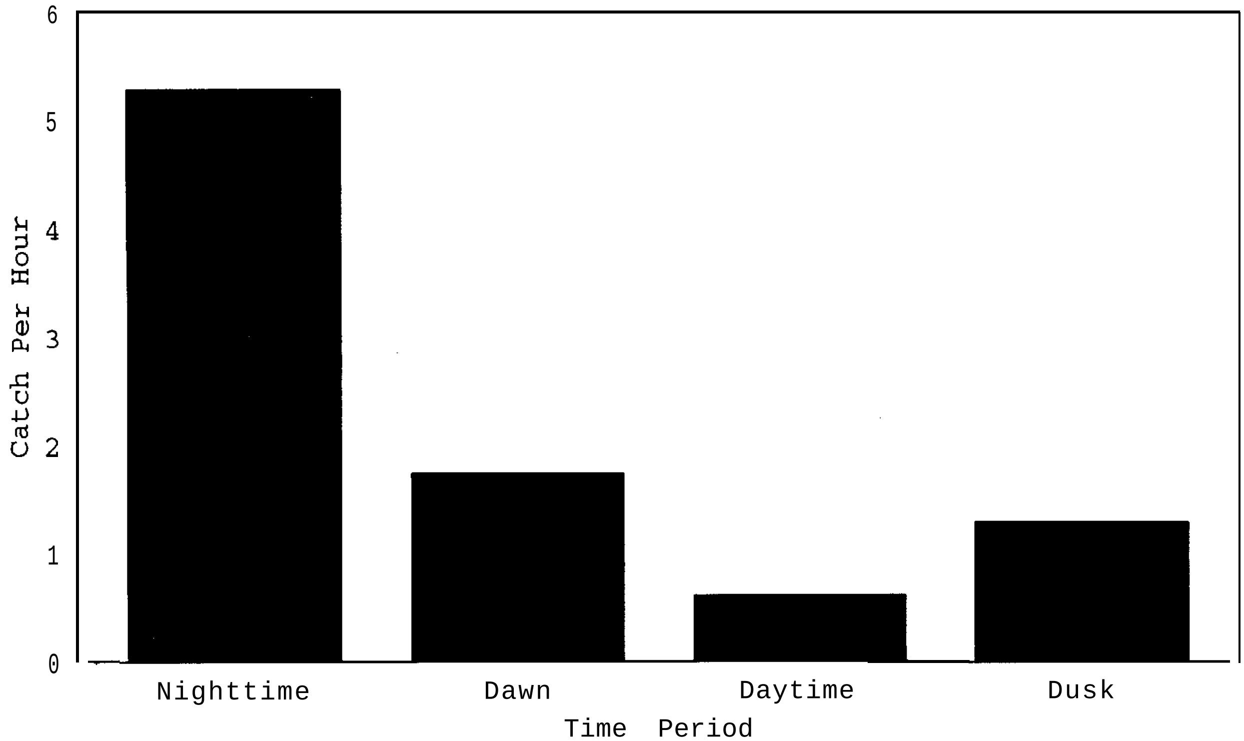

Figure 5.-Mean catch per hour of juvenile fall chinook salmon collected from nearshore and offshore nets during four time periods from the Columbia River, June 7 – 11, 1994.

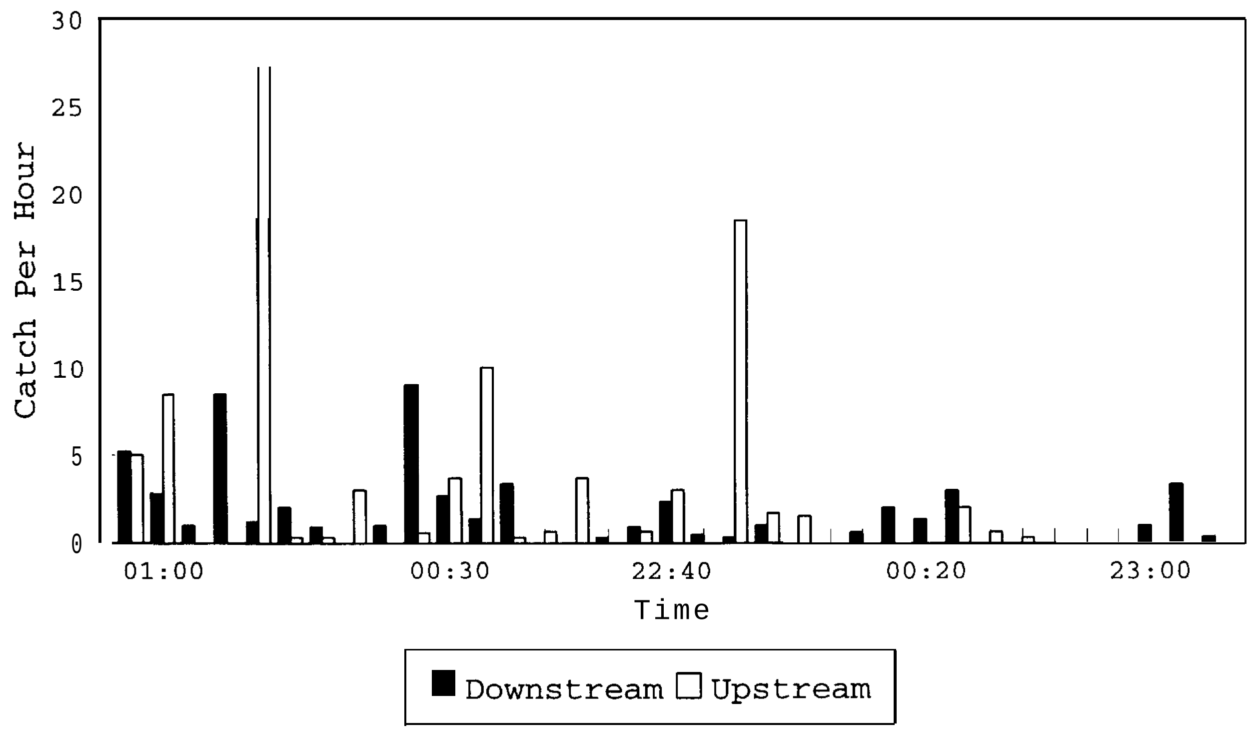

Figure 6.-Daily catches of juvenile fall chinook salmon in the upstream and downstream fyke nets in the Columbia River, June 7 – 11, 1994.

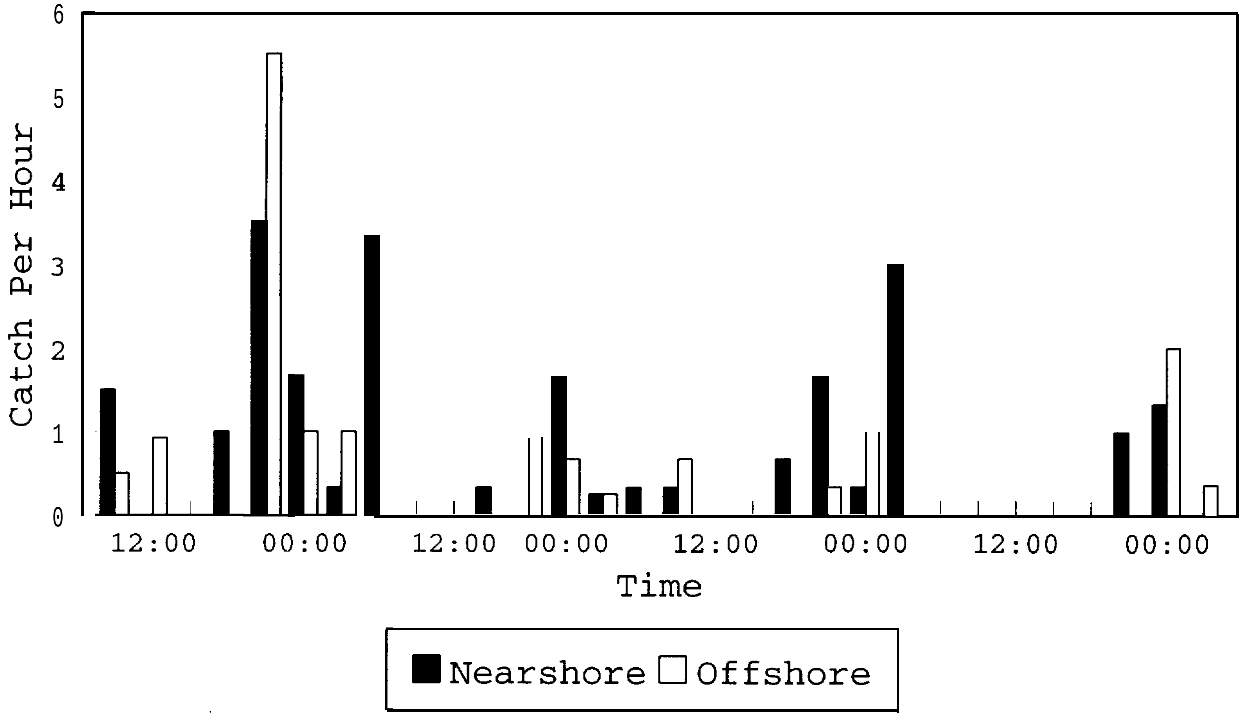

Figure 7.-Daily catches rates of juvenile fall chinook salmon in the nearshore and offshore traps from the downstream fyke net in the Columbia River, June 7 - 11, 1994.

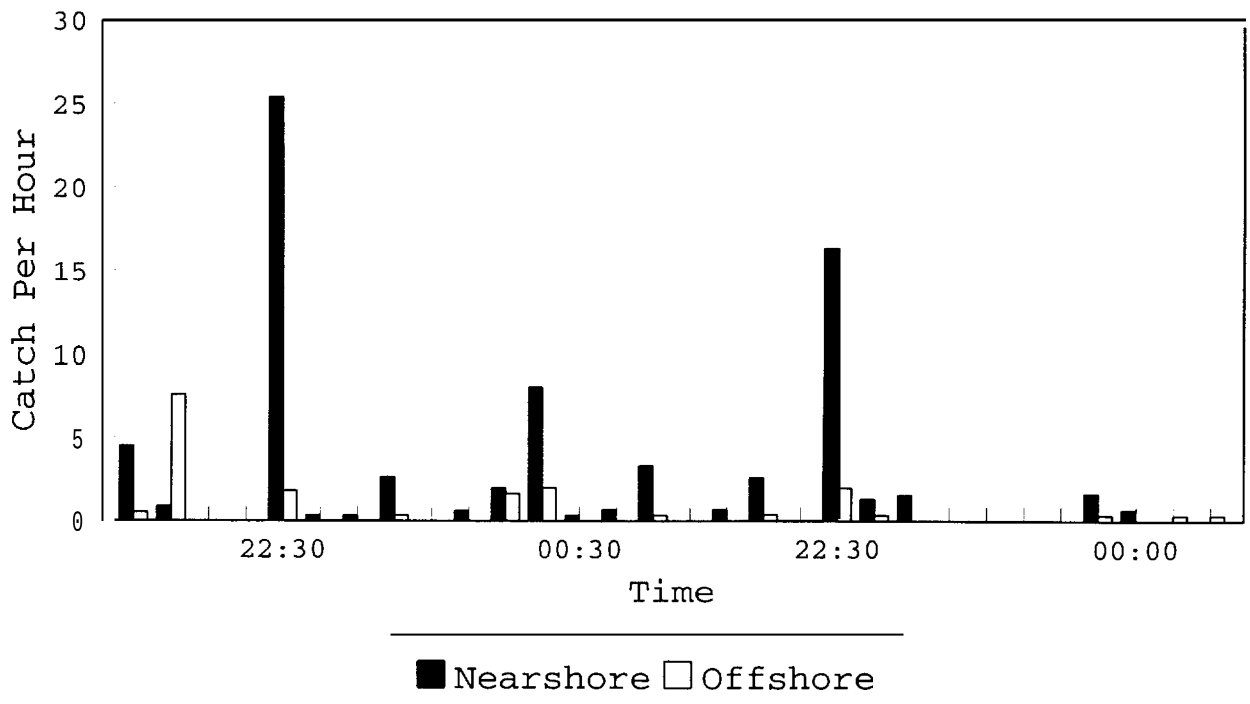

Figure 8.-Daily catch rates of juvenile fall chinook salmon in the nearshore and offshore traps in the upstream fyke net in the Columbia River, June 7 - 11, 1994.

associated with open water during dawn, daytime, and dusk, and with the bottom substrate during nighttime (Table 1). During daylight hours fish were generally active and moved or milled about regardless of the microhabitat they were associated with, During the nighttime period, however, they would generally lie quietly along the bottom, often just over small depressions.

Juvenile fall chinook salmon were observed moving both up and downstream in 1994. The highest movement was observed during daytime, with slightly less movement occurring during dawn and dusk (Figure 9). No moving fish were observed during the nighttime period. Fish moving upstream outnumbered downstream moving fish in each of the periods in which moving fish were observed (Figure 9), and tended to move more rapidly than those moving downstream (Figure 10). There was a trend toward increasing movement rate (in both directions) throughout the day and then a sharp drop after dark (Figure 10).

Juvenile fall chinook salmon were observed feeding during the daylight time periods. Feeding rate was highest during daytime (0.21 strikes/min, N = 102) and lowest during nighttime when no feeding events were observed. Feeding rates during dawn and dusk were 0.03 and 0.17 strikes/min (dawn: N = 19,; dusk: N = 89).

In all feeding events observed (N = 210), the strike occurred above and/or directly ahead of the point of initiation (Table 2). Even in instances where the initiation and strike occurred within the same third of the water column (Table 2), the fish generally moved upward and forward to capture the prey item. When a food item was identified, there would be a rapid dart, forward and upward, to the point of the strike. Immediately after the strike, the fish would flare to the side and swim downstream. Distance moved between initiation and strike averaged 4.2 body lengths (N = 55, SD = 3.02, range 0.37-14.4), and did not differ between time periods, $P = 0.1669$. Downstream flight distance after the strike often took the fish out of the field of view, so this distance was not estimated.

Competition for food did not appear to increase as the number of fish in the field of view increased (Table 3). We observed 51 cases where multiple fish were in the field of view at the time of a feeding. In 8 cases, 2 fish pursued the same food item (16%), and once, 3 fish pursued a single item (2%).

Discussion

Our catch rates indicate that most juvenile fall chinook salmon leave the Hanford Reach between April and June. Because we failed to detect any difference in directional movement during June, fishing both up and downstream nets earlier in the season may provide a better insight on when migration from this area

Table 1.-Number of juvenile fall chinook salmon associated with various microhabitats as observed from underwater video in nearshore rearing areas in the Columbia River, 1994.

	Habitat Type			
Time Period	Surface	Open Water	Submerged Vegetation	Substrate
Nighttime	0	15	2	57
Dawn	0	74	0	7
Daytime	7	251	1	73
Dusk	0	206	0	23

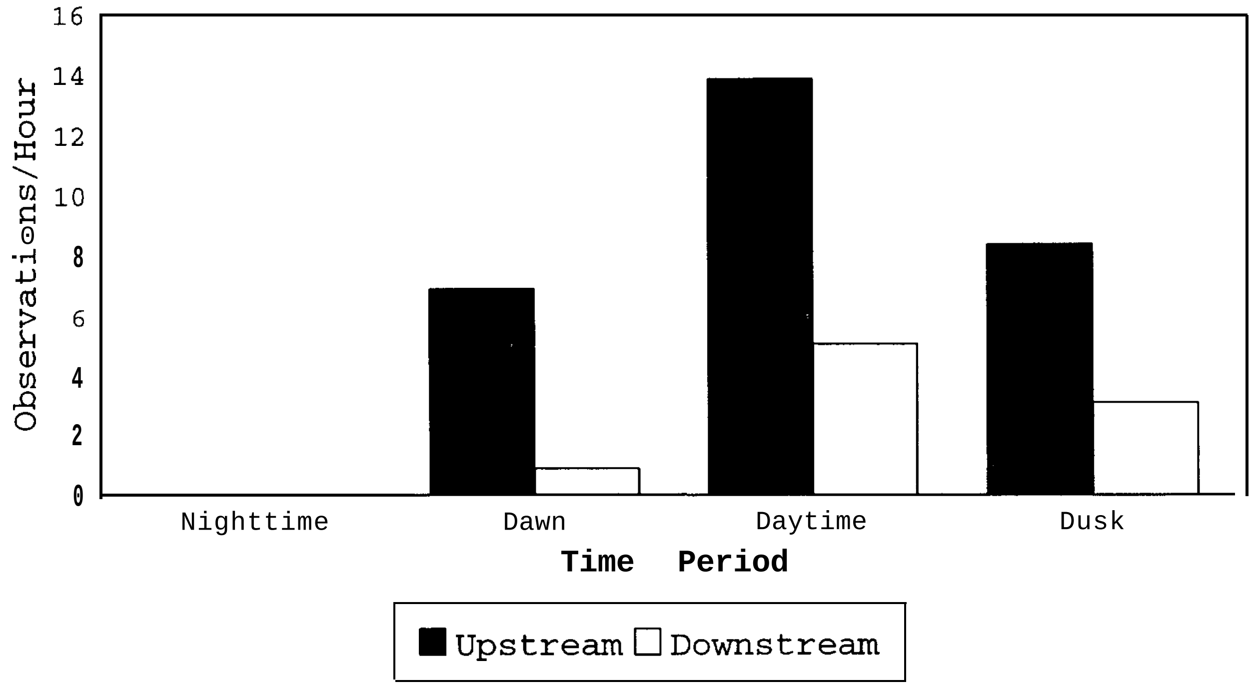

Figure 9.-Number of juvenile fall chinook salmon observed per hour moving up and downstream on underwater video tapes in the Columbia River between April and June, 1994.

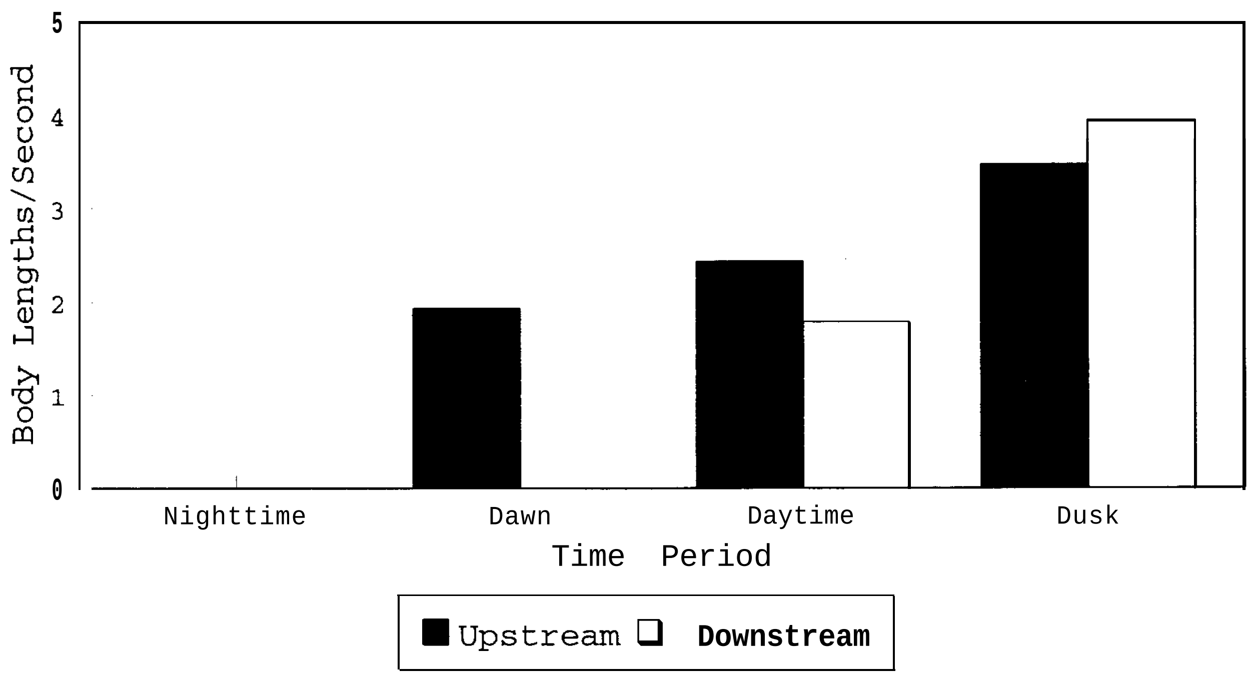

Figure 10.-Movement rates of juvenile fall chinook salmon observed moving up and downstream on underwater video tape from the Columbia River between April and June, 1994.

