Migrational Characteristics of Adult Spring, Summer, and Fall Chinook Salmon Passing through Reservoirs and Dams of the Mid-Columbia River

Final Report

CZES

Coastal Zone and Estuarine Studies Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

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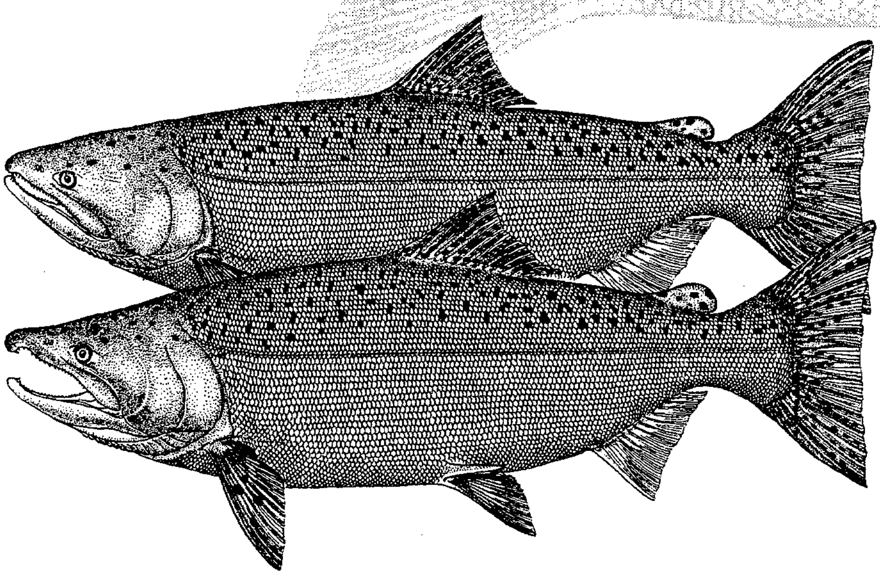
March 1995



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INTRODUCTION

No detailed radio-telemetry research to evaluate adult salmonid passage was conducted after the construction of the Public Utility District (PUD) dams on the mid-Columbia River. Consequently, adult fishways at the dams were operated using criteria based on research conducted at lower Columbia River and Snake River dams. However, discrepancies between expected fish counts at upstream dams compared to counts at downstream dams indicated that passage problems might exist at the mid-Columbia River dams.

In 1993, the National Marine Fisheries Service (NMFS), funded by Chelan County, Douglas County, and Grant County PUDs and the NMFS conducted radio-telemetry research to document adult fish passage and passage problems. Studies were designed to determine migration rates, passage success, dam-passage behavior, and final destinations of adult spring, summer, and fall chinook salmon *(Oncorhynchus tshawytscha)* in the main stem and tributaries of the mid-Columbia River (Fig. 1).

The University of Idaho conducted a separate but concurrent study to radio-track spring and summer chinook salmon in the Snake River; NMFS shared data and tagging efforts with them.