Table 2.-Number of observations of all possible combinations of initiation and strike locations in the water column of feeding juvenile fall chinook salmon as determined from underwater video from the Columbia River, 1994.

Initiation Location	Strike Location	Number of Fish Observed
Surface	Surface	0
Surface	Upper 1/3	0
Surface	Middle 1/3	0
Surface	Lower 1/3	0
Surface	Bottom	0
Upper 1/3	Surface	56
Upper 1/3	Upper 1/3	2
Upper 1/3	Middle 1/3	0
Upper 1/3	Lower 1/3	0
Upper 1/3	Bottom	0
Middle 1/3	Surface	62
Middle 1/3	Upper 1/3	39
Middle 1/3	Middle 1/3	31
Middle 1/3	Lower 1/3	0
Middle 1/3	Bottom	0
Lower 1/3	Surface	17
Lower 1/3	Upper 1/3	7
Lower 1/3	Middle 1/3	19
Lower 1/3	Lower 1/3	1
Lower 1/3	Bottom	0
Bottom	Surface	0
Bottom	Upper 1/3	8
Bottom	Middle 1/3	5
Bottom	Lower 1/3	10
Bottom	Bottom	0

Table 3.-The number of competitive events for food between juvenile fall chinook salmon as observed from underwater video from April - July, 1994. “Number Present" refers to the number of fish present on screen per feeding event. “Number Per Prey Item" refers to the number of fish attempting to capture the same food item. "Number of Events" refers to the frequency of each competive interaction observed.

Number Present	Number Per Prey Item	Number of Events
1	1	159
2	1	18
2	2	4
3	1	12
3	2	3
4	1	3
5	1	5
6	1	2
6	2	1
7	3	1
8	1	1
12	1	1

occurs. Dauble et. al (1989) collected peak numbers of juvenile fall chinook salmon moving downstream in the Hanford Reach in fyke nets between 2200 and 0000 hours during the middle of May. This suggests downstream movement may be associated with the peak nighttime activity we observed in early June. Conversely, Mains and Smith (1956) collected peak numbers of juvenile fall chinook salmon in the Hanford Reach during March and April, with a second peak during June and July consisting mainly of age one chinook. However, this study failed to account for upstream movement, so it is unclear whether this early peak actually represents directed movement.

Our observations of juvenile fall chinook salmon moving both up and downstream suggests little seaward migration is occurring through the nearshore corridor. Although many fish were captured moving downstream during the early run, it is difficult to draw conclusions since we did not have a net in place to capture fish moving upstream. Connor et al. (1993, 1994a, and 1994b) have shown that juvenile fall chinook salmon show high fidelity to nearshore areas during rearing and may begin to actively migrate upon reaching a size of 85 mm FL. Larger fish may prefer the higher velocities found off shore for seaward migration, which would be consistent with field and laboratory studies (Lister and Genoe 1970; Stein 1972; Taylor 1991).

It is possible that nearshore movements are related to feeding activity. Levels of feeding and movement during the four time periods mirrored one another during our study. We observed that juvenile fall chinook salmon orient themselves upstream while feeding and will travel up to 14 body lengths to capture a prey item. This could explain the amount of upstream movement observed if the distance moved in search of a food item is greater than the downstream movement observed after a strike. Finally, since juvenile fall chinook salmon spend a significant portion of the day feeding, nearshore movement patterns could represent searches for food.

Microhabitat utilization by juvenile fall chinook salmon appears to change throughout the day. During daylight hours the majority of fish observed were distributed throughout the water column and did not appear to be associated with any particular physical structure. Stein et al. (1972) also found juvenile fall chinook salmon distributed throughout the water column during the day and near the bottom at night in the Sixes River, Oregon. In contrast, Lister and Genoe (1970) found juvenile fall chinook salmon to be inactive during the day, suggesting they were hiding in the substrate, and most active at night in the Big Qualicum River, British Columbia. They also found juvenile fall chinook salmon to be strongly associated with shoreline cover such as fallen trees or undercut root-wads. We observed very little use of submerged vegetation by juvenile fall chinook salmon in our study area.

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CHAPTER SEVEN

Osmoregulatory Performance, Migration Behavior, and Marking of Subyearling Chinook Salmon at McNary Dam to Estimate Adult Contribution

by

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Introduction

Research conducted at McNary Dam from 1981 to 1983 determined that subyearling chinook salmon *Oncorhynchus tshawytscha* which emigrated earlier in the summer exhibited greater adult contribution than did later emigrants (Giorgi et al. 1990). No physical or biological factor could be isolated as a causal factor for this phenomenon even though a primary objective of the study was to examine the influence of flows on juvenile emigration and survival. Giorgi et al. (1990) attributed this failure to an inability to recover sufficient numbers of marked fish at John Day Dam to estimate their travel time through John Day Reservoir and the interaction among flow, temperature, fish size, physiological development, and origin of the fish.

This study was initiated in an attempt to resolve the questions pertaining to the influence of summer flows on the emigration of subyearling chinook salmon and their contribution **as** adults. The primary objective for this fourth year of study was to mark and release sufficient numbers of subyearling chinook salmon at McNary Dam to estimate their travel time through John Day Pool and to determine if release groups remained temporally discrete during emigration. A 'second objective was to describe the physiological development of premigrants from the Hanford Reach of the Columbia River and run-at-large fish marked and released at McNary Dam by using seawater challenges. The final objective was to describe the seasonal development of the migratory behavior of these fish at different water velocities in a series of laboratory experiments.

Methods

Marking and Release

Subyearling chinook salmon were collected from the juvenile fish collection facility at McNary Dam. The dam is equipped with submersible traveling screens to divert juvenile fish from the turbine intakes into gatewells and then to raceways. Fish entering the collection facility were subsampled by operation of a timed gate in the conduit moving fish to the holding raceways. Each group of fish was collected by repeated subsampling during a 24-h period starting at 0700 hours. The subsample rate ranged from 5% to 20% of the total number of fish diverted.

Subyearling chinook salmon were marked with coded-wire tags (CWT) and branded with cold brands (Jefferts et al. 1963; Mighell 1969). Fish were anesthetized with a preanesthetic of benzocaine (ethyl P-aminobenzoate) and an anesthetic of tricaine methanesulfonate (MS-2221 similar to that described by Matthews et al. (1986). Juvenile fish were then sorted by species and marked with either CWT and cold brands or CWT alone. Three segments of the emigration were marked; early, middle, and late. These segments approximated the 10, 50, and 90th percentiles of subyearling chinook salmon passage past McNary Dam. During each day of marking, 4,000 fish were to be branded and tagged. Branded fish received a unique combination of character, location, and rotation to identify the fish for subsequent determination of emigration time to John Day Dam. Fish which received only a CWT could not be used in travel time estimates but were marked to provide increased numbers of tagged fish to evaluate adult returns. Marked fish were released into the fish bypass system at McNary Dam between 2200 and 2300 hours on the day of marking. Juvenile salmon were collected at John Day Dam using an air-lift pump on turbine 3B (Brege et al. 1990), and the brands on recaptured fish were recorded.

The marking program included measures to ensure the quality of subyearling chinook salmon released at McNary Dam. Fish that were previously branded, adipose fin clipped and CWT tagged, descaled, or had injuries likely to result in mortality were not marked (Wagner 1995). Fish with fork lengths < 55 mm were also not marked. Twenty-five to 50 fish per day were held for 48 h to measure delayed mortality and CWT loss. Fish surviving the delayed mortality test were transported down stream by barge or truck to prevent confounding of emigration time estimates to John Day Dam.

Travel time of CWT groups was estimated to the nearest day by the method used by the Fish Passage Center (FPC) i.e., the difference between the median date of release at McNary Dam and the date nearest the median date of recovery based on the passage indices at John Day Dam. However, unlike FPC, we only estimated travel time to the nearest day and did not interpolate to the nearest tenth of a day. Flow at John Day Dam and temperature at McNary Dam during travel times were estimated by averaging from the day after fish were released at McNary Dam through the median day of recovery at John Day Dam. Travel time of CWT groups to John Day Dam was related to gill ATPase activity, release date, fork length, flow, and temperature using Pearson correlation analysis (SAS Institute 1990). Differences were considered statistically significant at $P \leq 0.05$.

Gill ATPase and Seawater Challenges

Gill Na^+,K^+-adenosine triphosphatase (ATPase) samples were collected from wild subyearling fall chinook salmon in the Hanford Reach of the Columbia River to assess smoltification of premigrants used in laboratory experiments. Gill ATPase samples were also collected from run-at-large emigrants at McNary Dam to characterize the smoltification of fish that were marked for travel time analysis.

Twenty-four-hour seawater challenges were employed to evaluate the physiological status of both premigrant subyearling chinook salmon from the Hanford Reach and subyearlings actively emigrating past McNary Dam. The general procedures of the seawater challenges followed Blackburn and Clarke (1987). Recirculating flow-through systems were used for challenged and control fish. The seawater system was composed of four 80-L plastic containers which drained into a sump reservoir and a pump that recirculated salt water from the sump to the plastic containers. The freshwater control system was identical to the seawater system except that only two containers were used. Each container held 15 fish which were allowed to acclimate for 24 h prior to being challenged. Chillers were placed in sump reservoirs to maintain water temperature at ambient river temperature up to 18.3°C. Artificial sea salt was dissolved and added to the sump reservoir of the seawater system to infuse salt water into the tanks without handling or disturbing the fish. A desired salinity of 30 parts-per-thousand (ppt) was usually achieved within one hour. Unchallenged control fish were maintained in fresh water.

At the end of a 24-h challenge, fish were immobilized in their tanks with 30 mg/L MS-222. Anesthetized fish were weighed to the nearest gram (g), measured to the nearest 1 mm fork length (FL), rinsed in fresh water, and their tails blotted dry before being severed. Blood was collected from the caudal artery in ammonium heparinized Natelson tubes, centrifuged, and the plasma immediately frozen in liquid nitrogen. Blood was pooled from three fish at a time to obtain an adequate sample of plasma from small fish collected early in the season, and was carried out through the remainder of the season for consistency. Gill filaments were collected for determination of Na^+,K^+-ATPase activity. Blood plasma was analyzed for Na^+ and K^+ by flame photometry and gill Na^+,K^+-ATPase activity was measured using a microassay (Schrock et al. 1994).

Both premigrant and actively emigrating subyearling chinook salmon were used in seawater challenges in 1994. Premigrants used in challenges were collected biweekly from the Hanford Reach from mid April to the end of June, 1994. Fish were collected with beach seines and transported in 80 L plastic containers to Cook, Washington. Oxygen was supplied to containers and water temperatures were maintained at ± 1°C of ambient river temperature. Actively emigrating subyearling chinook salmon were collected at the McNary Dam fish collection facility concurrently with marking. Four separate challenges were conducted from early July to October to characterize the seawater adaptability of emigrants during the early, middle, late, and post-season portions of the outmigration.

Migration Experiments

Movement behavior was studied in a compartmentalized fluvial tank (Figure 1) to determine the seasonal changes in migratory disposition of both premigrant and actively emigrating subyearling fall chinook salmon. Tests were conducted biweekly from May through August using fish collected from the Hanford Reach and from McNary Dam. Two tanks were used to provide fish with a series of up and downstream choices under different water velocities and light conditions. Each tank was 4.8 m long and was divided down the middle by a partition. Additional partitions were set perpendicular to the center partition to divide the tank into 16 compartments measuring 0.5 m wide by 0.6 m long by 0.6 m deep. Holes (0.1 m diameter) were cut in each compartment partition 0.2 m from the bottom and were staggered as shown in Figure 2 to increase the complexity of passage through the tank. Cone traps were set in two partitions to trap fish entering the farthest up and downstream compartments. A pump circulated water through the tank and a chiller maintained the water at ambient river temperature. Water depth in each tank was 0.4 m and velocities of 0, 15, 30, or 45 cm/s were maintained at each partition hole by adjusting a valve plumbed between the pump and the tank. Daytime tests were usually conducted from 0800 to 1600 h while nighttime tests were run from 2000 to 0400 h the next day.

Fish behavior was monitored remotely using video equipment. Four overhead video cameras were used to view all compartments during a test (Figure 1). By using a quad unit and VCR, images from all four cameras could be recorded simultaneously onto one video tape. Nighttime illumination was provided using infrared lights.

Tests were begun by placing screens over the partition holes of the acclimation compartment and introducing 10 fish (Figure 1). Placing fish in this compartment allowed seven upstream and eight downstream choices to be made before reaching the ends of the tank. Fish were allowed a 4-h acclimation period after which the screens were removed and the fish were allowed to move freely about the tank. Fish were then videotaped in 12-h time lapse mode for 4 h. At the end of each test, fish locations were recorded and the fish were either removed and weighed (g) and measured (mm) or else were left in the tank if they were to be used again.

A completely randomized design was used to evaluate movement behavior under all combinations of velocity and light, except the 45 cm/s velocity, which was only used during the daytime when sufficient numbers of fish could be obtained. Since two replicate tanks were used, each combination of light and velocity

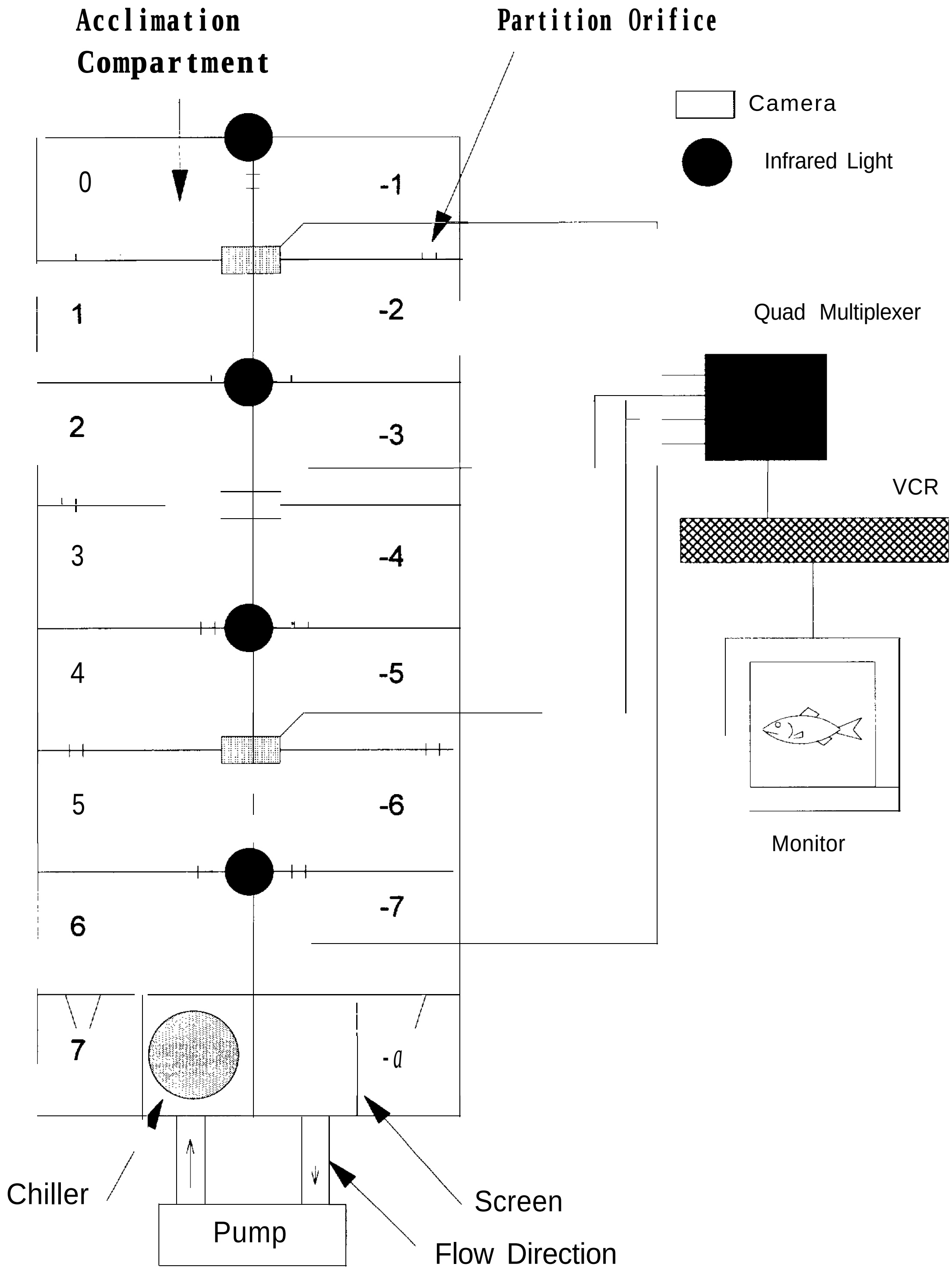

Figure 1.-Schematic of the tank, with compartment numbering convention, used to test migration behavior of subyearling chinook salmon in 1994.

were tested in each tank using different fish. New groups of fish were used for each water velocity tested in each tank. Each group of fish was evaluated twice at a particular velocity; once under light conditions and once in darkness. To avoid potential bias from starting both tests of a given velocity under the same light condition, the starting light condition between the two tanks was varied. For example, if a test began during the day and was followed by a night test in one tank, then that same water velocity would be tested in the second tank by starting at night and following it with a daytime test. The order of velocities tested were randomly determined for each tank. The following diagram is an example of a testing schedule for a given week:

	Tuesday		Wednesday		Thursday		Friday	
Tank	Day	Night	Day	Night	Day	Night	Day	Night
1	30*	30	0	0	15	15	45	
2	45	15	15	30	30	0	0	

* Velocities are in cm/s.

Tests were analyzed to obtain a net movement score, direction and mean rate of movement, and activity levels of fish. Scores were assigned to each fish based on the compartment it was located in at the end of the test. The acclimation compartment served as a reference and was assigned a score of 0. Then each compartment up and downstream were numbered sequentially, with downstream compartments being negative. Therefore, the higher the score for a given fish, the further upstream it traveled, and conversely, the lower the score, the further downstream it was at the end of the test. Scores for individual fish were summed to produce a net movement score for the test.

Each videotaped test was scanned for the times fish entered the up and downstream traps to derive movement rates. Fish which did not enter a trap during a test were assigned a time of 4 h, the maximum duration of each test. Times were coupled with fish locations at the end of each test to determine movement rates, which were expressed as compartments per hour. Like scores, movement rates also received a sign to indicate the net direction of movement.

To determine how final scores and movement rates were related to fish behavior during each test, the activity levels of fish were measured by counting the number of partitions that were passed within subsampled time blocks. Four 15-min time blocks within each test were scanned for the number of partitions that fish passed; no attempt was made to distinguish individual fish.

Activities from the four blocks were summed and adjusted for the number of fish in the traps and were expressed as the number of partitions passed per fish per hour.

Results

Marking, Release, and Recapture

In 1994, subyearling chinook salmon were marked to index the early, middle, and late portions of the outmigration. As in previous years, the marking of these segments was to correspond roughly to the 10, 50, and 90th percentiles of subyearling passage past McNary Dam. On July 17, a massive subyearling chinook salmon kill occurred from thermal stress which resulted in the McNary juvenile fish collection facility being dewatered for a 2 week period (Wagner 1995). All fish were bypassed during this time and were not available for sampling or marking. Because of the gap in data collection, passage index information is incomplete (Figure 2a). Based on the arrivals of PIT-tagged fish from Priest Rapids State Fish Hatchery and the Hanford Reach, the early group (N = 49,698) marked from June 21-30 consisted mainly of Priest Rapids fish. The middle group (N = 49,891) was marked from July 7-16 and comprised mainly of wild fish from the Hanford Reach. The late group (N = 31,980) was marked from August 2 to September 14 at a time of decreasing fish abundance in the system. As a result, the desired number marked fish was not achieved for this replicate (Wagner 1995).