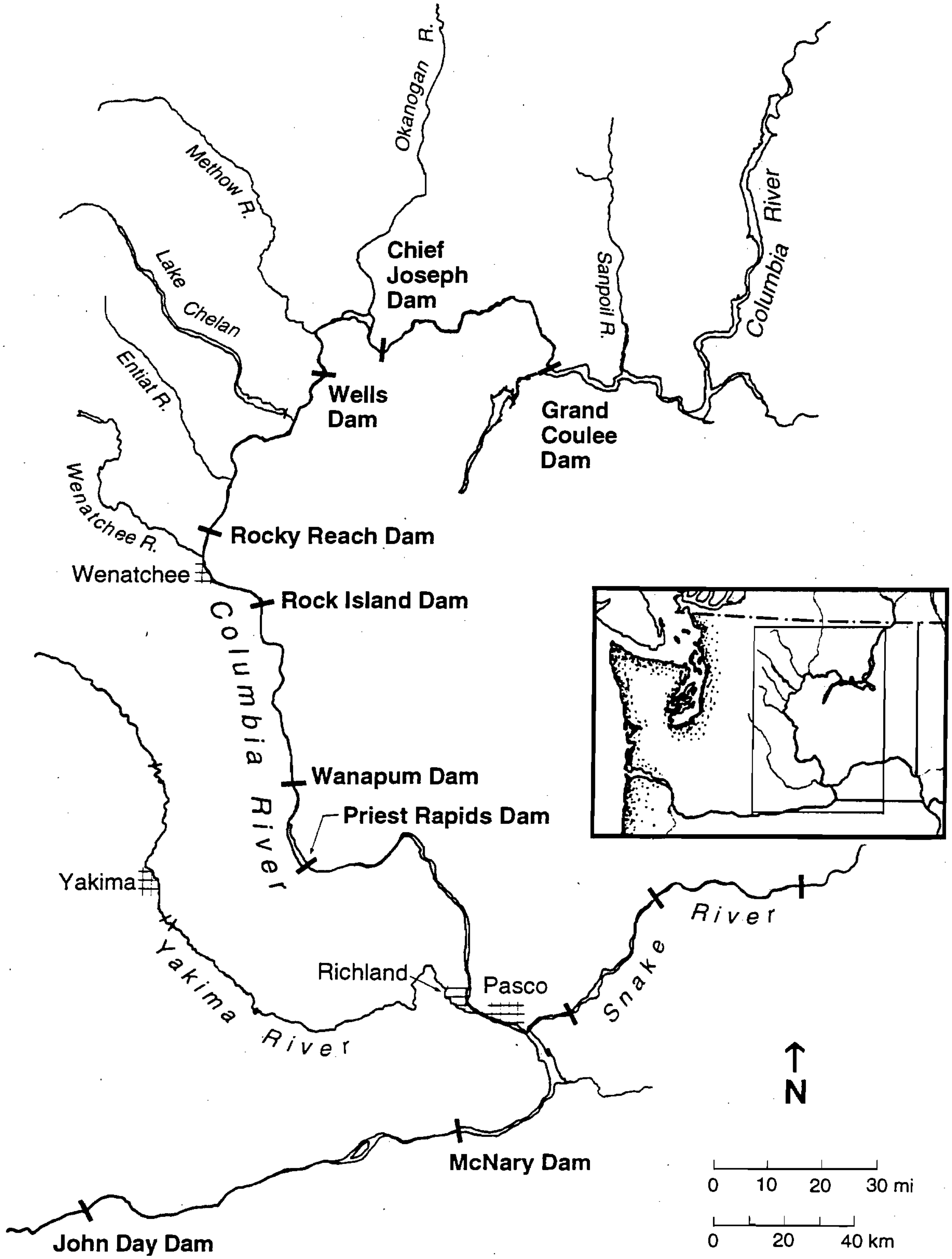

Figure 1.--Study area for the 1993 mid-Columbia River radio-telemetry study.

OBJECTIVES

The study had five objectives, as follow:

Objective 1: Determine the date and time of arrival for radio-tagged fish at tailraces, fishway openings (collection channels and fish ladders), intermediate points in the fishway, and fishway exits at Priest Rapids (River Kilometer [RKm] 638.9, River Mile [RM] 397.1); Wanapum (RKm 669.0, RM 415.8); Rock Island (RKm 729.5, RM 453.4); Rocky Reach (RKm 762.2, RM 473.7); and Wells Dams (RKm 829.6, RM 515.6).

Objective 2: Determine fate of radio-tagged fish.

Objective 3: Determine the proportion of fish using each fishway opening at each dam.

Objective 4: Determine the efficiency of fishway openings.

Objective 5: Determine incidence of fallbacks (fish detected downstream from a dam after having been detected exiting one of the fish ladders at the same dam) at each dam.

MATERIALS AND METHODS

Field work began in February with setup of trapping and tagging facilities at John Day Dam (RKm 346.9, RM 215.6) and ended in late November with adult spawning. The terms "spring," "summer," and "fall," as applied to runs of chinook salmon in this study, are based on established dates for fish counting at Columbia River Basin dams (U.S. Army Corps of Engineers 1993).

Study Area

The study area included the Columbia River from McNary Dam (RKm 469.8, RM 292.0) to Chief Joseph Dam (RKm 877.1, RM 545.1), and the major Columbia River tributaries upstream from the confluence of the Snake and Columbia Rivers. Chief Joseph Dam has no fish ladders, and therefore is the upstream limit for migrating adult salmon on the mainstem Columbia River.

Radio-Telemetry Tags

Radio-telemetry tags for the study were purchased from Lotek Engineering Inc.[1], of Newmarket, Ontario, Canada. Each tag was powered by two 7.2-V lithium batteries, with life spans of about 8 months, to ensure detection throughout the migration and spawning periods. The transmitter and battery were sealed with Scotch Cast in a cylindrical plastic capsule 8.25-cm long x 1.5-cm diameter, which allowed tagging of fish as small as 60-cm fork length. Tags weighed about 30 g in air and had a 43-cm, 22-gauge, flexible-whip antenna attached to one end. Each tag transmitted a unique identification code within the range of 149.320 to 149.800 MHz.

Radio Tagging

Radio tagging of adult salmon involved three major procedures: trapping, tagging, and releasing.

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

We collected, tagged, and released spring and summer chinook salmon at John Day Dam from 19 April to 4 June and from 7 June to 29 July, respectively. At Priest Rapids Dam, spring chinook salmon were radio tagged from 24 to 25 May, and fall chinook salmon tagged from 7 September to 27 October. No summer chinook salmon were tagged at Priest Rapids Dam. At Rocky Reach Dam, spring, summer, and fall chinook salmon were radio tagged from 7 June to 11 June, 27 July to 29 July, and 8 September to 27 October, respectively.

Trapping

Temporary adult trapping facilities were installed in the left-bank (river banks are designated left and right based on the direction of movement of the water, i.e. looking downstream) fish ladder at John Day Dam (Fig. 2). Fish that passed over a denil fishway were selected for tagging by an observer controlled pneumatic flipper gate that routed the fish into an anesthetic tank.

At Priest Rapids Dam, the existing adult trap near the exit of the left-bank fish ladder was used to collect fish for radio tagging (Fig. 3). A picketed-lead gate was positioned over the left orifice to divert fish to a denil and via a flume to the trap. Non-target fish were released into the fish ladder upstream from the trapping facility by activating a hydraulic diversion gate in the flume.