A total of 130,019 subyearling chinook salmon were collected at McNary Dam, marked, and released in the tailrace (Table 1). Of the fish that were marked, 35,181 received CWTs only. An additional 2,550 marked fish were transported after being held for 48 h to estimate delayed mortality and CWT loss, which was 1.2% and 0.3%, respectively. A total of 35,848 early emigrants were tagged and marked with nine unique brands, and an additional 13,350 received CWTs only. The middle group of 35,935 emigrants were also tagged and marked with nine unique brands, and an additional 13,431 fish received CWTs only. The marking of this group was completed the day before McNary Dam went into emergency bypass operation. Only 23,055 subyearlings were branded and tagged to index the late segment of the outmigration, and an additional 8,400 fish received CWTs only. It took 44 d to mark this group, and marking started late due to the bypass situation.

Columbia River flows generally decreased while temperatures increased during the marking of subyearling chinook salmon at McNary Dam in 1994. Flows at McNary Dam averaged 168 KCFS during passage of the early mark group. Average flow was 156 KCFS during marking of the middle group and remained at this level until the end of July. While McNary Dam was in bypass operation,

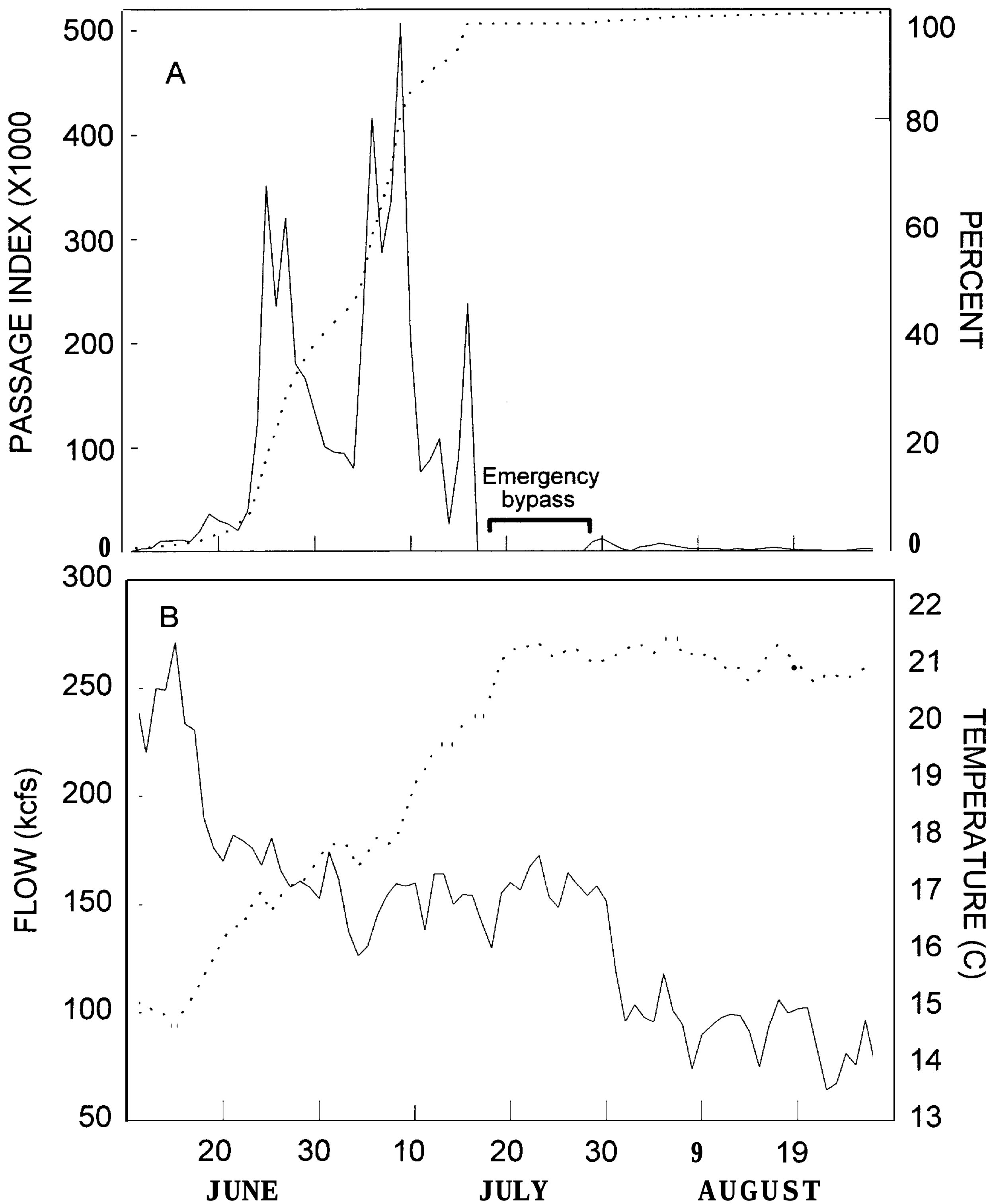

Figure 2.-Daily (solid line) and cumulative (dotted line) passage index (x1000) of subyearling chinook salmon (A) and daily flow (solid line) and temperature (dotted line;B) at McNary Dam, 1994.

Table 1.-Date, coded wire tag (CWT) code, number of subyearling chinook salmon released in the McNary Dam tailrace, and the number of fish held for 48 h to evaluate tag loss and mortality, 1994. Asterisks indicate fish which did not receive freeze brands.

Date	CWT Code	Marked & Released	Marked & Held	Percent Tag Loss	Percent Mortality
Jun 21-23	05-35-48	11,881	100	0.0	2.0
Jun 23	05-35-59	4,450 *	50	0.0	0.0
Jun 24-26	05-35-49	11,989	100	0.0	0.0
Jun 26	05-35-60	4,450 *	50	0.0	0.0
Jun 27-29	05-35-50	11,978	100	0.0	1.0
Jun 29-30	05-35-61	4,450 *	100	1.0	0.0
Subtotal		49,198	500	0.2	0.6
Jul 7-9	05-35-51	12,077	100	0.0	0.0
Jul 9	05-35-62	4,475 *	75	1.3	0.0
Jul 10-12	05-35-52	11,852	150	0.0	0.7
Jul 12	05-35-63	4,506 *	50	2.0	0.0
Jul 14-16	05-35-53	12,006	100	0.0	0.0
Jul 16	05-36-05	4,450 *	50	0.0	0.0
Subtotal		49,366	525	0.4	0.2
Aug 2-8	05-35-54	11,700	300	0.3	3.0
Aug 8-13	05-36-06	4,225 *	200	0.0	0.0
Aug 14-31	05-35-55	11,355	700	0.1	1.1
Aug 31-Sep 14	05-36-07	4,175 *	325	0.6	0.9
Subtotal		31,455	1,525	0.3	1.5
Total		130,019	2,550	0.3	1.1

an average of 12 KCFS was spilled daily. Flows were dramatically reduced during the marking of the late group and averaged 85 KCFS. Water temperatures during marking increased from 17°C in late June to 21°C by the end of August (Figure 2b).

The number of subyearling chinook salmon recaptured at John Day Dam ranged from 56 to 191 fish for the eight CWT replications and from 180 to 494 for the early, middle, and late groups (Table 2). Estimated travel times were 16, 11, and 15 days for the early, middle, and late branded groups, respectively. Graphically, the emigration distributions of the three groups past John Day Dam appear fairly distinct, however, the median dates of passage of the early and middle groups were both significantly different from the late group but not from each other (Figure 3). Travel times of CWT groups were not significantly correlated with flow, temperature, gill ATPase activity, median release date, or fork length (Table 3) and did not follow the trend observed in 1991-1993 (Figure 4).

Gill ATPase and Seawater Challenges

Gill ATPase activity of premigrant subyearling chinook salmon from the Hanford Reach was low but became elevated by the time of passage past McNary Dam (Figure 5). Gill ATPase activities increased with fish size in the Hanford Reach and continued to rise at McNary Dam until mid July. The subsequent decline in gill ATPase throughout the remainder of the season at McNary Dam was also observed from 1991-1993 (Figure 4). Premigrant subyearling chinook salmon from the Hanford Reach were seawater challenged for the first time in 1994. These fish ranged in size from about 40 mm FL in late April to 75 mm FL in late June. Mortality was high early in the season, but then decreased steadily to late June (Figure 6). Once actively emigrating fish began passing McNary Dam, mortality remained low with the exception the challenge conducted on August 5.

Plasma sodium levels of seawater challenged fish followed a trend similar to that of mortality (Figure 6). Values were high early in the season and then declined until early July. Levels increased again in August then dropped to 170 mmol/L in October. The plasma sodium values of subyearling chinook salmon collected at McNary Dam in 1994 were higher than in 1992 and 1993. Mean values from these years were all below 160 mmol/L. Plasma sodium levels in control fish remained fairly constant throughout the season.

Gill ATPase activities of seawater challenged and control fish were similar and followed a trend of increasing activity with time until early July (Figure 7). Activities decreased until late August and then rose slightly in October.

Table 2.–Median dates and number of subyearling chinook salmon released at McNary Dam and the number recovered, passage index (PI) and percent detection (%) at John Day Dam, 1994.

McNary Dam Release			Recovery at John Day Dam			
CWT Group	Median Date	Number	Median Date	Number	PI	%
05-35-48	22 Jun	11,881	3 Jul	64	699	5.9
05-35-49	25 Jun	11,989	8 Jul	56	585	4.9
05-35-50	27 Jun	11,978	20 Jul	60	647	5.4
Early	25 Jun	35,848	11 Jul	180	1,931	5.4
05-35-51	8 Jul	12,077	22 Jul	139	1,458	12.1
05-35-52	11 Jul	11,852	21 Jul	164	1,713	14.5
05-35-53	15 Jul	12,006	23 Jul	191	1,976	16.5
Middle	11 Jul	35,935	22 Jul	494	5,147	14.3
05-35-54	5 Aug	11,700	17 Aug	147	939	8.0
05-35-55	20 Aug	11,355	2 Sep	116	619	5.5
Late	8 Aug	23,055	23 Aug	263	1,558	6.8

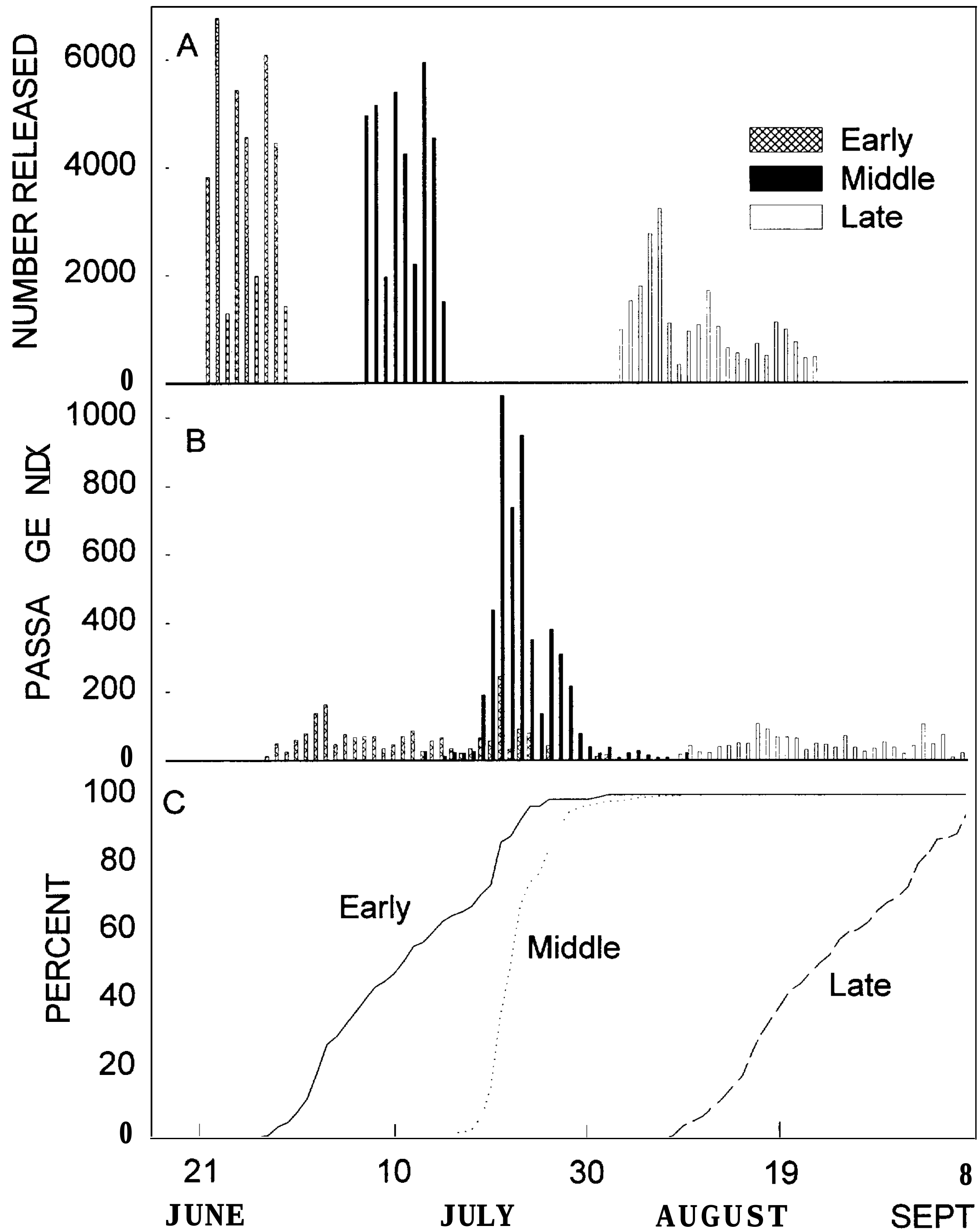

Figure 3.-Number of subyearling chinook salmon marked and released at McNary Dam with cumulative percent passage index (A) and the passage index of early, middle, and late emigrating marked groups (B) and the cumulative percent frequency of each group (C) recovered at John Day Dam, 1994.

Table 3.-Correlation of subyearling chinook salmon travel time from McNary Dam to John Day Dam with median release date, flow, temperature, gill ATPase activity, and fork length of coded wire-tagged (CWT) groups, 1994.

CWT Group	Travel Time (d)	Median Date	Flow (kcfs)	Temp. (°C)	ATPase Activity	FL (mm)
Early						
05-35-48	11	22 Jun	163	17.2	16.9	105
05-35-49	13	25 Jun	153	17.6	----	105
05-35-50	23	27 Jun	152	18.8	14.2	107
Middle						
05-35-51	14	8 Jul	154	20.1	21.6	110
05-35-52	10	11 Jul	153	20.3	22.2	110
05-35-53	8	15 Jul	155	20.9	----	112
Late						
05-35-54	12	5 Aug	93	21.1	17.1	125
05-35-55	13	20 Aug	81	20.7	11.7	130
r		-0.230	0.021	-0.272	-0.419	-0.153

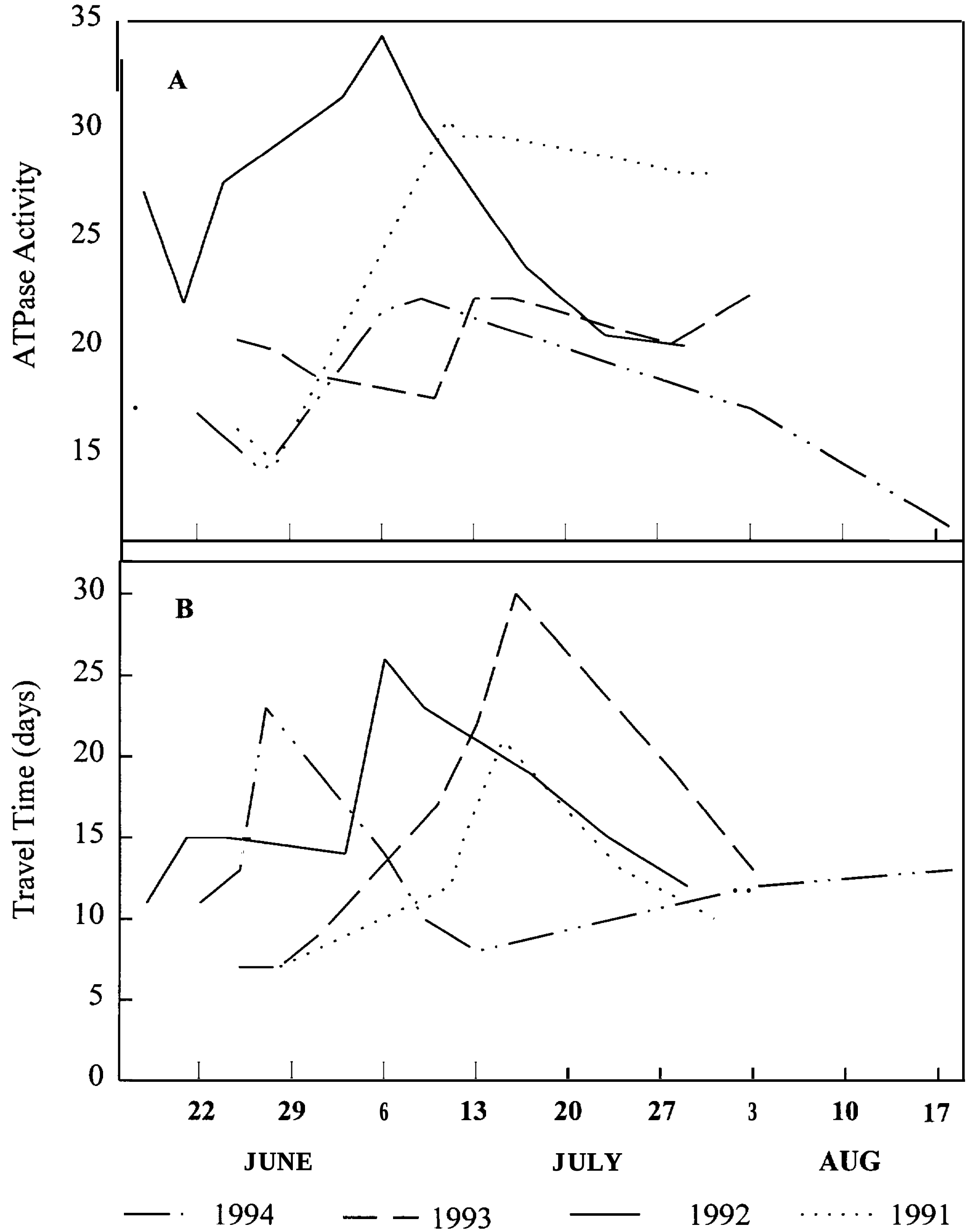

Figure 4.-Gill ATPase activity (A) and travel time to John Day Dam (B) calculated from median date of release of groups of subyearling chinook salmon marked at McNary Dam, 1991-1994.