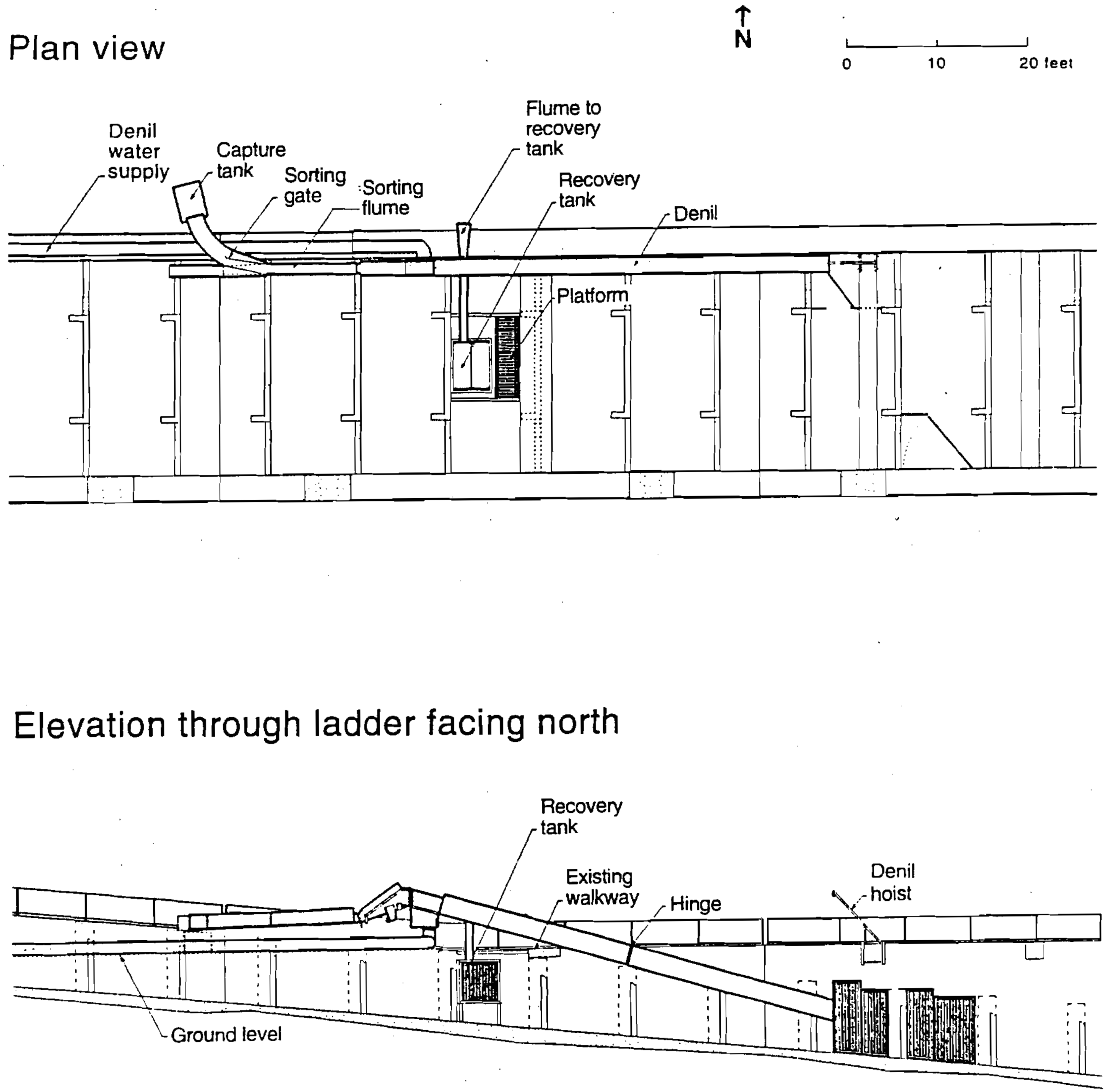


Figure 2.--Adult trap at John Day Dam south fish ladder, 1993.

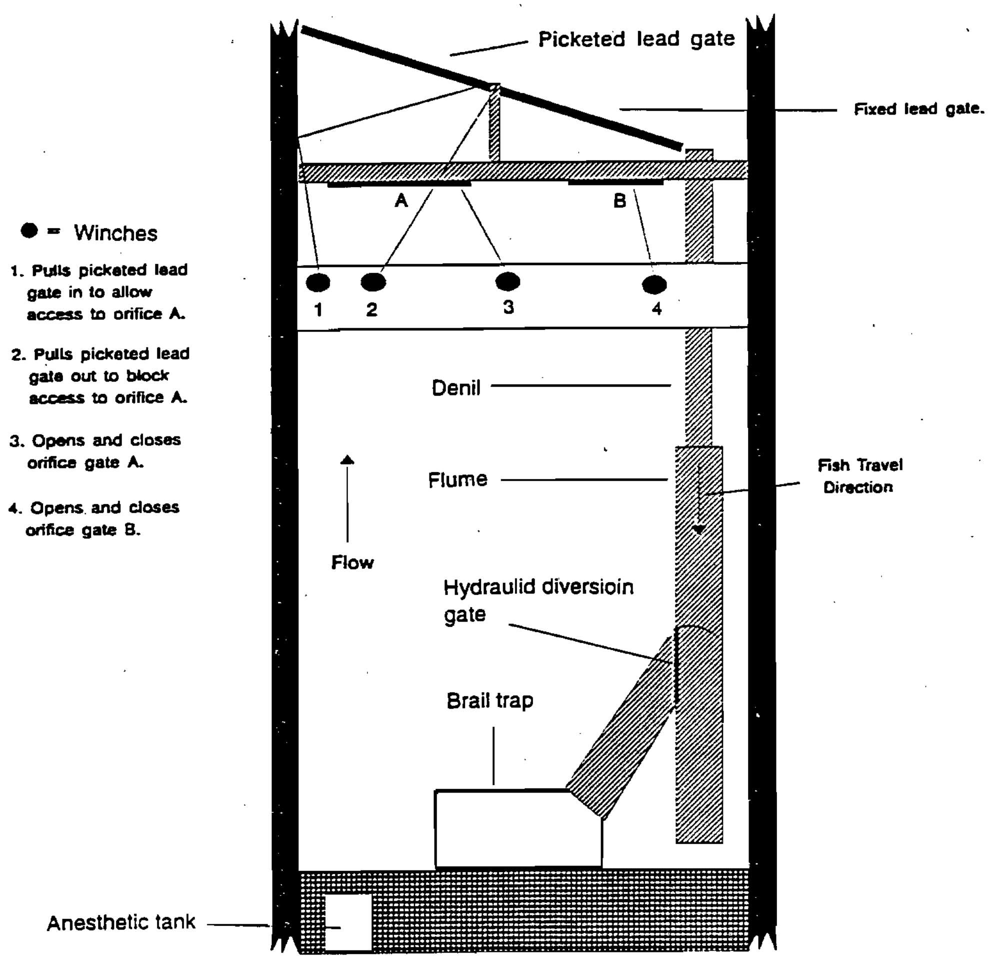


Figure 3.--Diagrammatic top view of adult trap at Priest Rapids Dam, 1993.

At Rocky Reach Dam, the existing Buckley trap in the fish ladder was used to collect fish (Fig. 4). The trap was lowered to cover two submerged weir orifices in the fish ladder. The trap floor in front of the right-side orifice was covered with a sheet of white plastic to facilitate viewing the fish from above water as they entered the trap. The left-side orifice was closed by a slide gate to prevent escape. The trap was raised when target fish were observed in the trap. Fish were transferred via a 46.1-cm diameter pipe from the trap to a tank located on a 3.0-m x 6.1-m barge in the forebay. Non-target fish were immediately released into the fish ladder upstream from the trap or removed from the collection tank and released into the forebay.

Tagging

Salmon were anesthetized with a tricaine methane sulfonate (MS-222) solution of about 40 ppm. After examination for marks, tags, or injuries, fish were measured. Chinook salmon longer than 60-cm fork length without severe head injuries were radio tagged. Fish were supported in the water, and a radio tag was inserted through the mouth and into the stomach of the fish. The entire tagging procedure lasted approximately 2 to 5 minutes per fish. Fish remained in water throughout the tagging process.

Releasing

After tagging, fish were placed into a holding tank until they recovered from the anesthetic. At John Day and Priest Rapids Dams, recovered fish were released back into fish ladders

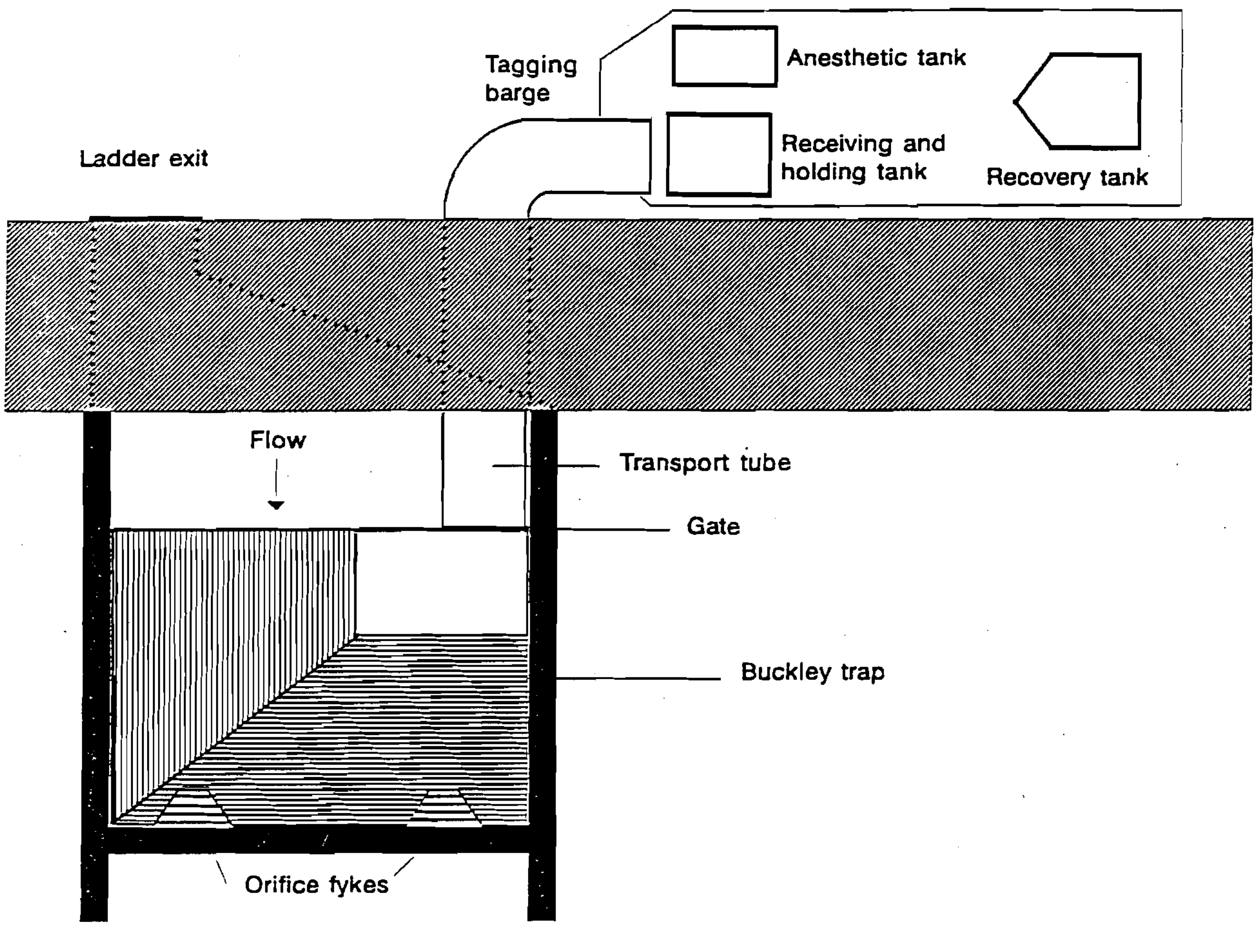


Figure 4.--Diagrammatic top view of Buckley trap at Rocky Reach Dam, 1993.

upstream from the traps. At Rocky Reach Dam, tagged spring and summer chinook salmon were transported downstream from the dam and released into the tailrace. Fall chinook salmon were released directly into the forebay from the floating work-barge on which they were tagged.