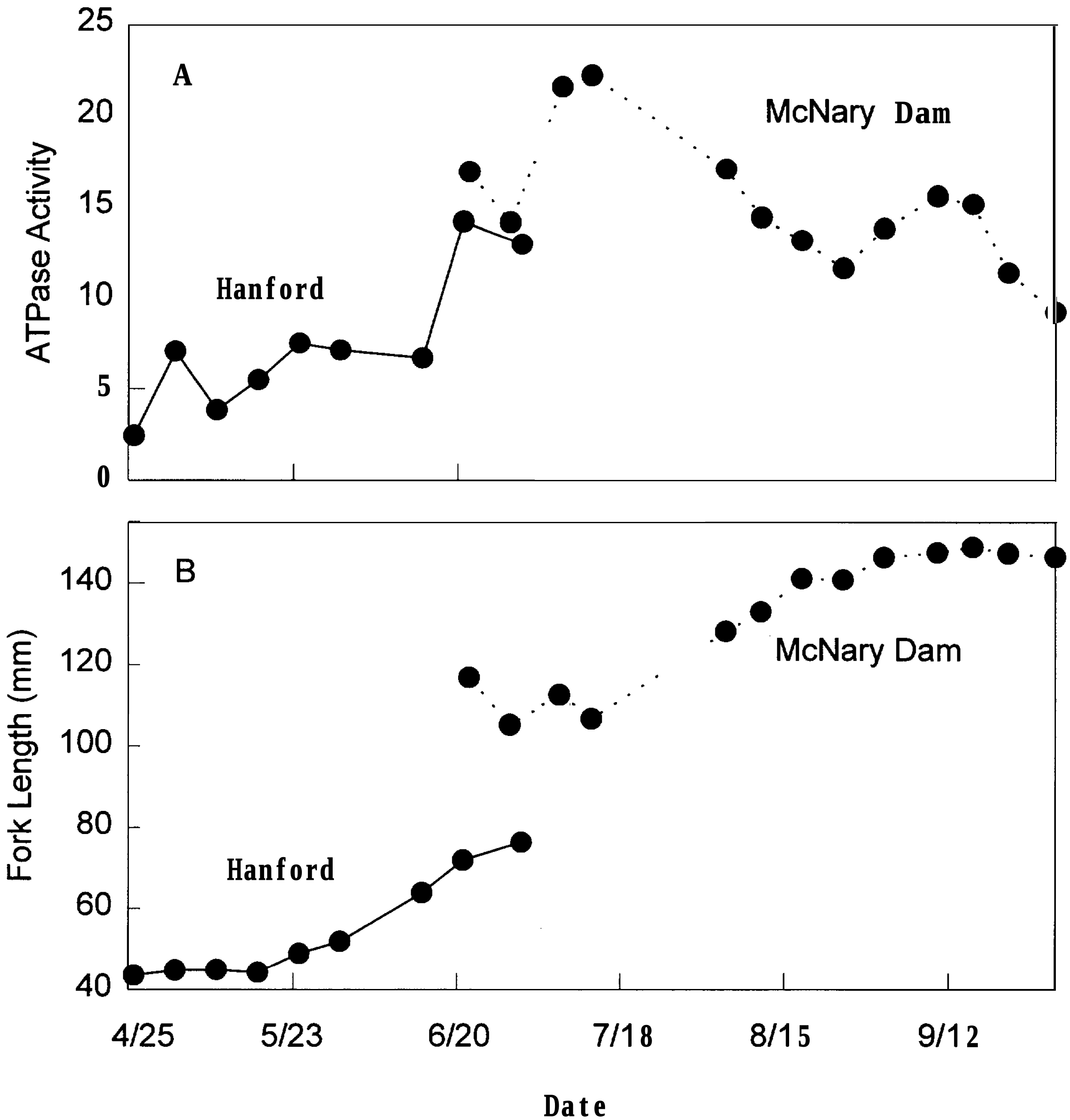

Figure 5.-Gill ATPase activities (A) and fork lengths (B) of subyearling chinook salmon collected in the Hanford Reach of the Columbia River and at McNary Dam in 1994.

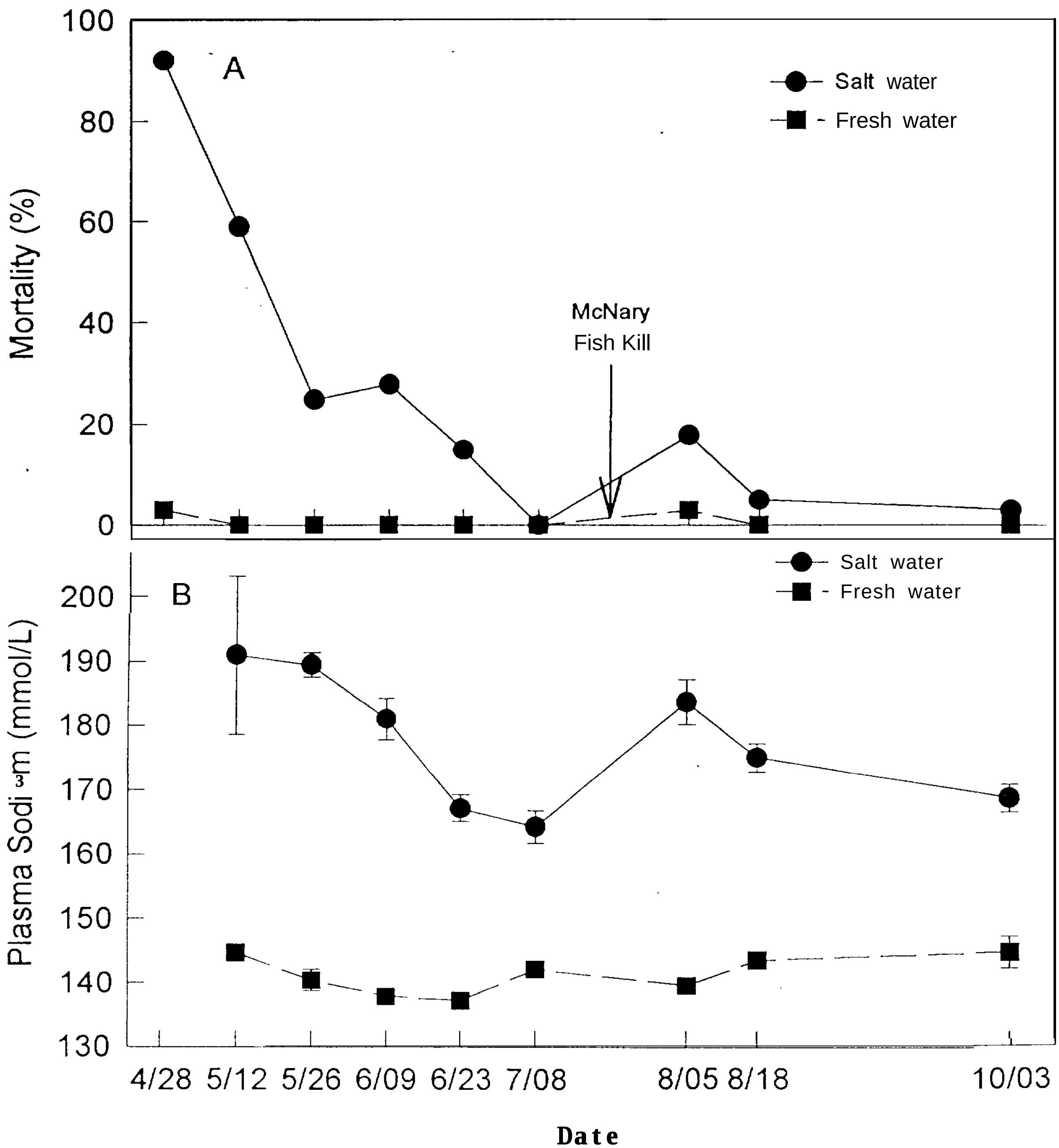

Figure 6.-Percent mortality (A) and plasma sodium levels (B), with standard error bars, of seawater challenged subyearling chinook salmon in 1994.

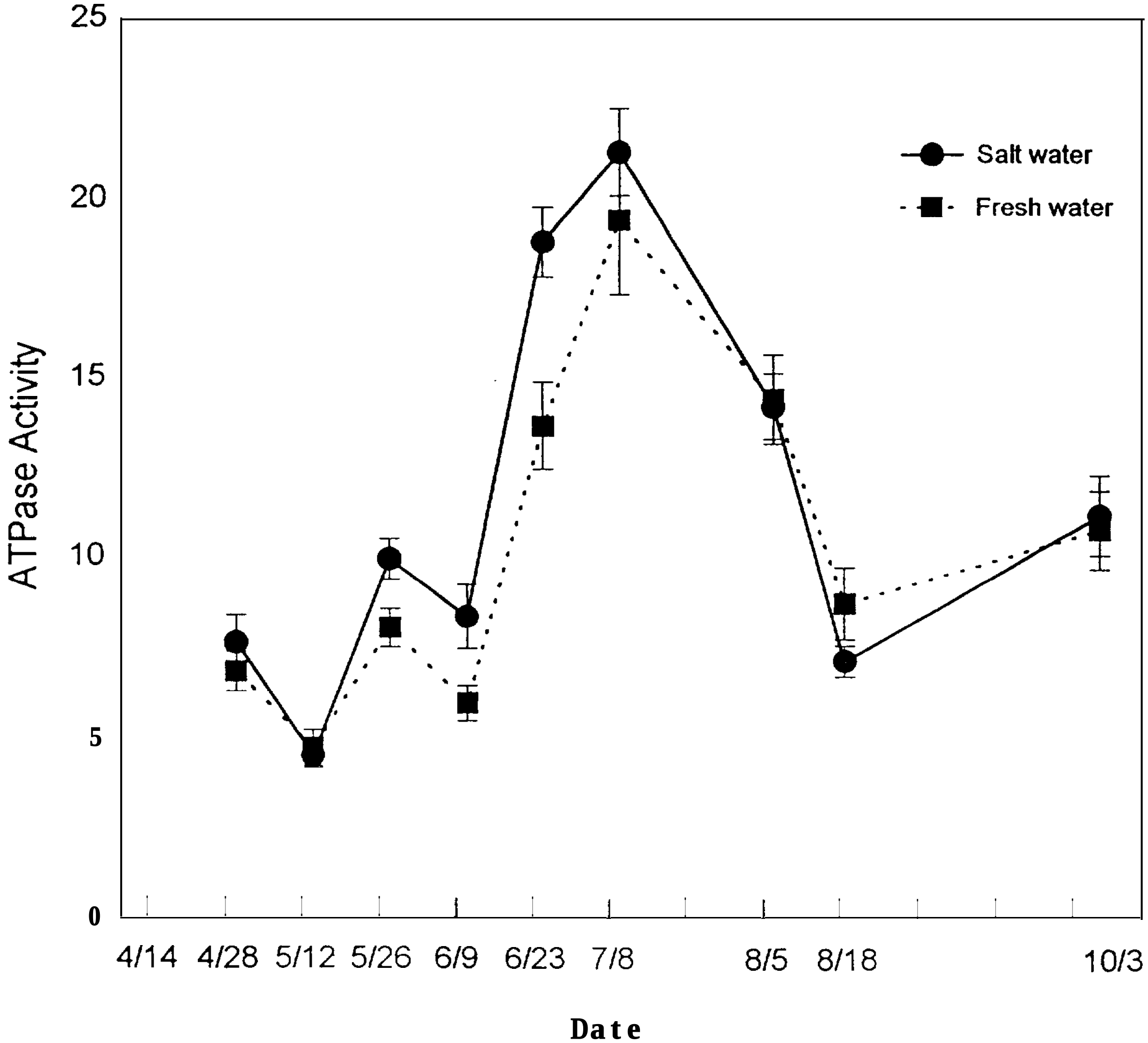

Figure 7.-Gill ATPase activities, with standard error bars, of seawater challenged subyearling chinook salmon in 1994.

Migration Experiments

Although migration experiments were begun in early May, the full complement of data collection did not begin until mid May when complete camera coverage was achieved. In addition, no nighttime data was collected for the 30 cm/s velocity during the week of August 1 due to an error in scheduling the testing sequence.

Movement scores of subyearling chinook salmon in migration tests were influenced by water velocity, light intensity, and seasonality. Fish exposed to 0 cm/s water velocity under both light and dark conditions exhibited net movement scores near 0 and were variable throughout the season with respect to direction (Figure 8). In contrast, net movement scores were considerably lower in tests conducted when water velocities were present (Figures 8-9). Fish in these tests primarily exhibited strong downstream movement early in the season, after which downstream movements lessened and some net upstream movements were observed after the end of June. Movement at night was almost exclusively downstream when velocity was present. Net nighttime movement was highest for fish tested at 15 cm/s, and as was true of fish tested at 30 cm/s, it was strongest early in May and June. Although the data is limited, the highest net downstream movement was observed for fish exposed to a water velocity of 45 cm/s during the day (Figure 9). Examining day and night movement together, a velocity of 15 cm/s produced the greatest downstream movement.

Movement rates were variable, but were generally highest and in a downstream direction, during the day at 45 cm/s, early in the season (Figure 10). This was also observed in fish tested at 15 and 30 cm/s, but movement rates were lower. Movement rates were generally lowest for fish exposed to no velocity regardless of movement direction, light conditions, and time of year. Nighttime rates were highest for fish moving downstream in water velocities of 15 or 30 cm/s; the 45 cm/s velocity was not tested at night.

Activity levels of fish were also measured to gauge movement behavior during a test. Activity is expressed as the mean number of partitions passed per fish per hour in a test. The higher the activity number, the more fish moved around the tank during a test. This is important for interpreting movement and rate data. For example, fish in a particular test may have been assigned a movement score near 0 at the end of the test if they all ended up near the acclimation compartment. A high activity level for this test would reveal that the fish moved throughout the tank many times despite their final location. Conversely, a high final score and low activity level would indicate that fish moved directly to the up or downstream ends of the tank.

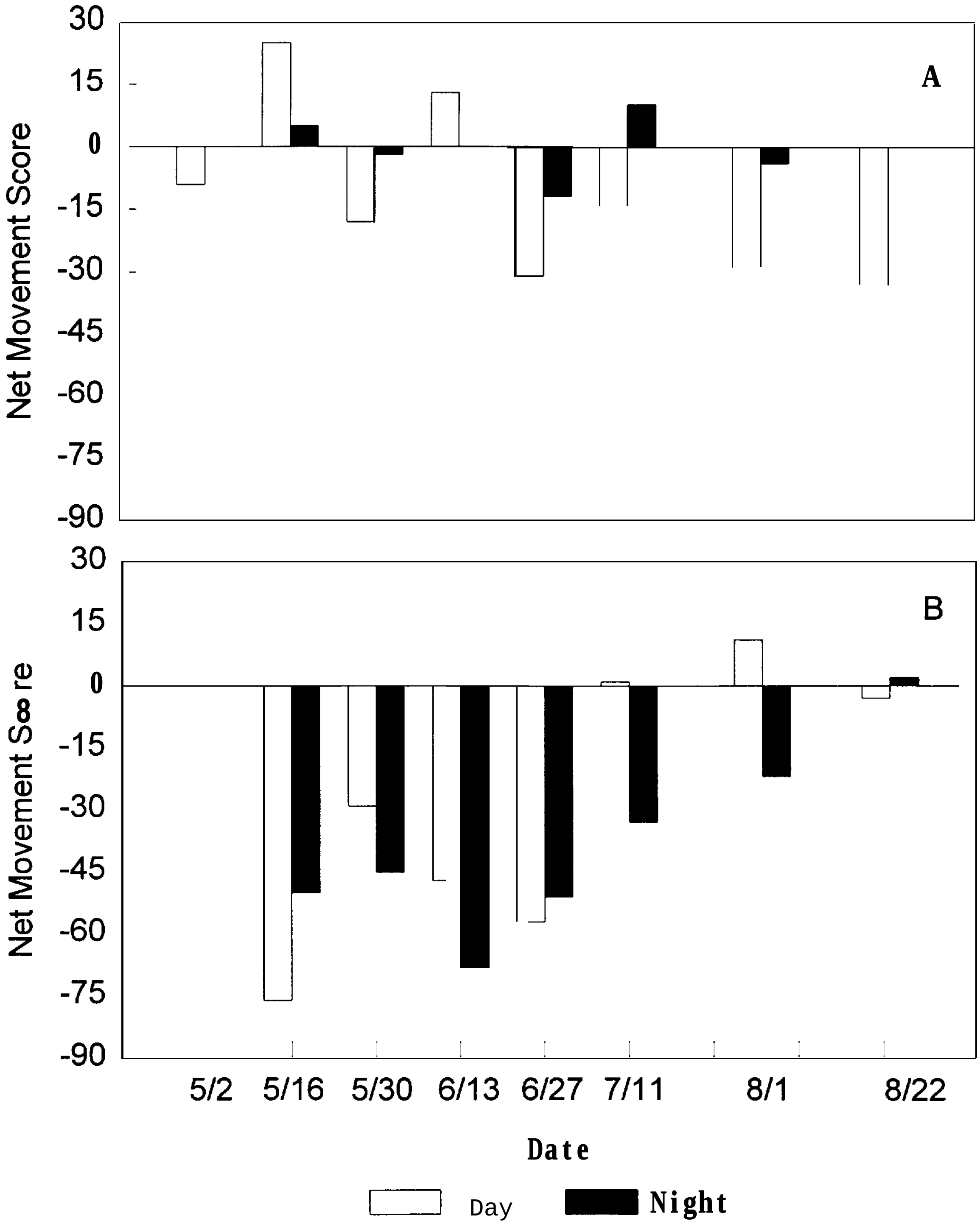

Figure 8.-Net movement scores of subyearling chinook salmon in migration tanks tested at 0 cm/s (A) and 15 cm/s (B) during the day and night in 1994. Negative scores indicate downstream movement; positive scores indicate upstream movement.

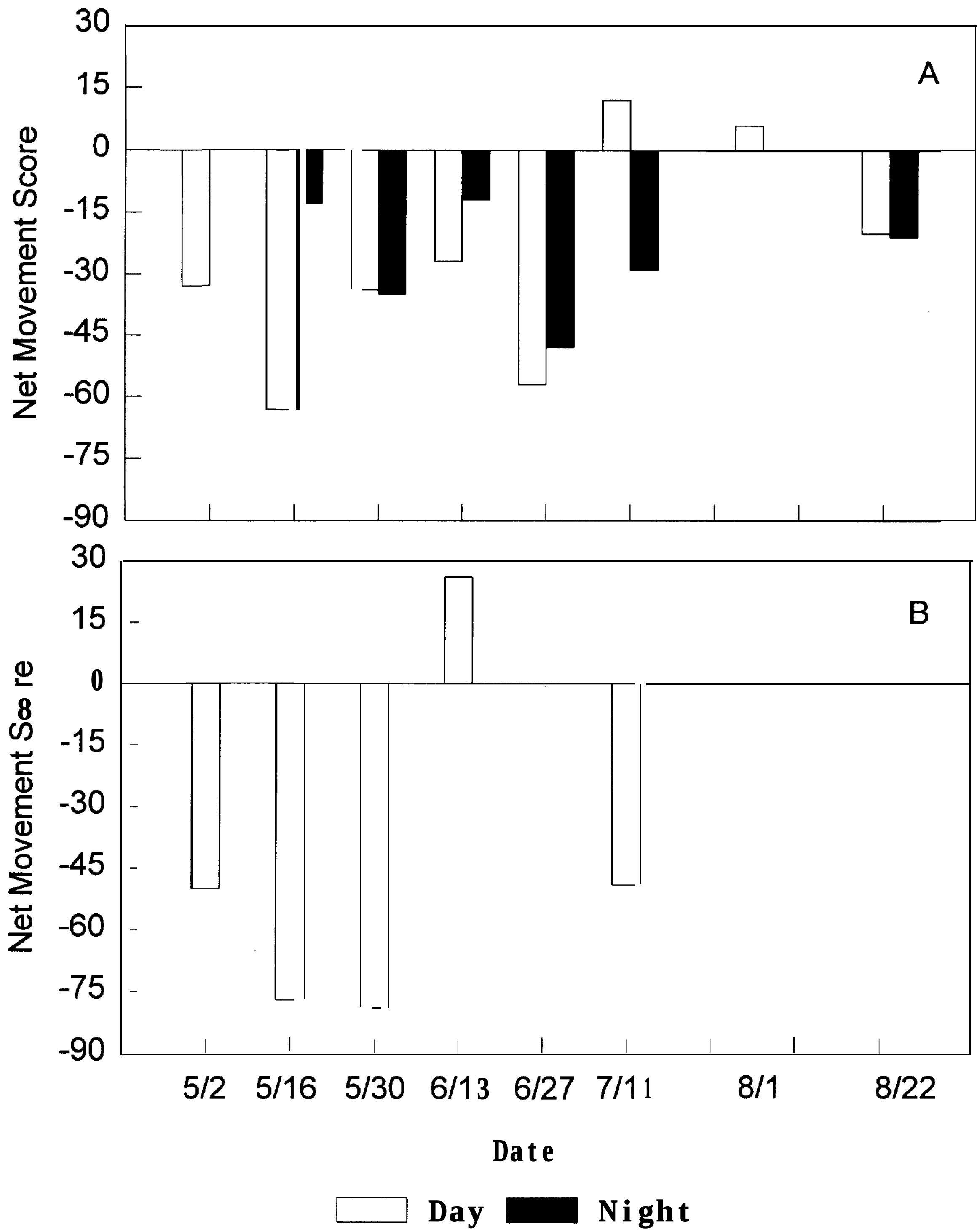

Figure 9.-Net movement scores of subyearling chinook salmon in migration tanks tested at 30 cm/s (A) and 45 cm/s (B) during the day and night in 1994. Negative scores indicated downstream movement; positive scores indicate upstream movement.