Radio Tracking

Radio tracking began when the first tagged fish was released. Fixed-site monitors were installed to continuously record the presence of radio-tagged fish in specific areas. Mobile surveillance from auto, boat, and airplane was used to monitor fish between fixed-site monitors and to locate and recover stationary tags.

The general location and numerical designation of fixed-site monitors at dams are listed in Table 1. Specific locations of fixed-site monitors and antennae at the dams are shown in Appendix Figures A1 to A5. Information for fixed-site monitors on major tributaries is presented in Table 2. Data collected from fixed-site monitors were downloaded to lap-top computers. The frequency of downloading ranged from every day to once a week, depending on fish activity within range of the monitor.

Radio-Telemetry Monitoring Equipment

All monitors used Lotek Model SRX-400 telemetry receivers for signal detection, data processing, and data storage.

Table 1.--Mainstem Columbia River, fixed-site telemetry monitors and antennae used during the 1993 spring, summer, and fall chinook salmon radio-telemetry study.

Monitor number	Monitor location (upstream progression)	River Km	Number of antennae	Antennae type
1	John Day Dam (left-bank fish ladder)	346.9	1	Underwater coaxial cable
2	John Day Dam (right-bank fish ladder)	346.9	1	Underwater coaxial cable
4	McNary Dam (left-bank fish ladder)	469.8	1	Underwater coaxial cable
5	McNary Dam (right-bank fish ladder)	469.8	1	Underwater coaxial cable
98	Priest Rapids Dam (right-bank aerial)	639.5	2	9-element Yagi
97	Priest Rapids Dam (right-bank fish ladder)	639.6	4	Underwater coaxial cable
96	Priest Rapids Dam (right collection channel)	639.6	7	Underwater coaxial cable
95	Priest Rapids Dam (mid collection channel)	639.6	6	Underwater coaxial cable
94	Priest Rapids Dam (left collection channel)	639.6	4	Underwater coaxial cable
93	Priest Rapids Dam (left-bank fish ladder)	639.6	6	Underwater coaxial cable
92	Priest Rapids Dam exit (left-bank fish ladder)	639.6	4	Underwater coaxial cable
91	Wanapum Dam (right-bank aerial)	669.0	2	9-element Yagi
90	Wanapum Dam (right-bank ladder entrance)	669.0	2	Underwater coaxial cable
89	Wanapum Dam (right collection channel)	669.0	7	Underwater coaxial cable
88	Wanapum Dam (mid collection channel)	669.0	6	Underwater coaxial cable
87	Wanapum Dam (left collection channel)	669.0	6	Underwater coaxial cable
86	Wanapum Dam entrance (left-bank fish ladder)	669.0	6	Underwater coaxial cable
85	Wanapum Dam exit (left-bank fish ladder)	669.0	4	Underwater coaxial cable
84	Wanapum Dam exit (right-bank fish ladder)	669.0	4	Underwater coaxial cable
83	Rock Island Dam (right-bank aerial)	729.5	2	9-element Yagi
82	Rock Island Dam (right powerhouse entrance)	729.5	7	Underwater coaxial cable

Table 1.--continued.

Monitor number	Monitor location (upstream progression)	River Km	Number of antennae	Antennae type
81	Rock Island Dam (left powerhouse entrance)	729.5	2	Underwater coaxial cable
80	Rock Island Dam (center fish ladder)	729.5	4	Underwater coaxial cable
79	Rock Island Dam (left-bank ladder entrance)	729.5	2	Underwater coaxial cable
78	Rock Island Dam (left-bank ladder exit)	729.5	5	Underwater coaxial cable
77	Rock Island Dam (right-bank ladder exit)	729.5	4	Underwater coaxial cable
76	Rocky Reach Dam (right-bank aerial)	762.2	2	9-element Yagi
75	Rocky Reach Dam (right collection channel)	762.2	7	Underwater coaxial cable
74	Rocky Reach Dam (mid collection channel)	762.2	7	Underwater coaxial cable
73	Rocky Reach Dam (left powerhouse entrance)	762.2	6	Underwater coaxial cable
72	Rocky Reach Dam (spillway entrance)	762.2	2	Underwater coaxial cable
71	Rocky Reach Dam (fish ladder exit)	762.2	4	Underwater coaxial cable
68	Wells Dam (right-bank aerial)	828.6	2	9-element Yagi
67	Wells Dam (right-bank ladder entrance)	829.6	4	Underwater coaxial cable
66	Wells Dam (left-bank ladder entrance)	829.6	4	Underwater coaxial cable
65	Wells Dam (left-bank ladder exit)	829.6	5	Underwater coaxial cable
64	Wells Dam (right-bank ladder exit)	829.6	5	Underwater coaxial cable

Table 2.--Fixed-site radio-telemetry monitors located on the tributaries of the Columbia River.

Monitor number	Monitor location	River	River Km	Antennae number	Antennae type
3	John Day River	John Day	7.9	1	6-element Yagi
6-14	Ice Harbor Dam	Snake	15.6	21 2	Underwater 9-element Yagi
99	Horn Rapids Dam	Yakima	29.0	2	6-element Yagi
70	Wenatchee River County Park	Wenatchee	8.4	2	6-element Yagi
69	Private Property (Bob Whitehall)	Entiat	5.1	2	4-element Yagi
63	Private Property (Wayne Marsh)	Methow	25.7	2	4-element Yagi
62	Monse	Okanogan	9.7	2	4-element Yagi

Fixed-site monitors using underwater antennae incorporated Lotek DSP-500 receiver/co-processors for simultaneous scanning of all antennae and frequencies. The receiver/co-processor detected transmitter signals and passed frequency, code, and signal strength to the SRX-400 receiver for data verification and storage.

Four types of antennae were used for signal detection: underwater; multiple-element Yagi; hand-held, 3-element, folding Yagi; and H antennae. Underwater antennae consisted of coaxial cable with about 37.5 cm of the shielding stripped from the distal end. The cable was suspended outside and within fish-ladder openings to detect the presence of radio-tags. The detection range of underwater antennae ranged from 4.6 to 6.1 m. Yagi multiple-element antennae were used as air antennae at fixed sites to monitor fish in a general area. A nine-element Yagi antenna was used aboard a 5.8-m work boat for mobile tracking. Mobile tracking was performed with a monitor equipped with hand-held or staff-mounted, 3-element, folding Yagi antennae. Two wing-strut mounted, H-pattern antennae were used on a high-winged aircraft for aerial tracking.

Data Collection

The data collected for each radio-tagged fish included:

1) Fish length and injuries.
2) Site, date, and times of both tagging and release of tagged fish.
3) Date and time that tagged fish entered the study area.

4) Dates and times of arrival at the tailrace of each mid-Columbia River dam, including fishway entrances and exits (location, date, and time).
5) Date and time of entry and exit to the Wenatchee, Entiat, Methow, and Okanogan Rivers.
6) Weekly mobile track data (River Kilometer, notes, date, and time).

Data Analysis

Because travel-time data are seldom distributed normally, we recorded ranges and median travel times. Data were analyzed with non-parametric statistical tests.

Specific goals of this study were met by analyzing data in the following categories:

Run Timing

Fixed-site monitors determined run timing (dates and hours) and between-site migration times. These units operated continuously, except for short periods during data downloading. Run timing was calculated for a number of study area sections upstream from McNary Dam fishways to entrances of spawning tributaries.

Travel Time

Travel time in each reservoir and at each dam was obtained from monitors in the tailrace, collection channel, and fish-ladder entrances and exits. Tributary monitors were located far enough upstream so that tagged fish in the reservoir were not recorded. Dual antennae on the tailrace and tributary receivers provided sequential data for determining direction of movement.

The following terms were used to categorize travel times for tagged fish:

- **Previous dam to tailrace**--Elapsed time between exit or tagging at a dam and the first record at the nearest monitor downstream from the next upstream dam.
- **Tailrace to arrival**--Elapsed time between the first record at the nearest monitor downstream from the dam and the first record immediately outside a collection-channel opening.
- **Arrival to entry**--Elapsed time between the first record immediately outside a collection-channel opening and the first record inside the collection channel.
- **Entry to last collection channel**--Elapsed time between the first record inside the collection channel and the last record inside the collection channel.
- **Last collection channel to ladder exit (ladder time)**--Elapsed time between the last record inside the collection channel and the last record at the fish-ladder exit. These data were segregated according to fishways.
- **Total passage time at specific dam**--Elapsed time between the first record immediately outside a collection-channel opening (arrival) and the last record at a fish-ladder exit.

Travel times for all radio-tagged fish were included in the analysis unless travel times between tagging sites were significantly different ($P = 0.05$).

Fate of Radio-Tagged Fish

The fates of individual radio-tagged fish were assigned to categories based on last known locations determined by fixed-site monitors and mobile and aerial tracking. For example, we assumed fish last detected in a tributary would have stayed in that tributary. Assigning tags last detected between dams to a specific category was more problematic since fish could have died, spawned, regurgitated the tag, or been harvested. To help determine possible categories, we encouraged the return of recovered radio tags and information on their fate by offering a $5 reward. The fate of each tagged fish was examined for correlation with location, total passage time, fallback, and collection-channel exit rates.

Adult Collection Channel Efficiency

Collection channel efficiency was calculated with data from fixed-site monitors at each of the collection-channel openings and at the fish-ladder exits. Net collection-channel entry was estimated for each opening by Equation 1.

$$\text{Net Entry} = \sum \text{entries} - \sum \text{exits} \qquad (1)$$

where

Σ entries = total entries (including multiple entries per fish) at a specific opening.

Σ exits = total exits **at that opening**.

Data were also analyzed to determine the direction of fish movement within the collection channel. Net, direction of movement for the radio-tagged fish was calculated from the chronological records of individual tagged fish. Given that a tag was recorded at a collection channel opening, and was inside the collection channel, and that the next consecutive record was inside the channel, the direction of movement between the two records (toward or away) was summed. Net direction of movement from each collection channel opening was determined by subtracting the total number of records where tags were moving away from the base of the fish ladder from the total number of records where tags were moving toward the fish ladder.

The percentage of entries at a given opening that resulted in arrivals at the base of the fish ladder was calculated by Equation 2.

$$\textit{Percent Arrival at Base of Fish Ladder} = \frac{\sum ebfl}{\sum e} \quad \textbf{(2)}$$

where

Σ ebfl = number of entries at a specific opening that reached the base of the fish ladder.

Σ e = total number of entries at that opening.