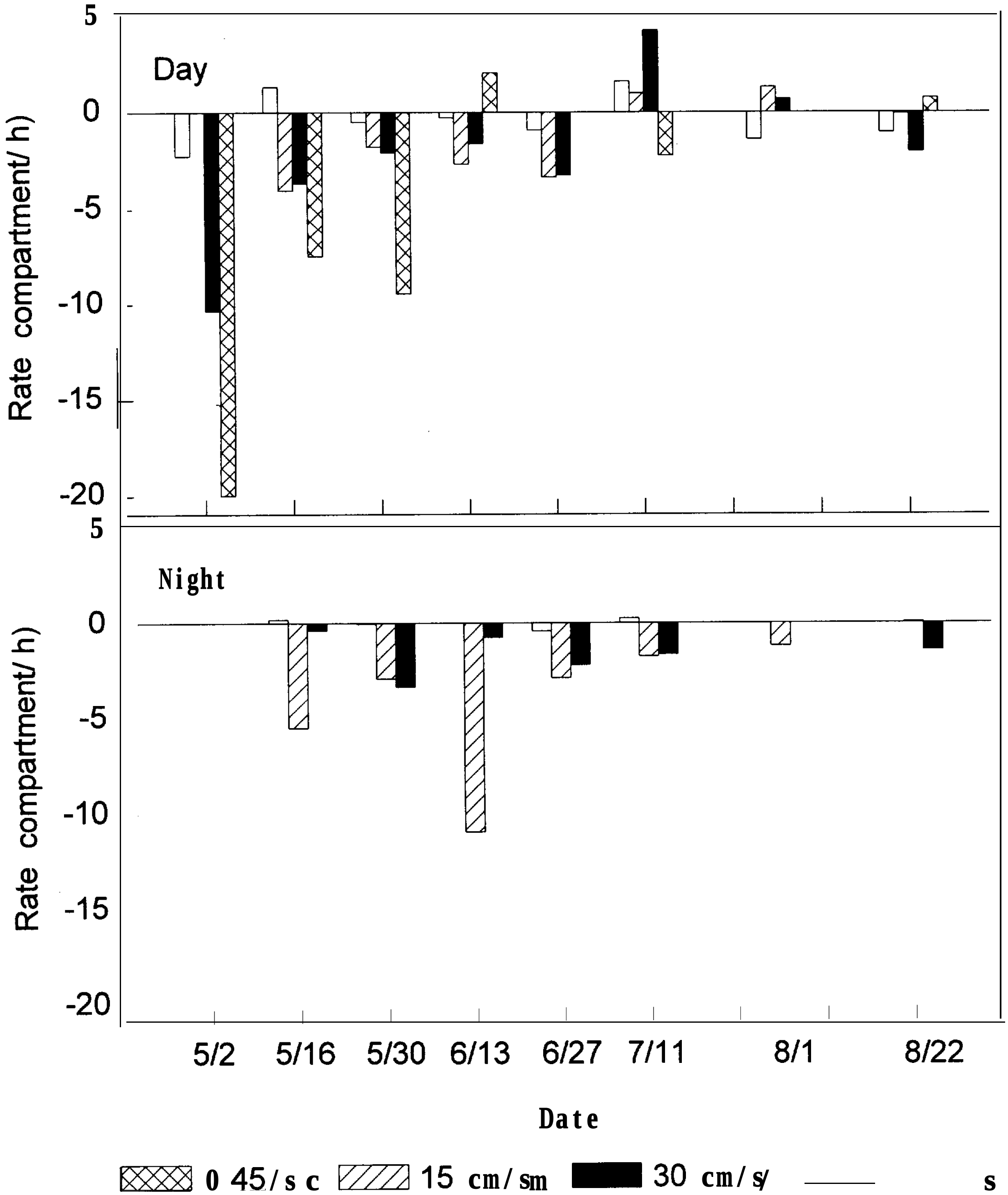

Figure 10.-Mean rates of movement of subyearling chinook salmon in migration tanks tested at different velocities during the day and night. Negative values indicate downstream movement rates; positive values indicate upstream movement rates.

Activity levels were highly variable with respect to water velocity throughout the season (Figure 11). Although movement scores and rates for fish tested at 0 cm/s during the day were generally near 0, activity levels were often higher than for tests when velocity was present. There were no apparent trends in activity levels when velocity was present, however, activities were low for fish tested at 45 cm/s during the day early in the season.

The most striking differences in activity levels were between day and night tests. Daytime activities were significantly higher than nighttime activity levels for all tests combined by week (Figure 11). Nighttime activities of fish tested at 15 and 30 cm/s were low while their movement rates and scores were often highly negative indicating that at night fish moved downstream more directly.

Discussion

Travel time of branded subyearling chinook salmon from McNary to John Day Dam was not significantly correlated with any of the physical and physiological variables tested in 1994 as was true in 1992 and 1993. The reason for this may be that travel times in 1994 showed no simple pattern of either increasing or decreasing over time. This made the likelihood of obtaining any significant correlations involving travel time improbable, especially given the small sample sizes used in correlation analyses.

The trend in travel time was opposite of those from 1991-1993 (Figure 4). In 1994, the fastest travel times occurred for fish marked during the middle portion of the outmigration. This group always had the slowest travel times in previous years. The early and late groups traveled at rates similar to those in 1991-1993. The marking of the middle group was completed just prior to the fish kill at McNary Dam in mid July. At this time, McNary Dam began spilling about 12 KCFS and total flows remained near 155 KCFS for the following two weeks. It is also suspected that the peak of wild fish passage past McNary Dam occurred during this time (Wagner 1995). Perhaps the combination of river flows and stock of the middle group contributed to their faster travel times in 1994. However, similar flows were also experienced in 1993 during the middle of the subyearling outmigration and travel times were the slowest encountered that year for that group. Finally, Skalski (1989) has shown that various assumptions related to passage index calculation at John Day Dam are often violated due to shifts in dam operations and subsequently may lead to biased travel time estimates. This may explain the observed travel time pattern. With four years of travel time data, it is unclear how travel time relates to other variables,

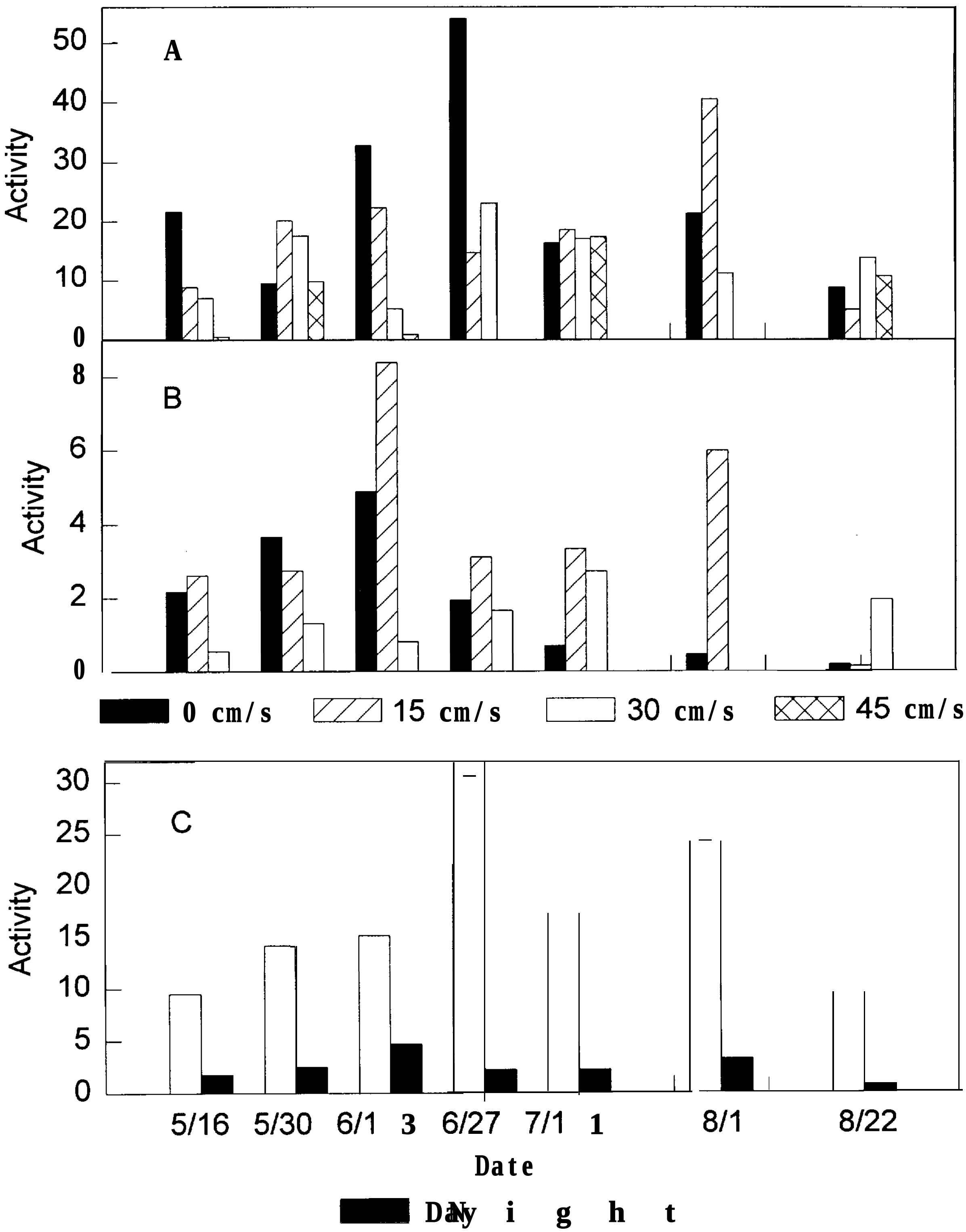

Figure 11.-Activity levels, expressed as number of partitions passed per fish per hour, of subyearling chinook salmon in migration tanks tested at different velocities during the day (A) and night (B) an all velocities combined (C) in 1994.

either singularly or in concert. Giorgi et al. (1990) also could not relate subyearling chinook salmon travel times through John Day Reservoir in the early 1980s to environmental variables. Adult return information may clarify now uncertain relationships.

Run-at-large gill ATPase activities followed a trend similar to that observed in 1991-1993, but values were generally low, as in 1993. High gill ATPase activities have been related to decreased travel times in juvenile spring chinook salmon (Beeman et al. 1991) but this was not observed in subyearling fall chinook salmon from 1991-1993. However, in 1994, the fastest travel times were associated with the highest gill ATPase activities, but correlation between these variables *was* not significant. The departure of 1994 travel time data from the trends observed in 1991-1993 makes it difficult to define a relationship between gill ATPase activity and travel time for subyearling chinook salmon.

The development of osmoregulatory competence in subyearling chinook salmon appears to be partly a function of fish size. As fish rear and grow in the Hanford Reach, osmoregulatory competence and gill ATPase activity increase as size increases. Upon reaching about 70 mm FL, subyearling chinook salmon had low mortality in 24-h seawater challenges and were able to regulate their plasma sodium to 165 mmol, the value used by Clarke and Shelbourn (1985) to characterize a chinook salmon smolt. Development of seawater tolerance and increasing gill ATPase activity in fish that are about 70 mm FL may act to cue migration. Fish larger than about 70 mm were not abundant in nearshore areas of the Hanford Reach and probably have moved off shore to begin emigrating seaward.

Emigrating subyearlings that passed McNary Dam in 1994 did not perform as well in seawater challenges as fish tested in 1992 and 1993. Data collected in previous years indicated active emigrants at McNary Dam performed well in seawater challenges regardless of when they passed. Plasma sodium levels and mortality were higher in 1994 than expected. This may be due in part to poor in-river conditions in late July and August, which may have had negative impacts on fish. Many fish were killed at McNary Dam in mid July from thermal stress (Wagner 1995), which also increases susceptibility to disease. In late July, 125 subyearlings were collected at John Day Dam and transported to Cook, Washington. In four days, all but seven fish had died of *Flexibacter columnaris* infection. This indicates that environmental and fish conditions were poor and mortality was probably high in John Day Reservoir. Conditions improved by early October and fish had increased survival and competence in seawater challenges despite being tested very late in the emigration season.

To date it is unclear how water velocity influences initiation of downstream migration and travel time of subyearling chinook salmon. Unlike the swimming trials conducted by Nelson et al. (1993, 1994), which examined swimming performance, the migration tests described here were more behaviorally oriented. Each fish passing a partition must make a choice to respond to the velocity encountered either by passing the partition or avoiding the velocity. The tank was designed to prevent fish from simply being washed downstream. In each compartment there were adequate zero velocity refuges that a fish could occupy if it did not choose to respond to the velocity. These tests do not provide causal mechanisms for observed behaviors, but do allow examination of similar behaviors exhibited in Nelson's experiments by using a different test apparatus.

It appears movement behavior in migration tanks is influenced by water velocity and seasonality. Mean movement scores and rates were generally higher when water velocity was present. In addition, movement was strongest in a downstream direction earlier in the season when fish were presumably still premigrants. During this time, fish in the Hanford Reach exhibited rapid growth and increases in gill ATPase activities. These factors may have contributed to increased movement during this time. In contrast, active migrants collected at McNary Dam in July and August showed a decrease in movement rates and had lower downstream scores, with more net upstream movement. This may be a result of fish either being in poor condition, which may affect behavior, or having decreased propensity to respond to water velocity during that time of the year. These fish were also considerably larger than the premigrants tested and may have behaved differently in the tanks. This was also a time when gill ATPase activity and river flows began to decline. However, this behavior was similar to the findings of Nelson et al. (1994) who showed subyearling chinook salmon exhibited a potential net upstream movement in August and Giorgi et al. (1990) who recaptured marked subyearlings upstream of release locations in John Day Reservoir.

Subyearling chinook salmon that moved at night in migration experiments did so almost exclusively in a downstream direction early in the season when the water velocity was 15 and 30 cm/s. The low activity levels of nighttime tests indicate that fish moved directly to the downstream traps and did not move back and forth between partitions as was often observed during the day. Although strong downstream movements were observed during the day as well, activity levels of test fish were high indicating fish may not be displaced downstream as rapidly as they might be at night.

Various environmental, physiological, and developmental factors act together to cue the seaward migration of subyearling chinook salmon. Although many correlative relations exist between the aforementioned variables and juvenile chinook salmon emigration (Beeman et al. 1991; Berggren and Filardo 1993), causal mechanisms of migration are still lacking. Nelson et al. (1993,1994) presented evidence that migration may result from downstream displacement brought about by reduced swimming performance. The experiments discussed here suggest a possible behavioral component to migration as well. Additional experimental data collected in 1995 may add to our understanding of this behavioral component.

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LIST OF APPENDICES

Appendix 1.-River kilometer (Rkm), landmark, and description of areas where fall chinook salmon redds were counted, 1987-1994.

Rkm	Landmark	Site Description
238.6	Ten Mile Range	From Ten Mile Range No. 1 to No. 6
239.9	Three Mile Island	Upstream of Ten Mile Range No. 3
243.8	Tenmile Creek	Idaho side of center channel just above Ten Mile Canyon
244.4	Ten Mile Canyon	Downstream of RM 152 flag on navigation chart
245.2	Big Bench Point	Idaho side above RM 152 flag on navigation chart
252.6	Warehouse at Couse Creek	Between range at RM 157 and mouth of Couse Creek
257.1	Lower Buffalo Range	Washington channel at head of island
259.0	Upper Buffalo Rapids	Idaho side channel at tongue
261.3	Captain Johns Creek	Adjacent to island on Idaho side
262.6	Captain John Rapids	Idaho side at RM 163 flag, and WA channel at rapids
265.0	Lower Billy Creek Rapids	Idaho side, Billy Creek to first ravine downstream
265.6	Perkins Gulch (ID side)	Gravel pockets, Idaho side next to shore above point
265.8	Perkins Gulch (WA side)	Scattered from center channel to Washington side
266.0	Fisher Gulch	No location data except for river mile
266.5	Billy Creek Range	Deep-water area off Washington-side beach
266.9	Match Line	Below navigation chart match line, near RM 166 flag
267.4	Fisher Range	Shallow gravel at Washington side of center channel
267.7	Lower Lewis Rapids	Washington side below Rapids No. 68 (Deep and shallow)
271.4	Grande Ronde River	Directly in front of Grande Ronde River mouth
272.7	Lewis Point	At head of Rapids No. 70
277.6	Deer Head Rapids	Small pocket of gravel in center-channel rock outcrop
279.8	Shovel Creek	No location data except for river mile
286.9	Cache Creek Range	Small gravel bar on Idaho side
288.0	Upper Cochran Range	In-line with Upper Cochran Range at tongue
289.0	Cougar Bar Range No. 4	Idaho side, range 3 to second small beach above range 4
306.4	Knight Creek	Near Oregon shore at upstream edge of Knight Creek fan
307.0	Eureka Bar	Spread out on Oregon shore
308.4	Imnaha River	Spread out along gravel bar on Oregon side
311.2	Divide Creek	Near instream rocks on Idaho side
311.7	Divide to Zig Zag	On Idaho side downstream of Oregon-side gravel-sand bar
311.8	Big Canyon Creek	At gravel-sand bar on Oregon side
312.1	Big Canyon Range	On Idaho side at head of split in river
312.3	Zig Zag Creek	In pool tailout between Idaho-side beach and rapid
315.4	Rapid No. 97	Off gravel bar on Idaho side above split
315.7	Dug Bar, OR	No location data except for river mile
319.9	Robinson Gulch	On Idaho side at match line on navigation chart
320.0	Deep Creek	No location data except for river mile
320.8	Trail Gulch	Idaho side above rapids No. 103
328.4	Near Blankenship Ranch	No location data except for river mile
330.2	Copper Creek	Oregon-side bar below lodge
330.8	Getta Creek	Idaho side below Getta Creek
332.1	High Range No.1	Idaho side gravel bar at Rapids No. 115

Appendix 1 (Continued).

Rkm	Landmark	Site Description
334.4	Lookout Creek Range	At head of rapids No. 117
334.5	Lookout Creek	Idaho-side gravel bar below Lookout Creek
337.4	Camp Creek	No location data except for river mile
340.9	McCarty Creek	Oregon-side gravel bar
343.2	Pleasant Valley Creek	Oregon side between RM 213 flag and Rapids No. 127
344.0	Lower Pleasant Rapid	Idaho side downstream of point
345.1	Pittsburg Range	Off gravel bar on Idaho side
345.5	Pittsburg Range	Oregon side above range
347.7	Klopton Creek	Small gravel pocket on Oregon side
349.6	Coral Creek Reef	Idaho and Oregon sides above Rapids No. 133
350.4	Durham Rapids	Idaho side at head of Rapids No. 135
351.1	Cat Gulch	No location data except for river mile
352.9	Kirby Range No. 5	Near small gravel bar on Idaho side
358.5	Suicide Rock	On both sides between point and Oregon-side bar
359.0	Hominy Creek	Oregon side below shallow gravel bar
359.9	Temperance Creek	Below Creek, no location data except for river mile
379.2	Hat Creek	From creek mouth downstream to rapid head
379.9	Saddle Creek	From creek mouth upstream to rapid base
380.9	Dry Gulch	Idaho side, no location data except for river mile
381.3	Lower Dry Gulch	Idaho channel at head of gravel bar
383.7	Three Creek Rapids	At head of first rapid above Three Creeks
387.1	Rocky Bar Camp	At gravel pockets on Oregon side downstream of camp
391.5	Warm Springs Camp	Upstream of camp on Idaho side
393.6	Brush Creek	Idaho side downstream from Brush Creek
396.6	Rocky Point	Oregon side at head of rapid

Appendix 2. Discharge data for the Snake, Imnaha, Salmon and Grande Ronde Rivers, August 1993 - June 1994.

Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River	Snake River at Anatone
18-Aug 1993	17100	245	8620	1380	28800
19-Aug 1993	19500	232	8060	1240	28100
20-Aug 1993	21500	225	7440	1160	31800
21-Aug 1993	12100	239	7130	1200	26300
22-Aug 1993	11800	254	7410	1170	20300
23-Aug 1993	12600	223	7530	1110	21600
24-Aug 1993	12500	211	7050	1040	22200
25-Aug 1993	14200	207	6640	968	21600
26-Aug 1993	11000	206	6360	967	21300
27-Aug 1993	11700	197	6160	936	18700
28-Aug 1993	10400	192	5990	885	19700
29-Aug 1993	7420	192	5850	890	17400
30-Aug 1993	13500	188	5750	878	16500
31-Aug 1993	12600	183	5600	850	21400
01-Sep 1993	14000	178	5440	811	19700
02-Sep 1993	14200	173	5250	773	21500
03-Sep 1993	13800	170	5110	732	20800
04-Sep 1993	14500	167	4970	693	20700
05-Sep 1993	12400	163	4860	682	20700
06-Sep 1993	14200	159	4790	664	18700
07-Sep 1993	15500	157	4730	640	21600
08-Sep 1993	15200	157	4660	597	21400
09-Sep 1993	16300	157	4560	576	22500
10-Sep 1993	15600	154	4500	561	21000
11-Sep 1993	13400	151	4430	548	21000
12-Sep 1993	9320	151	4400	547	18100
13-Sep 1993	5950	155	4440	543	13400
14-Sep 1993	5950	151	4440	554	11400
15-Sep 1993	5980	148	4440	574	11300
16-Sep 1993	6010	148	4440	586	11300
17-Sep 1993	6030	147	4380	612	11400
18-Sep 1993	11900	145	4350	611	13100
19-Sep 1993	9750	148	4410	603	17100
20-Sep 1993	13000	145	4460	617	16200
21-Sep 1993	12700	144	4440	623	19100
22-Sep 1993	13900	143	4380	621	18300
23-Sep 1993	18700	142	4330	613	22700
24-Sep 1993	12700	139	4310	611	20700
25-Sep 1993	14100	137	4310	613	18500
26-Sep 1993	17300	136	4290	614	21400
27-Sep 1993	17300	132	4250	610	22700
28-Sep 1993	21100	131	4220	605	24200
29-Sep 1993	22400	129	4220	604	26900
30-Sep 1993	19800	128	4150	596	26700

Appendix 2. (Continued).

Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River	Snake River at Anatone
01-Oct 1993	22800	127	4100	583	27100
02-Oct 1993	23600	126	4060	598	28400
03-Oct 1993	15400	126	4040	609	24300
04-Oct 1993	24700	123	4030	604	23400
05-Oct 1993	19000	123	4060	601	27200
06-Oct 1993	18600	124	4060	598	23900
07-Oct 1993	19600	142	4210	589	23200
08-Oct 1993	18400	147	4450	625	24100
09-Oct 1993	15200	137	4580	650	22600
10-Oct 1993	13700	133	4640	643	19400
11-Oct 1993	18500	130	4680	633	21900
12-Oct 1993	18200	129	4680	640	23300
13-Oct 1993	17400	131	4670	674	24300
14-Oct 1993	21500	150	4750	698	22600
15-Oct 1993	22100	147	4920	704	29400
16-Oct 1993	19700	143	5070	734	25700
17-Oct 1993	16500	155	5100	763	23600
18-Oct 1993	14500	146	5010	763	21500
19-Oct 1993	11200	144	4870	728	19600
20-Oct 1993	13800	142	4790	705	18000
21-Oct 1993	11700	140	4730	694	18800
22-Oct 1993	11600	135	4680	682	17200
23-Oct 1993	9520	133	4630	675	16300
24-Oct 1993	9560	131	4610	665	15200
25-Oct 1993	9480	129	4580	649	15100
26-Oct 1993	9510	129	4530	646	15100
27-Oct 1993	9520	129	4460	633	15100
28-Oct 1993	9550	136	4470	642	15000
29-Oct 1993	9530	147	4570	668	15000
30-Oct 1993	9490	137	4550	673	15100
31-Oct 1993	9480	134	4450	661	15000
01-Nov 1993	9450	135	4420	669	14900
02-Nov 1993	9450	132	4420	650	14900
03-Nov 1993	9450	132	4370	639	14800
04-Nov 1993	9470	132	4400	646	14800
05-Nov 1993	9510	134	4400	636	14900
06-Nov 1993	9460	129	4390	628	14900
07-Nov 1993	9450	125	4180	619	14800
08-Nov 1993	9500	119	4000	609	14500
09-Nov 1993	9580	123	3930	587	14500
10-Nov 1993	9540	142	3820	596	14400
11-Nov 1993	9520	129	4000	614	14300
12-Nov 1993	9490	126	4040	609	14500
13-Nov 1993	9500	138	3890	601	14500
14-Nov 1993	9520	131	3930	574	14400
15-Nov 1993	9600	118	4030	582	14500

Appendix 2. (Continued).

Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River	Snake River at Anatone
16-Nov 1993	9520	136	3830	619	14600
17-Nov 1993	9450	133	3880	641	14400
18-Nov 1993	9630	130	4080	648	14500
19-Nov 1993	9610	111	4090	629	14700
20-Nov 1993	9580	99	3870	588	14500
21-Nov 1993	9560	126	3480	565	14200
22-Nov 1993	9580	142	3380	604	13900
23-Nov 1993	9590	127	3970	611	14000
24-Nov 1993	9540	90	3850	522	14400
25-Nov 1993	9480	40	3340	370	13500
26-Nov 1993	9520	37	2650	540	12900
27-Nov 1993	9530	55	2290	600	12500
28-Nov 1993	9510	130	2470	970	12600
29-Nov 1993	9500	160	3330	981	13100
30-Nov 1993	9510	160	4030	847	14100
01-Dec 1993	9550	152	4380	903	14900
02-Dec 1993	9560	143	4590	1010	15300
03-Dec 1993	9530	136	4380	891	15300
04-Dec 1993	9550	146	4300	845	15100
05-Dec 1993	9490	130	4240	815	15000
06-Dec 1993	9490	114	4060	734	14800
07-Dec 1993	9500	132	3900	726	14500
08-Dec 1993	9540	144	3660	773	14500
09-Dec 1993	9540	145	3860	806	14300
10-Dec 1993	9490	139	4240	816	14700
11-Dec 1993	9560	151	4270	856	15000
12-Dec 1993	9570	149	4260	882	15000
13-Dec 1993	9570	137	4210	820	15000
14-Dec 1993	9590	134	4030	764	14800
15-Dec 1993	9570	137	3770	744	14600
16-Dec 1993	9550	134	3560	729	14200
17-Dec 1993	9540	131	3620	704	14100
18-Dec 1993	10200	124	3840	660	14500
19-Dec 1993	12500	98	3680	500	15300
20-Dec 1993	14300	89	3330	460	18000
21-Dec 1993	13200	99	3090	500	17000
22-Dec 1993	12500	99	2720	520	16400
23-Dec 1993	13100	113	2940	584	16200
24-Dec 1993	11600	91	3010	470	16400
25-Dec 1993	11500	107	3090	540	14200
26-Dec 1993	11700	122	3000	640	15300
27-Dec 1993	11700	133	3180	610	15400
28-Dec 1993	12400	110	3290	540	15500
29-Dec 1993	12200	128	3370	643	16400
30-Dec 1993	12200	148	3520	696	16400
31-Dec 1993	10600	138	3590	686	15900

Appendix 2. (Continued).

Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River	Snake River at Anatone
01-Jan 1994	9750	144	3630	759	15000
02-Jan 1994	9520	134	3800	880	14400
03-Jan 1994	9560	138	4070	1370	14900
04-Jan 1994	9610	140	4100	1680	15600
05-Jan 1994	13500	154	4160	2290	17700
06-Jan 1994	12400	141	4200	1880	20000
07-Jan 1994	14500	125	4060	1520	18400
08-Jan 1994	14200	132	3910	1290	20400
09-Jan 1994	14100	134	3660	1190	19200
10-Jan 1994	14000	128	3580	1140	18400
11-Jan 1994	15400	127	3820	1140	19700
12-Jan 1994	12700	128	3880	1210	19800
13-Jan 1994	14500	128	3860	1290	19000
14-Jan 1994	15700	127	3880	1440	20500
15-Jan 1994	11800	128	3920	1610	19800
16-Jan 1994	13700	128	3900	1620	17800
17-Jan 1994	19200	119	3820	1490	22400
18-Jan 1994	19400	115	3770	1350	24200
19-Jan 1994	15200	114	3660	1260	22700
20-Jan 1994	15500	112	3520	1180	19500
21-Jan 1994	17700	117	3290	1110	21200
22-Jan 1994	12100	122	3210	1080	20200
23-Jan 1994	12100	128	3290	1070	15900
24-Jan 1994	14200	136	3340	1070	18000
25-Jan 1994	13200	136	3550	1050	17800
26-Jan 1994	16400	136	3780	1050	19800
27-Jan 1994	15600	132	3790	1040	20400
28-Jan 1994	10100	130	3730	1000	18900
29-Jan 1994	9620	116	3560	958	14900
30-Jan 1994	10100	130	3360	919	14700
31-Jan 1994	11800	90	3220	874	15100
01-Feb 1994	10100	63	2900	790	15500
02-Feb 1994	10600	70	2360	760	14300
03-Feb 1994	11000	85	2260	779	14200
04-Feb 1994	12600	95	2440	818	14500
05-Feb 1994	12700	100	2690	772	16200
06-Feb 1994	10400	105	2770	799	15200
07-Feb 1994	14800	110	3010	825	15200
08-Feb 1994	19700	119	3150	770	22200
09-Feb 1994	22600	115	3330	702	26000
10-Feb 1994	12500	115	3440	746	19800
11-Feb 1994	12800	110	3390	796	17700
12-Feb 1994	13400	120	3400	757	16500
13-Feb 1994	11600	116	3520	739	16700
14-Feb 1994	13400	134	3530	730	17200
15-Feb 1994	14600	133	3480	725	18300

Appendix 2. (Continued).

Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River	Snake River at Anatone
16-Feb 1994	15600	131	3460	721	18200
17-Feb 1994	14500	137	3590	750	20000
18-Feb 1994	15700	147	3640	872	19600
19-Feb 1994	16800	125	3670	841	20400
20-Feb 1994	15500	126	3620	788	20500
21-Feb 1994	14400	125	3490	763	19700
22-Feb 1994	14400	121	3450	749	18700
23-Feb 1994	16100	125	3510	832	18700
24-Feb 1994	13700	134	3590	1340	20600
25-Feb 1994	11000	126	3500	1230	17900
26-Feb 1994	9820	132	3530	1170	15800
27-Feb 1994	9800	149	3660	1390	15100
28-Feb 1994	11300	149	3860	2180	16600
01-Mar 1994	9560	160	3910	3030	17800
02-Mar 1994	9870	455	3970	4630	18900
03-Mar 1994	11700	465	4200	6400	24300
04-Mar 1994	10500	514	4470	7470	25200
05-Mar 1994	11900	512	4820	6840	26100
06-Mar 1994	13600	426	4930	5700	25800
07-Mar 1994	15300	356	4680	4710	26500
08-Mar 1994	15900	324	4350	3880	26100
09-Mar 1994	13600	292	4160	3250	22600
10-Mar 1994	13800	287	4120	2970	20400
11-Mar 1994	13100	277	4110	2910	22400
12-Mar 1994	11400	257	4120	2890	19200
13-Mar 1994	12900	251	4090	2900	20000
14-Mar 1994	15700	262	4060	3040	21700
15-Mar 1994	14300	298	4160	3450	24900
16-Mar 1994	16900	378	4470	4220	24500
17-Mar 1994	21100	389	4940	4270	29300
18-Mar 1994	15600	363	5180	3970	29000
19-Mar 1994	20800	346	5080	3740	26700
20-Mar 1994	14600	315	4930	3370	28200
21-Mar 1994	22100	302	4690	3140	29000
22-Mar 1994	12700	278	4530	2920	23700
23-Mar 1994	17900	251	4430	2650	23800
24-Mar 1994	16800	239	4280	2420	25100
25-Mar 1994	12800	234	4150	2260	21800
26-Mar 1994	9410	223	4050	2150	17000
27-Mar 1994	9360	224	4190	2170	16400
28-Mar 1994	10100	244	4310	2430	17400
29-Mar 1994	9410	290	4410	2940	17700
30-Mar 1994	9380	337	4580	3460	18400
31-Mar 1994	9380	374	4880	3850	19300
01-Apr 1994	9410	382	5190	4000	19800
02-Apr 1994	9400	436	5620	4460	20600

Appendix 2. (Continued).

Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River	Snake River at Anatone
03-Apr 1994	9410	542	6280	5030	22100
04-Apr 1994	9340	550	6920	5080	23300
05-Apr 1994	9350	481	6800	4710	22900
06-Apr 1994	11000	452	6390	4680	22400
07-Apr 1994	12700	437	6130	4720	26100
08-Apr 1994	13100	408	5890	4510	25000
09-Apr 1994	12000	420	5630	4530	22700
10-Apr 1994	15100	408	5500	4570	26100
11-Apr 1994	14200	403	5380	4480	25500
12-Apr 1994	17400	437	5490	4570	27100
13-Apr 1994	12100	476	5770	4560	27200
14-Apr 1994	13600	490	5950	4380	24400
15-Apr 1994	13300	480	5940	4070	25200
16-Apr 1994	11300	539	5970	4170	23100
17-Apr 1994	9630	718	6760	4730	23700
18-Apr 1994	13300	1010	8900	5690	26300
19-Apr 1994	9770	1230	12000	6960	32400
20-Apr 1994	10200	1300	15400	7620	34000
21-Apr 1994	9690	1320	18200	8360	39300
22-Apr 1994	11700	1250	20800	7940	41600
23-Apr 1994	16200	1140	23300	7020	46800
24-Apr 1994	13900	1240	22200	6660	50000
25-Apr 1994	11800	1260	20900	6490	44700
26-Apr 1994	14200	1280	19300	6130	41800
27-Apr 1994	19400	1170	17100	5530	45400
28-Apr 1994	17000	1050	15300	5080	41300
29-Apr 1994	24100	937	13900	4740	43800
30-Apr 1994	24300	884	13000	4580	44600
01-May 1994	24300	813	12500	4330	43600
02-May 1994	22700	757	12200	4080	41800
03-May 1994	23100	723	12100	3930	40500
04-May 1994	23300	756	12300	4010	41000
05-May 1994	24400	919	13000	4600	43800
06-May 1994	24900	940	14300	4770	45300
07-May 1994	24800	995	16400	4960	48200
08-May 1994	24400	1110	19700	5490	51800
09-May 1994	25300	1260	23900	6130	57900
10-May 1994	25100	1300	26900	6510	62100
11-May 1994	23300	1270	28100	6330	64300
12-May 1994	10700	1430	30300	6910	55600
13-May 1994	9560	1300	31400	6540	51900
14-May 1994	9550	1110	28800	5570	49100
15-May 1994	11300	1010	25600	4980	44500
16-May 1994	9570	901	23500	4660	43000
17-May 1994	9590	975	21700	4270	38500
18-May 1994	9630	958	20700	4060	37200

Appendix 2. (Continued).

Date	Hells Canyon Dam	Imnaha River	Salmon River	Grande Ronde River	Snake River at Anatone
19-May 1994	10400	969	19600	3900	35600
20-May 1994	9580	993	18900	4300	35700
21-May 1994	9480	988	18700	4710	35100
22-May 1994	9480	998	18500	4820	35500
23-May 1994	11300	961	18700	4850	35800
24-May 1994	17000	948	18200	4850	39700
25-May 1994	14700	966	18400	4880	42100
26-May 1994	13800	1040	19100	4970	40200
27-May 1994	14600	1140	21200	5120	42800
28-May 1994	13700	1030	22600	4830	44800
29-May 1994	13800	914	22000	4490	43100
30-May 1994	14300	822	20500	4030	41500
31-May 1994	15200	812	19200	3770	40400
01-Jun 1994	9500	837	19300	3510	37000
02-Jun 1994	9480	826	20900	3380	35500
03-Jun 1994	9430	804	19800	3300	35100
04-Jun 1994	9530	845	18800	3510	34000
05-Jun 1994	9520	814	17800	3430	33100
06-Jun 1994	9500	793	16800	3310	31600
07-Jun 1994	9480	767	16100	3200	30800
08-Jun 1994	9500	695	15300	2890	29600
09-Jun 1994	9530	632	14400	2640	28400
10-Jun 1994	9520	632	13400	2520	27200

Appendix 3. Water temperature at two locations in the Snake River, August 1993 - June 1994.

Date		Billy Creek Rkm 265	Pittsburg Landing Rkm 347
18-Aug	1993	20.7	21.1
19-Aug	1993	20.8	20.9
20-Aug	1993	20.8	20.9
21-Aug	1993	20.7	20.9
22-Aug	1993	20.6	21.0
23-Aug	1993	20.7	21.0
24-Aug	1993	20.2	20.7
25-Aug	1993	19.5	20.4
26-Aug	1993	19.4	20.4
27-Aug	1993	19.4	20.5
28-Aug	1993	19.3	20.3
29-Aug	1993	18.9	20.0
30-Aug	1993	18.6	20.2
31-Aug	1993	19.4	20.2
01-Sep	1993	19.7	20.5
02-Sep	1993	20.1	20.4
03-Sep	1993	20.2	20.4
04-Sep	1993	20.3	20.4
05-Sep	1993	20.4	20.2
06-Sep	1993	20.3	20.2
07-Sep	1993	20.3	20.3
08-Sep	1993	20.4	20.3
09-Sep	1993	20.5	20.5
10-Sep	1993	20.6	20.5
11-Sep	1993	20.5	20.5
12-Sep	1993	19.5	19.6
13-Sep	1993	18.6	19.3
14-Sep	1993	17.8	19.3
15-Sep	1993	17.5	19.3
16-Sep	1993	17.6	19.2
17-Sep	1993	17.6	19.0
18-Sep	1993	17.4	19.1
19-Sep	1993	17.9	19.1
20-Sep	1993	17.5	18.9
21-Sep	1993	17.3	18.6
22-Sep	1993	17.0	18.4
23-Sep	1993	17.0	18.6
24-Sep	1993	17.4	18.4
25-Sep	1993	17.1	18.5
26-Sep	1993	17.3	18.3
27-Sep	1993	17.4	18.3
28-Sep	1993	17.4	18.3
29-Sep	1993	17.7	18.2
30-Sep	1993	17.8	18.2
01-Oct	1993	17.6	18.1
02-Oct	1993	17.6	18.0

Appendix 3. Continued.

Date		Billy Creek Rkm 265	Pittsburg Landing Rkm 347
03-Oct	1993	17.5	17.9
04-Oct	1993	17.2	17.8
05-Oct	1993	17.4	17.7
06-Oct	1993	17.1	17.7
07-Oct	1993	17.0	17.4
08-Oct	1993	16.6	17.1
09-Oct	1993	16.0	16.9
10-Oct	1993	15.7	16.7
11-Oct	1993	15.6	16.7
12-Oct	1993	16.0	16.8
13-Oct	1993	16.0	16.7
14-Oct	1993	15.6	16.5
15-Oct	1993	15.7	16.5
16-Oct	1993	15.5	16.4
17-Oct	1993	15.3	16.3
18-Oct	1993	15.1	16.1
19-Oct	1993	14.7	16.0
20-Oct	1993	14.2	15.7
21-Oct	1993	14.0	15.5
22-Oct	1993	13.7	15.4
23-Oct	1993	13.6	15.3
24-Oct	1993	13.3	15.2
25-Oct	1993	12.9	14.6
26-Oct	1993	12.3	14.4
27-Oct	1993	11.9	14.3
28-Oct	1993	11.9	14.3
29-Oct	1993	11.9	14.1
30-Oct	1993	11.6	13.9
31-Oct	1993	11.3	13.7
01-Nov	1993	11.1	13.7
02-Nov	1993	10.9	13.5
03-Nov	1993	10.9	13.3
04-Nov	1993	10.8	13.4
05-Nov	1993	10.5	13.0
06-Nov	1993	10.1	12.7
07-Nov	1993	9.8	12.4
08-Nov	1993	9.5	12.1
09-Nov	1993	9.2	11.9
10-Nov	1993	9.2	11.9
11-Nov	1993	9.0	11.6
12-Nov	1993	8.7	11.4
13-Nov	1993	8.2	11.2
14-Nov	1993	8.1	11.0
15-Nov	1993	8.0	10.7
16-Nov	1993	8.2	10.7
17-Nov	1993	8.2	10.6
18-Nov	1993	8.2	10.3

Appendix 3. Continued.