Total passage efficiency, indicating successful ladder passage from collection channel entry at a specific opening, was determined using Equation 3.

$$\textit{Total Passage Efficiency} = \frac{\sum pe}{\sum p} \qquad (3)$$

where

Σ pe = ladder exits from collection channel entry at a specific opening.

Σ p = total ladder exits.

Fish-Ladder Selection

A fast scanning fixed-site monitor recorded activity at individual adult collection-channel openings. Each fixed-site monitor collected data simultaneously from up to seven antennae.

Fallback

Fish detected in the tailrace of a dam subsequent to an exit record at the top of a fish ladder were classified as fallbacks. Fallbacks were determined by assessing fish activity from sequential data obtained from monitors in the collection channels, fish-ladder exits, tailraces, and by mobile tracking. We also assigned a fate to each fallback.

RESULTS AND DISCUSSION

A total of 742 spring, 426 summer, and 279 fall chinook salmon were radio tagged and released.

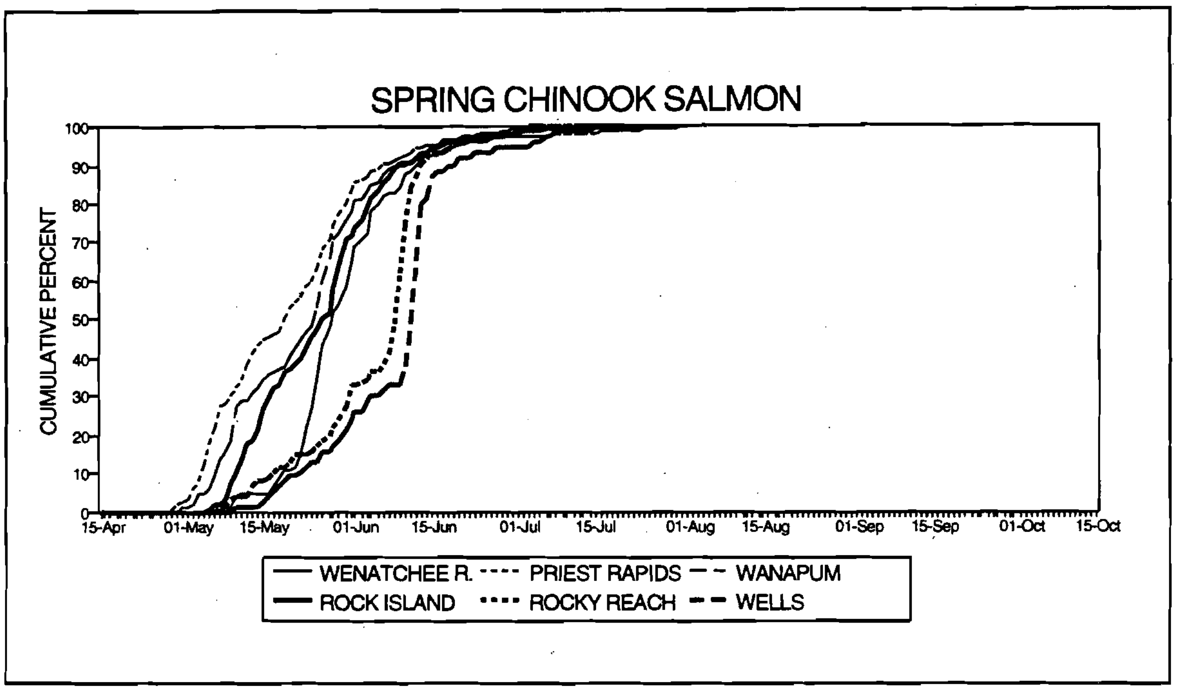
The average flows at Priest Rapids Dam during spring, summer, and fall chinook salmon migrations were 124.0, 105.9, and 75.7 kcfs, respectively. Water was spilled at each dam during spring and summer migrations, with the exception of the summer chinook salmon migration at Rocky Reach Dam. With one minor exception (one day at Rock Island Dam), there was no spill during the fall chinook salmon migration.

Run Timing/Separation

Run timing of spring and summer chinook salmon at the Wenatchee River, Priest Rapids Dam, Wanapum Dam, and Rock Island Dam was considerably earlier than run timing for fish that passed Rocky Reach and Wells Dams (Fig. 5). Differences were most apparent during the early stages of the migration.

There were, however, no distinct separations between the different stocks of spring chinook salmon adults destined for the Wenatchee, Entiat, Methow, and Okanogan Rivers at Priest Rapids, Rocky Reach, and Wells Dams (Fig. 6).

At Priest Rapids Dam, the run timing of radio-tagged spring chinook salmon adults was late relative to the total population counted passing the dam (Fig. 7). The difference was caused by a differential between the run and tagging schedule at John Day Dam. Three percent of the run had past John Day Dam when tagging