Date		Billy Creek Rkm 265	Pittsburg Landing Rkm 347
19-Nov	1993	7.7	9.9
20-Nov	1993	7.2	9.6
21-Nov	1993	7.0	9.4
22-Nov	1993	7.1	9.4
23-Nov	1993	6.6	8.7
24-Nov	1993	5.6	7.9
25-Nov	1993	4.8	7.7
26-Nov	1993	4.7	7.4
27-Nov	1993	4.9	7.1
28-Nov	1993	5.1	7.1
29-Nov	1993	5.2	7.2
30-Nov	1993	5.3	7.4
01-Dec	1993	5.3	7.3
02-Dec	1993	5.2	7.1
03-Dec	1993	5.2	7.0
04-Dec	1993	5.4	6.9
05-Dec	1993	5.1	6.5
06-Dec	1993	4.7	6.4
07-Dec	1993	4.5	6.5
08-Dec	1993	4.7	6.7
09-Dec	1993	5.1	6.5
10-Dec	1993	5.4	6.6
11-Dec	1993	5.6	6.5
12-Dec	1993	5.6	6.2
13-Dec	1993	5.2	6.0
14-Dec	1993	4.7	6.0
15-Dec	1993	4.7	6.0
16-Dec	1993	4.9	6.0
17-Dec	1993	4.9	5.9
18-Dec	1993	4.7	5.8
19-Dec	1993	4.5	5.6
20-Dec	1993	4.6	5.6
21-Dec	1993	4.7	5.4
22-Dec	1993	4.6	5.3
23-Dec	1993	4.5	5.3
24-Dec	1993	4.4	5.1
25-Dec	1993	3.8	4.7
26-Dec	1993	3.6	4.6
27-Dec	1993	3.5	4.6
28-Dec	1993	3.4	4.4
29-Dec	1993	3.3	4.4
30-Dec	1993	3.4	4.3
31-Dec	1993	3.6	4.2
01-Jan	1994	3.7	4.3
02-Jan	1994	3.6	4.3
03-Jan	1994	3.9	4.5
04-Jan	1994	4.1	4.5

Appendix 3. Continued.

Date		Billy Creek Rkm 265	Pittsburg Landing Rkm 347
05-Jan	1994	4.3	4.4
06-Jan	1994	4.3	4.3
07-Jan	1994	3.9	4.2
08-Jan	1994	3.8	4.4
09-Jan	1994	4.1	4.4
10-Jan	1994	4.2	4.4
11-Jan	1994	4.3	4.5
12-Jan	1994	4.5	4.4
13-Jan	1994	4.5	4.3
14-Jan	1994	4.5	4.1
15-Jan	1994	4.2	4.1
16-Jan	1994	4.0	4.0
17-Jan	1994	3.9	3.9
18-Jan	1994	3.8	3.7
19-Jan	1994	3.6	3.6
20-Jan	1994	3.4	3.5
21-Jan	1994	3.2	3.4
22-Jan	1994	3.4	3.4
23-Jan	1994	3.3	3.4
24-Jan	1994	3.4	3.4
25-Jan	1994	3.6	3.3
26-Jan	1994	3.7	3.4
27-Jan	1994	3.7	3.2
28-Jan	1994	3.6	3.1
29-Jan	1994	3.3	3.1
30-Jan	1994	3.1	3.2
31-Jan	1994	2.8	2.9
01-Feb	1994	2.5	2.8
02-Feb	1994	2.3	2.8
03-Feb	1994	2.2	2.8
04-Feb	1994	2.3	2.7
05-Feb	1994	2.3	2.6
06-Feb	1994	2.3	2.7
07-Feb	1994	2.2	2.7
08-Feb	1994	2.2	2.5
09-Feb	1994	2.3	2.5
10-Feb	1994	2.4	2.6
11-Feb	1994	2.4	2.7
12-Feb	1994	2.5	2.6
13-Feb	1994	2.7	2.7
14-Feb	1994	2.9	2.9
15-Feb	1994	3.2	3.0
16-Feb	1994	3.4	3.0
17-Feb	1994	3.7	3.1
18-Feb	1994	3.7	3.2
19-Feb	1994	3.7	3.2
20-Feb	1994	3.6	3.2

Appendix 3. Continued.

Date		Billy Creek Rkm 265	Pittsburg Landing Rkm 347
21-Feb	1994	3.6	3.4
22-Feb	1994	3.7	3.4
23-Feb	1994	3.7	3.5
24-Feb	1994	3.5	3.3
25-Feb	1994	3.2	3.4
26-Feb	1994	3.5	3.5
27-Feb	1994	3.9	3.7
28-Feb	1994	4.3	3.7
01-Mar	1994	4.8	4.1
02-Mar	1994	5.5	4.3
03-Mar	1994	5.9	4.3
04-Mar	1994	6.0	4.4
05-Mar	1994	5.5	4.3
06-Mar	1994	5.0	4.3
07-Mar	1994	4.7	4.3
08-Mar	1994	4.8	4.5
09-Mar	1994	5.0	4.6
10-Mar	1994	5.5	4.7
11-Mar	1994	5.9	4.7
12-Mar	1994	6.0	4.8
13-Mar	1994	5.9	4.8
14-Mar	1994	6.1	4.9
15-Mar	1994	6.5	5.0
16-Mar	1994	6.7	5.2
17-Mar	1994	6.3	5.1
18-Mar	1994	6.2	5.2
19-Mar	1994	6.0	5.1
20-Mar	1994	5.8	5.0
21-Mar	1994	6.1	5.2
22-Mar	1994	5.9	5.3
23-Mar	1994	5.9	5.9
24-Mar	1994	6.3	6.4
25-Mar	1994	6.8	6.7
26-Mar	1994	7.3	7.1
27-Mar	1994	7.8	7.3
28-Mar	1994	8.3	7.5
29-Mar	1994	8.8	7.7
30-Mar	1994	9.0	7.8
31-Mar	1994	9.1	7.9
01-Apr	1994	9.2	8.0
02-Apr	1994	9.6	8.0
03-Apr	1994	9.9	8.0
04-Apr	1994	9.1	7.7
05-Apr	1994	8.7	7.9
06-Apr	1994	9.0	8.3
07-Apr	1994	8.9	8.3
08-Apr	1994	8.8	8.6

Appendix 3. Continued.

Date		Billy Creek Rkm 265	Pittsburg Landing Rkm 347
09-Apr	1994	9.2	8.8
10-Apr	1994	9.3	8.7
11-Apr	1994	9.4	8.9
12-Apr	1994	9.8	9.1
13-Apr	1994	9.4	9.1
14-Apr	1994	9.5	9.2
15-Apr	1994	10.0	9.4
16-Apr	1994	10.7	9.9
17-Apr	1994	11.6	10.2
18-Apr	1994	12.4	10.2
19-Apr	1994	12.3	10.1
20-Apr	1994	12.3	10.4
21-Apr	1994	12.3	10.3
22-Apr	1994	11.3	10.4
23-Apr	1994	10.9	10.6
24-Apr	1994	10.9	11.0
25-Apr	1994	10.3	11.3
26-Apr	1994	10.5	11.4
27-Apr	1994	10.5	11.2
28-Apr	1994	10.7	11.2
29-Apr	1994	10.8	11.3
30-Apr	1994	11.0	11.2
01-May	1994	10.9	11.4
02-May	1994	11.5	11.1
03-May	1994	11.7	11.0
04-May	1994	12.1	11.5
05-May	1994	12.4	12.2
06-May	1994	12.9	12.4
07-May	1994	13.4	12.6
08-May	1994	13.9	13.0
09-May	1994	14.0	13.1
10-May	1994	13.8	13.3
11-May	1994	13.6	13.5
12-May	1994	13.7	13.8
13-May	1994	13.2	13.8
14-May	1994	13.0	13.9
15-May	1994	12.8	13.9
16-May	1994	12.4	14.0
17-May	1994	12.2	13.9
18-May	1994	11.9	14.1
19-May	1994	12.2	14.3
20-May	1994	12.4	14.3
21-May	1994	12.6	14.3
22-May	1994	13.1	14.3
23-May	1994	13.5	14.4
24-May	1994	14.4	14.4
25-May	1994	15.0	14.5

Appendix 3. Continued.

Date	Billy Creek Rkm 265	Pittsburg Landing Rkm 347
26 -May 1994	15.4	14.8
27 -May 1994	15.2	14.6
28 -May 1994	14.1	14.5
29-May 1994	13.4	15.1
30 -May 1994	13.6	15.6
3 l-May 1994	14.2	15.4
01-Jun 1994	14.3	15.4
02-Jun 1994	14.3	15.7
03-Jun 1994	14.8	16.1
04-Jun 1994	15.4	16.0
05-Jun 1994	15.6	15.8
06-Jun 1994	15.3	15.7
07-Jun 1994	15.0	15.4
08-Jun 1994	14.7	15.9
09-Jun 1994	15.4	16.6
10-Jun 1994	16.1	16.7

Appendix 4. Data for chinook salmon juveniles that were PIT tagged in the Snake and Clearwater rivers then detected at Lower Granite Dam in 1994.

Tag code	Release date	Release length (mm)	Release site	Detection date	Detection length	Days at large	Race	Age
7F7D454E54	09/06/94	103	SNAKER	08/07/94	121	29.08	Sprg/summ	0
IF62407847	07/06/94	104	SNAKER	13/07/94	144	36.13	Sprg/summ	0
1F5A6C2477	31/05/94	74	SNAKER	29/07/94	158	58.79	Sprg/summ	0
1F5E313919	08/06/94	88	SNAKER	11/07/94	132	40.93	Sprg/summ	0
1F58085A27	01/06/94	95	SNAKER	29/07/94	169	58.05	Sprg/summ	0
1F587E3655	31/05/94	93	SNAKER	12/07/94	145	41.78	Sprg/summ	0
7F7D3D7320	15/06/94	95	SNAKER	24/06/94	96	9.29	Sprg/summ	0
7F7D397510	01/06/94	95	SNAKER	23/06/94	100	28.09	Sprg/summ	0
1F5E441F20	05/05/94	64	SNAKER	18/07/94	160	74.06	Sprg/summ	0
7F7D2C0037	08/06/94	86	SNAKER	03/08/94	159	56.03	Sprg/summ	0
1F5E215111	01/06/94	96	SNAKER	29/06/94	115	28.29	Sprg/summ	0
1F5E776F1D	18/05/94	74	SNAKER	17/07/94	135	59.76	Sprg/summ	0
1F5F156D00	17/05/94	83	SNAKER	06/08/94	176	80.86	Sprg/summ	0
200F1A684F	31/05/94	92	SNAKER	18/07/94	129	48.06	Sprg/summ	0
1F6243724A	19/05/94	80	SNAKER	09/07/94	137	51.10	Sprg/summ	0
7F7D454E46	09/06/94	78	SNAKER	16/07/94	133	37.09	Sprg/summ	0
1F602B084E	01/06/94	89	SNAKER	06/07/94	129	34.83	Sprg/summ	0
1F571F0F5C	31/05/94	75	SNAKER	04/07/94	116	46.59	Sprg/summ	0
1F573E527A	31/05/94	88	SNAKER	17/07/94	135	46.71	Sprg/summ	0
7F7D45565B	15/06/94	100	SNAKER	05/08/94	151	51.20	Sprg/summ	0
1F56717C1E	02/06/94	104	SNAKER	08/07/94	126	35.64	Sprg/summ	0
1F57605A50	07/06/94	103	SNAKER	14/07/94	147	43.25	Sprg/summ	0
7F7D455C4D	15/06/94	84	SNAKER	20/07/94	137	34.89	Sprg/summ	0
1F5F4E397B	07/06/94	83	SNAKER	04/08/94	158	25.23	Fall	0
7F7D783E26	24/05/94	69	SNAKER	28/06/94	112	34.78	Fall	0
7F7D0E502F	08/06/94	70	SNAKER	04/07/94	106	26.02	Fall	0
7F7D10021D	08/06/94	78	SNAKER	29/08/94	171	82.46	Fall	0
7F7D0E2273	07/06/94	86	SNAKER	04/07/94	121	26.89	Fall	0
7F7D1B643C	09/06/94	83	SNAKER	09/07/94	125	30.13	Fall	0
7F7D2B3E7E	08/06/94	94	SNAKER	07/07/94	136	28.69	Fall	0
7F7D2B5C3A	08/06/94	79	SNAKER	28/07/94	148	49.95	Fall	0
7F7D2B6255	25/05/94	66	SNAKER	08/07/94	126	44.12	Fall	0
7F7D2A7E14	09/06/94	95	SNAKER	05/07/94	121	25.21	Fall	0
7F7D77025F	31/05/94	73	SNAKER	24/09/94	185	115.74	Fall	0
7F7B013148	24/05/94	67	SNAKER	11/07/94	129	47.54	Fall	0
IF62227865	31/05/94	79	SNAKER	25/07/94	152	55.10	Fall	0
1F562F0A52	22/06/94	96	SNAKER	10/07/94	123	17.19	Fall	0
IF60376763	09/06/94	81	SNAKER	09/07/94	126	30.07	Fall	0
1F60410B35	01/06/94	70	SNAKER	11/07/94	122	39.99	Fall	0
1F6043615D	02/06/94	82	SNAKER	18/07/94	129	45.84	Fall	0
1F62206A75	09/06/94	78	SNAKER	16/07/94	127	36.14	Fall	0
7F7D7C3B12	24/05/94	70	SNAKER	30/07/94	160	66.64	Fall	0
IF62234319	01/06/94	67	SNAKER	06/07/94	109	35.00	Fall	0
7F7D7C4328	24/05/94	61	SNAKER	12/09/94	169	111.35	Fall	0
IF62320449	31/05/94	85	SNAKER	06/08/94	168	66.50	Fall	0
IF62350545	31/05/94	76	SNAKER	05/07/94	123	34.81	Fall	0
IF62382621	08/06/94	87	SNAKER	11/07/94	130	32.08	Fall	0
7F7D7C5068	24/05/94	71	SNAKER	08/07/94	130	44.54	Fall	0
1F6244417A	31/05/94	75	SNAKER	18/07/94	147	47.23	Fall	0
7F7D392569	24/05/94	67	SNAKER	11/08/94	148	79.19	Fall	0
7F7D45452F	09/06/94	82	SNAKER	07/07/94	116	27.92	Fall	0
7F7D455225	08/06/94	82	SNAKER	11/07/94	124	33.05	Fall	0
7F7D453A28	15/06/94	83	SNAKER	24/07/94	139	39.11	Fall	0
7F7D453C79	09/06/94	92	SNAKER	06/08/94	165	58.14	Fall	0
7F7D453E1C	09/06/94	90	SNAKER	12/07/94	132	32.53	Fall	0
7F7D454271	08/06/94	86	SNAKER	24/07/94	144	45.90	Fall	0
7F7D45293E	09/06/94	90	SNAKER	10/07/94	127	31.02	Fall	0
7F7D3D784F	15/06/94	88	SNAKER	06/08/94	158	52.07	Fall	0
7F7D454841	08/06/94	85	SNAKER	07/07/94	125	28.50	Fall	0
7F7D454A0E	09/06/94	85	SNAKER	22/07/94	146	42.76	Fall	0
7F7D454C7A	15/06/94	97	SNAKER	15/07/94	138	29.85	Fall	0

Appendix 4. (Continued).

Tag code	Release date	Release length (mm)	Release site	Detection date	Detection length	Days at large	Race	Age
7F7D454D33	08/06/94	80	SNAKER	03/07/94	116	24.42	Fall	0
7F7D453643	15/06/94	a7	SNAKER	10/07/94	117	24.19	Fall	0
7F7D2B667D	25/05/94	66	SNAKER	09/09/94	174	107.25	Fall	0
7F7D3E0D2F	09/06/94	96	SNAKER	25/06/94	102	16.40	Fall	0
7F7D3A0357	09/06/94	80	SNAKER	11/07/94	122	26.00	Fall	0
7F7D3B6E6D	24/05/94	66	SNAKER	08/07/94	118	45.33	Fall	0
7F7D392827	01/06/94	83	SNAKER	13/07/94	136	41.19	Fall	0
7F7D392F54	25/05/94	66	SNAKER	15/07/94	130	50.23	Fall	0
7F7D39357D	26/05/94	70	SNAKER	12/07/94	128	47.14	Fall	0
7F7D397029	09/06/94	96	SNAKER	15/07/94	137	35.87	Fall	0
7F7D454E5B	15/06/94	93	SNAKER	10/07/94	122	24.75	Fall	0
7F7D3D781A	09/06/94	90	SNAKER	02/07/94	117	22.37	Fall	0
1F622B0450	31/05/94	61	SNAKER	10/07/94	117	40.10	Fall	0
7F7D3D6D02	15/06/94	85	SNAKER	03/07/94	120	17.60	Fall	0
7F7D45561F	08/06/94	75	SNAKER	12/07/94	119	33.75	Fall	0
7F7D455306	08/06/94	88	SNAKER	07/07/94	124	28.55	Fall	0
1F60341736	25/05/94	75	SNAKER	07/07/94	129	42.18	Fall	0
1F56293F23	31/05/94	85	SNAKER	11/07/94	134	40.30	Fall	0
1F5E3A4603	01/06/94	84	SNAKER	02/07/94	137	31.62	Fall	0
IF57716732	01/06/94	76	SNAKER	04/07/94	117	32.75	Fall	0
1F5738232F	02/06/94	64	SNAKER	07/07/94	107	34.40	Fall	0
1F5955191A	31/05/94	88	SNAKER	10/07/94	137	40.11	Fall	0
1F5F684159	08/06/94	70	SNAKER	11/07/94	121	33.11	Fall	0
1F59521125	31/05/94	67	SNAKER	10/07/94	116	39.86	Fall	0
1F59514A6D	02/06/94	73	SNAKER	11/09/94	164	101.20	Fall	0
1F57615C4D	08/06/94	70	SNAKER	07/08/94	156	59.19	Fall	0
1F57662301	25/05/94	a2	SNAKER	29/06/94	119	34.64	Fall	0
1F5E230E52	01/06/94	75	SNAKER	07/07/94	125	35.11	Fall	0
1F572A431D	26/05/94	65	SNAKER	17/07/94	130	51.37	Fall	0
1F5F512F02	25/05/94	66	SNAKER	14/07/94	131	50.04	Fall	0
1F5778276B	31/05/94	67	SNAKER	05/07/94	120	35.17	Fall	0
1F58035E28	02/06/94	76	SNAKER	13/07/94	135	41.10	Fall	0
1F5F0E6B09	02/06/94	a6	SNAKER	03/07/94	131	30.96	Fall	0
1F580A6817	01/06/94	70	SNAKER	29/06/94	94	28.60	Fall	0
1F5819363A	31/05/94	64	SNAKER	18/07/94	132	47.73	Fall	0
1F5E721B76	17/05/94	65	SNAKER	28/06/94	106	41.92	Fall	0
1F595B6F3E	01/06/94	78	SNAKER	07/07/94	134	36.02	Fall	0
1F587F5F2B	01/06/94	84	SNAKER	05/07/94	127	33.48	Fall	0
1F5F6B6037	26/05/94	67	SNAKER	08/07/94	126	42.14	Fall	0
1F564B4779	31/05/94	90	SNAKER	24/06/94	106	24.00	Fall	0
1F570E621A	07/06/94	64	SNAKER	13/08/94	141	66.81	Fall	0
1F6024233A	01/06/94	65	SNAKER	07/08/94	158	67.08	Fall	0
1F5E234D13	31/05/94	74	SNAKER	18/07/94	136	47.92	Fall	0
1F60033D41	18/05/94	65	SNAKER	07/08/94	165	81.35	Fall	0
1F5F7F087B	02/06/94	a3	SNAKER	03/07/94	120	30.90	Fall	0
1F56497C46	31/05/94	61	SNAKER	28/07/94	140	57.98	Fall	0
1F5F776C1F	31/05/94	76	SNAKER	05/07/94	127	35.05	Fall	0
1F595E7D2D	08/06/94	a6	SNAKER	14/07/94	136	36.00	Fall	0
1F5E78602B	08/06/94	102	SNAKER	16/07/94	147	37.14	Fall	0
1F5E331A36	09/06/94	87	SNAKER	27/06/94	105	18.00	Fall	0
1F5F6F090A	08/06/94	83	SNAKER	09/07/94	126	30.15	Fall	0
1F5E352E20	26/05/94	63	SNAKER	02/07/94	122	37.37	Fall	0
1F5F6C771F	25/05/94	78	SNAKER	05/08/94	179	72.13	Fall	0
1F59611710	02/06/94	69	SNAKER	10/07/94	122	37.48	Fall	0
1F595A5A54	31/05/94	65	SNAKER	28/08/94		89.08	Mixed	
7F7D3D7A33	15/06/94	96	SNAKER	09/07/94		23.85	Mixed	
7F7D3D701C	22/06/94	85	SNAKER	12/08/94		63.34	Mixed	
1F5E22550C	31/05/94	69	SNAKER	08/08/94		69.09	Mixed	
7F7D3D7514	09/06/94	66	SNAKER	18/08/94		69.65	Mixed	
1F5E1E6D78	31/05/94	68	SNAKER	28/10/94		150.05	Mixed	
IF59087709	25/05/94	70	SNAKER	09/08/94		83.54	Mixed	
7F7D454D43	08/06/94	78	SNAKER	09/08/94		61.78	Mixed	

Appendix 4. (Continued).

Tag code	Release date	Release length (mm)	Release site	Detection date	Detection length	Days at large	Race	Age
7F7D453D4D	22/06/94	95	SNAKER	07/07/94		27.95	Mixed	
7F7D455C28	15/06/94	90	SNAKER	27/10/94		133.71	Mixed	
IF57337562	31/05/94	70	SNAKER	20/08/94		80.54	Mixed	
1F563A1F32	09/06/94	88	SNAKER	17/08/94		75.45	Mixed	
1F5647467E	07/06/94	65	SNAKER	09/08/94		68.65	Mixed	
7F7D7C0B06	31/05/94	60	SNAKER	18/08/94		78.78	Mixed	
7F7D510A24	22/06/94	93	SNAKER	14/08/94		53.04	Mixed	
7F7D506F15	22/06/94	95	SNAKER	14/08/94		52.72	Mixed	
1F57232B3C	31/05/94	92	SNAKER	21/07/94		50.85	Mixed	
7F7D455C3A	08/06/94	97	SNAKER	08/08/94		61.28	Mixed	
7F7D453E23	15/06/94	86	SNAKER	24/07/94		39.24	Mixed	
7F7D455B4D	22/06/94	93	SNAKER	08/08/94		60.14	Mixed	
7F7D454104	15/06/94	88	SNAKER	19/08/94		64.66	Mixed	
7F7D455566	08/06/94	96	SNAKER	08/06/94		64.03	Mixed	
1F574E4A72	01/06/94	86	SNAKER	01/06/94		67.97	Mixed	
7F7D454F66	15/06/94	82	SNAKER	15/06/94		26.34	Mixed	
7F7D454F34	15/06/94	98	SNAKER	15/06/94		29.83	Mixed	
1F57564C68	02/06/94	71	SNAKER	02/06/94		81.79	Mixed	
7F7D37325E	18/05/94	78	SNAKER	18/05/94		4.74	Mixed	
1F5803176F	07/06/94	79	SNAKER	07/06/94		30.79	Mixed	
7F7D3A073E	14/04/94	66	SNAKER	14/04/94		77.55	Mixed	
1F60286079	24/05/94	63	SNAKER	24/05/94		155.84	Mixed	
1F62364504	31/05/94	76	SNAKER	31/05/94		82.33	Mixed	
1F5F697A1F	02/06/94	65	SNAKER	02/06/94		36.45	Mixed	
IF62342328	02/06/94	94	SNAKER	02/06/94		29.24	Mixed	
1F5F6A5147	18/05/94	68	SNAKER	18/05/94		83.91	Mixed	
1F62361C2D	07/06/94	63	SNAKER	07/06/94		64.29	Mixed	
1F622B2034	31/05/94	69	SNAKER	31/05/94		94.62	Mixed	
1F622A7A5B	31/05/94	76	SNAKER	31/05/94		79.14	Mixed	
1F623D566C	31/05/94	78	SNAKER	31/05/94		51.11	Mixed	
1F6241427C	02/06/94	64	SNAKER	02/06/94		89.16	Mixed	
1F5F663D5F	31/05/94	65	SNAKER	31/05/94		88.56	Mixed	
1F622F1C34	01/06/94	75	SNAKER	01/06/94		44.62	Mixed	
1F5F611809	17/05/94	81	SNAKER	17/05/94		31.61	Mixed	
1F621D6200	31/05/94	69	SNAKER	31/05/94		50.17	Mixed	
1F621F1050	24/05/94	66	SNAKER	24/05/94		80.39	Mixed	
IF60360942	26/05/94	76	SNAKER	26/05/94		78.46	Mixed	
1F603D7B49	26/05/94	62	SNAKER	26/05/94		140.71	Mixed	
1F6043023C	02/06/94	68	SNAKER	02/06/94		68.96	Mixed	
1F5F547D31	08/06/94	71	SNAKER	08/06/94		47.07	Mixed	
IF62265009	02/06/94	a4	SNAKER	02/06/94		81.46	Mixed	
1F621F3D23	15/06/94	99	SNAKER	15/06/94		83.97	Mixed	
1F5F762A62	31/05/94	98	SNAKER	31/05/94		14.22	Mixed	
1F5F737817	31/05/94	90	SNAKER	31/05/94		68.93	Mixed	
1F5F63346B	07/06/94	74	SNAKER	07/06/94		69.71	Mixed	
7F7D3A0161	26/05/94	74	SNAKER	26/05/94		65.51	Mixed	
200F1F367C	25/05/94	66	SNAKER	25/05/94		7.25	Mixed	
7F7D360C6B	09/06/94	68	SNAKER	09/06/94		61.11	Mixed	
1F60254C10	07/06/94	68	SNAKER	07/06/94		64.13	Mixed	
7F7D342C57	09/06/94	80	SNAKER	09/06/94		66.00	Mixed	
7F7D342C7A	09/06/94	81	SNAKER	09/06/94		61.14	Mixed	
7F7D346816	09/06/94	a9	SNAKER	09/06/94		63.26	Mixed	
7F7D341666	09/06/94	71	SNAKER	09/06/94		71.20	Mixed	
7F7D2C7D1F	24/05/94	65	SNAKER	24/05/94		76.39	Mixed	
1F5E354509	26/05/94	68	SNAKER	26/05/94		58.56	Mixed	
1F5E30676C	31/05/94	95	SNAKER	31/05/94		69.00	Mixed	
7F7D393962	20/04/94	66	SNAKER	20/04/94		61.64	Mixed	
7F7D341974	09/06/94	79	SNAKER	09/06/94		83.27	Mixed	
1F5E2B6870	07/06/94	82	SNAKER	07/06/94		68.05	Mixed	
7F7D1E7919	28/04/94	67	SNAKER	28/04/94		50.67	Mixed	
1F5F04116D	01/06/94	74	SNAKER	01/06/94		79.63	Mixed	
7F7D0E4049	07/06/94	78	SNAKER	07/06/94		22.61	Mixed	

Appendix 4. (Continued).

Tag code	Release date	Release length (mm)	Release site	Detection date	Detection length	Days at large	Race	Age
1F5F4E4D67	31/05/94	80	SNAKER	31/05/94		36.74	Mixed	
1F5F065B21	31/05/94	70	SNAKER	31/05/94		99.03	Mixed	
7F7D0E3371	07/06/94	73	SNAKER	07/06/94		146.86	Mixed	
1F5E43467A	25/05/94	81	SNAKER	25/05/94		83.23	Mixed	
7F7D2B005B	09/06/94	94	SNAKER	09/06/94		35.04	Mixed	
1F5E792C5E	31/05/94	96	SNAKER	31/05/94		42.52	Mixed	
7F7D2B467B	08/06/94	66	SNAKER	08/06/94		76.46	Mixed	
7F7D7D2F14	02/06/94	78	SNAKER	02/06/94		89.28	Mixed	
7F7D35760B	05/07/94	61	CLWR	18/08/94		44.11	Fall	0

Appendix 5. Data for chinook salmon juveniles that were PIT tagged in the Snake and Clearwater rivers, and Clearwater rivers as subyearlings in 1994 and detected in the Snake or Columbia rivers as yearlings in 1995.

Tag code	Release date	Release length (mm)	Release site	Detection site	Detection date	Days at large
1F56636A3E	25/05/94	64.00	SNAKER	GOJ	16/04/95	326.32
IF60232539	31/05/94	86.00	SNAKER	GOJ	06/04/95	309.33
7F7D453B7F	09/06/94	63.00	SNAKER	GOJ	12/04/95	306.49
7F7D3E0147	08/06/94	101.00	SNAKER	GOJ	14/04/95	310.50
7F7D3D735D	09/06/94	74.00	SNAKER	GOJ	15/04/95	309.37
7F7D453B2C	09/06/94	75.00	SNAKER	GOJ	15/04/95	309.59
1F57597140	31/05/94	90.00	SNAKER	GOJ	29/04/95	332.95
1F595D0427	26/05/94	62.00	SNAKER	GOJ	25/04/95	333.65
7F7D34136D	09/06/94	63.00	SNAKER	GOJ	14/04/95	309.24
1F5F512110	24/05/94	61.00	SNAKER	GOJ	30/04/95	341.29
7F7D454102	09/06/94	102.00	SNAKER	GOJ	14/04/95	308.75
1F5E2F4C08	24/05/94	63.00	SNAKER	GOJ	19/04/95	329.88
7F7D45502F	15/06/94	87.00	SNAKER	GRJ	12/04/95	301.27
7F7D506503	22/06/94	95.00	SNAKER	GRJ	12/04/95	294.42
7F7D455376	08/06/94	89.00	SNAKER	GRJ	15/04/95	311.16
1F587E010A	02/06/94	80.00	SNAKER	GRJ	05/04/95	306.63
7F7D336430	05/05/94	65.00	SNAKER	GRJ	14/04/95	344.43
1F57757B1A	02/06/94	83.00	SNAKER	GRJ	12/04/95	313.72
7F7D455022	09/06/94	78.00	SNAKER	GRJ	01/04/95	295.47
1F62397A4C	02/06/94	67.00	SNAKER	LMJ	01/04/95	302.64
1F5F041767	02/06/94	64.00	SNAKER	LMJ	03/04/95	304.35
7F7D36111E	09/06/94	72.00	SNAKER	LMJ	09/04/95	303.58
1F6233123A	01/06/94	60.00	SNAKER	LMJ	16/04/95	318.40
7F7D360E40	09/06/94	67.00	SNAKER	LMJ	15/04/95	310.22
7F7D76753E	24/05/94	62.00	SNAKER	LMJ	07/04/95	317.91
7F7D393069	19/05/94	61.00	SNAKER	LMJ	08/05/95	354.46
7F7D45433E	09/06/94	78.00	SNAKER	LMJ	02/04/95	296.64
7F7D342974	22/06/94	91.00	SNAKER	LMJ	04/04/95	286.33
1F57676A39	31/05/94	68.00	SNAKER	LMJ	08/04/95	311.94
1F5F06710B	26/05/94	65.00	SNAKER	LMJ	30/04/95	339.01
1F58037F07	26/05/94	77.00	SNAKER	LMJ	20/04/95	328.39
7F7D454231	15/06/94	88.00	SNAKER	LMJ	04/05/95	323.19
7F7D770707	24/05/94	61.00	SNAKER	LMJ	18/04/95	329.08
200F165A61	18/05/94	61.00	SNAKER	LMJ	01/04/95	317.95
1F5E30656E	25/05/94	63.00	SNAKER	LMJ	20/04/95	330.31
7F7D454414	08/06/94	74.00	SNAKER	LMJ	14/04/95	309.50
7F7D2B245B	08/06/94	75.00	SNAKER	LMJ	26/04/95	321.53
7F7D3D7775	15/06/94	80.00	SNAKER	LMJ	25/04/95	313.59
1F58020106	31/05/94	85.00	SNAKER	LMJ	02/04/95	306.25
1F601C7D68	31/05/94	66.00	SNAKER	LMJ	10/04/95	314.12
1F587F0505	31/05/94	63.00	SNAKER	LMJ	14/04/95	318.35
7F7D453D57	15/06/94	91.00	SNAKER	LMJ	06/04/95	294.63
7F7D454858	08/06/94	74.00	SNAKER	LMJ	15/04/95	310.48
7F7D454E3D	09/06/94	74.00	SNAKER	MCJ	12/04/95	306.59
7F7D3D790F	09/06/94	78.00	SNAKER	MCJ	08/04/95	303.41
7F7D454F37	15/06/94	78.00	SNAKER	MCJ	23/04/95	311.41
7F7D342140	09/06/94	92.00	SNAKER	MCJ	16/04/95	310.62
7F7D453B39	09/06/94	61.00	SNAKER	MCJ	02/04/95	296.77
7F7D3D7739	15/06/94	89.00	SNAKER	MCJ	10/04/95	299.40
1F57547D39	02/06/94	63.00	SNAKER	MCJ	17/04/95	318.91
7F7D454F10	15/06/94	66.00	SNAKER	MCJ	24/04/95	312.97
7F7D454830	15/06/94	94.00	SNAKER	MCJ	02/04/95	290.76
7F7D3D794F	15/06/94	93.00	SNAKER	MCJ	19/04/95	307.88
7F7D3D7742	15/06/94	93.00	SNAKER	MCJ	04/05/95	323.26
7F7D3D7516	09/06/94	84.00	SNAKER	MCJ	17/04/95	311.90
7F7D2C1307	05/05/94	67.00	SNAKER	MCJ	06/04/95	336.24
7F7D7C3F48	25/05/94	67.00	SNAKER	MCJ	03/05/95	343.48
7F7D76794B	24/05/94	63.00	SNAKER	MCJ	16/04/95	327.16
1F5F020F71	31/05/94	80.00	SNAKER	MCJ	08/04/95	312.29
1F5E320F42	26/05/94	61.00	SNAKER	MCJ	07/04/95	315.53

Appendix 5. (Continued).

Tag code	Release date	Release Length (mm)	Release site	Detection site	Detection date	Days at large
1F5E736D23	26/05/94	66.00	SNAKER	MCJ	11/04/95	320.12
1F5637597B	26/05/94	69.00	SNAKER	MCJ	11/04/95	319.52
1F57177F74	31/05/94	60.00	SNAKER	MCJ	14/04/95	318.31
1F572C6A74	31/05/94	70.00	SNAKER	MCJ	21/04/95	325.13
1F57727721	24/05/94	72.00	SNAKER	MCJ	19/04/95	330.24
7F7D774361	24/05/94	68.00	SNAKER	MCJ	20/04/95	331.18
7F7D2B1531	19/05/94	73.00	SNAKER	MCJ	21/04/95	337.22
1F5F6A5147	18/05/94	68.00	SNAKER	MCJ	18/04/95	335.00
1F5E1B6107	31/05/94	68.00	SNAKER	MCJ	04/04/95	307.71
7F7D3D7710	09/06/94	63.00	SNAKER	MCJ	02/05/95	327.11
1F6000235E	02/06/94	65.00	SNAKER	MCJ	21/04/95	323.19
1F58020502	02/06/94	81.00	SNAKER	MCJ	08/05/95	339.87
7F7D454406	08/06/94	80.00	SNAKER	MCJ	03/04/95	299.45
7F7D2B515B	08/06/94	79.00	SNAKER	MCJ	04/04/95	300.32
7F7D454958	08/06/94	76.00	SNAKER	MCJ	27/04/95	322.56
1F5E347E51	02/06/94	68.00	SNAKER	MCJ	12/04/95	313.31
7F7D45437B	09/06/94	62.00	SNAKER	MCJ	05/04/95	299.30
1F5E7E2164	31/05/94	81.00	SNAKER	MCJ	20/04/95	323.92
1F601E766D	02/06/94	65.00	SNAKER	MCJ	07/04/95	308.64
1F5947447D	01/06/94	87.00	SNAKER	MCJ	01/05/95	333.48
1F60416F51	01/06/94	95.00	SNAKER	MCJ	21/04/95	324.40
1F5904770D	01/06/94	79.00	SNAKER	MCJ	15/04/95	318.42
7F7D50604E	22/06/94	93.00	SNAKER	MCJ	25/04/95	307.01
7F7D342C52	14/06/94	75.00	CLWR	GOJ	29/04/95	319.44
7F7D36104F	21/06/94	77.00	CLWR	GOJ	15/04/95	298.46
7F7D454F1E	14/06/94	75.00	CLWR	GOJ	14/04/95	303.98
7F7D357A15	21/06/94	79.00	CLWR	GOJ	18/04/95	301.26
1F573C3F0F	28/06/94	78.00	CLWR	GOJ	01/05/95	327.74
7F7D454227	14/06/94	64.00	CLWR	GRJ	07/04/95	297.35
7F7D453E79	21/06/94	75.00	CLWR	GRJ	17/04/95	307.24
7F7D346A12	14/06/94	74.00	CLWR	GRJ	26/04/95	315.87
7F7D505E15	28/06/94	71.00	CLWR	GRJ	09/04/95	284.81
7F7D45520C	29/06/94	71.00	CLWR	GRJ	10/04/95	285.25
7F7D361216	21/06/94	79.00	CLWR	GRJ	07/04/95	289.96
7F7D2B694A	14/06/94	75.00	CLWR	GRJ	14/04/95	304.78
7F7D45457E	14/06/94	76.00	CLWR	GRJ	14/04/95	304.91
7F7D506343	21/06/94	77.00	CLWR	LMJ	04/05/95	317.03
7F7D342C26	06/07/94	86.00	CLWR	LMJ	17/04/95	300.47
7F7D45204F	05/07/94	79.00	CLWR	LMJ	15/04/95	284.32
7F7D510A28	21/06/94	75.00	CLWR	LMJ	28/04/95	310.77
7F7D340F7A	28/06/94	75.00	CLWR	MCJ	27/04/95	303.47
1F5962071F	14/06/94	75.00	CLWR	MCJ	26/04/95	323.18
7F7D357A61	22/06/94	78.00	CLWR	MCJ	25/04/95	306.48
7F7D340C15	14/06/94	68.00	CLWR	MCJ	24/04/95	314.09
7F7D50672E	21/06/94	64.00	CLWR	MCJ	25/04/95	307.89

Appendix 6.-Total number of incidental fish caught by electrofishing in McNary Reservoir and the Hanford Reach of the Columbia River, Washington, 1994-1995.

Common Name	Scientific Name	Total Catch McNary	Hanford
Bass	*Micropterus spp.*	1	
Bluegill	*Lepomis macrochirus*	8	3
Carp	*Cyprinus carpio*	7	19
Crappie	*Pomoxis spp.*	1	
Largemouth bass	*Micropterus salmoide*	2	2
Largescale sucker	*Catostomus macroheilus*	88	145
Minnow	*Cyprinidae*		1
Mountain whitefish	*Prosopium williamsoni*		1
Northern squawfish	*Ptychocheilus oregonensis*	6	35
Peamouth	*Mylocheilus caurinus*		3
Pumpkinseed	*Lepomis gibbosus*	3	
Rainbow trout	*Oncorhynchus mykiss*	1	24
Redside shiner	*Richardsonius balteatus*	2	148
Sculpins	*Cottidae*	103	9
Smallmouth bass	*Micropterus dolomieui*	98	18
Spring chinook	*Oncorhynchus tshawytscha*	1	21
Threespine stickleback	*Gasterosteus aculeatus*		1
Walleye	*Stizostedion vitreum*	1	
Yellow perch	*Perca flavescens*	2	2
Unidentified		65	85