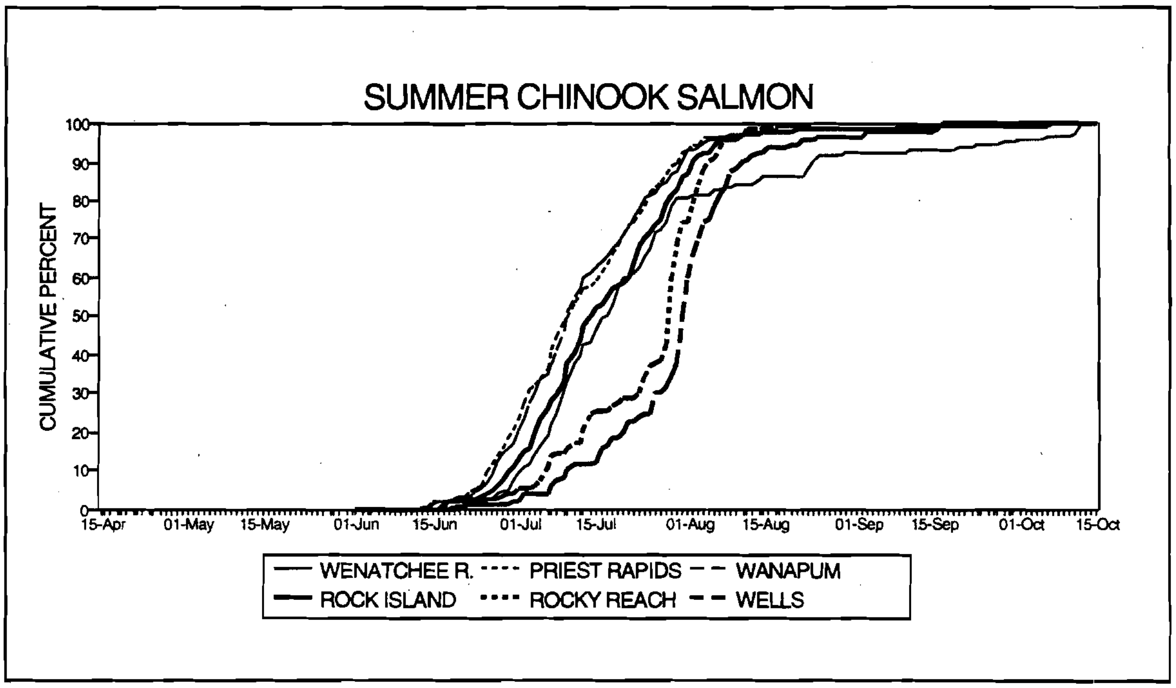


Figure 5.--Run timing of radio-tagged chinook salmon in the mid-Columbia River, 1993.

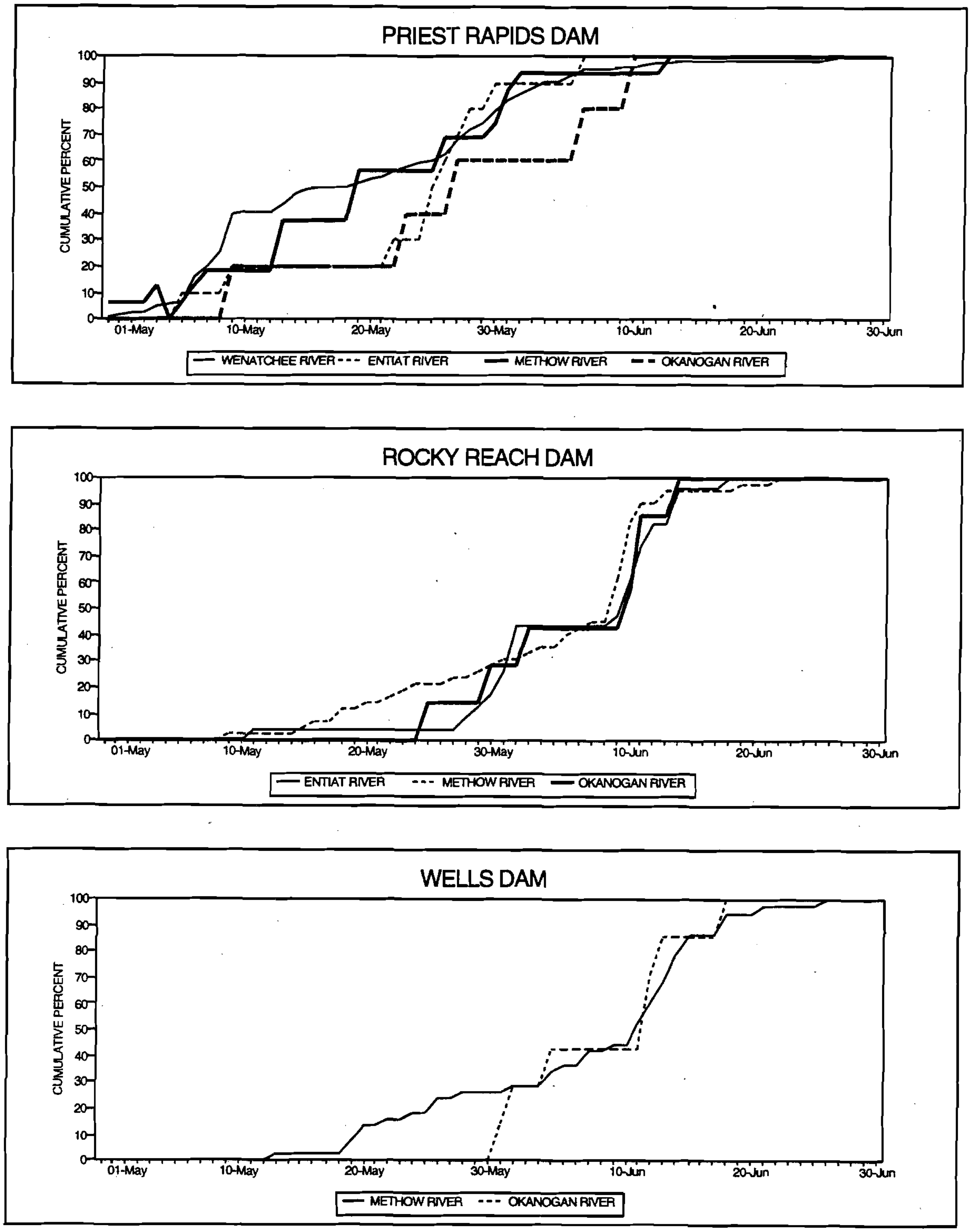
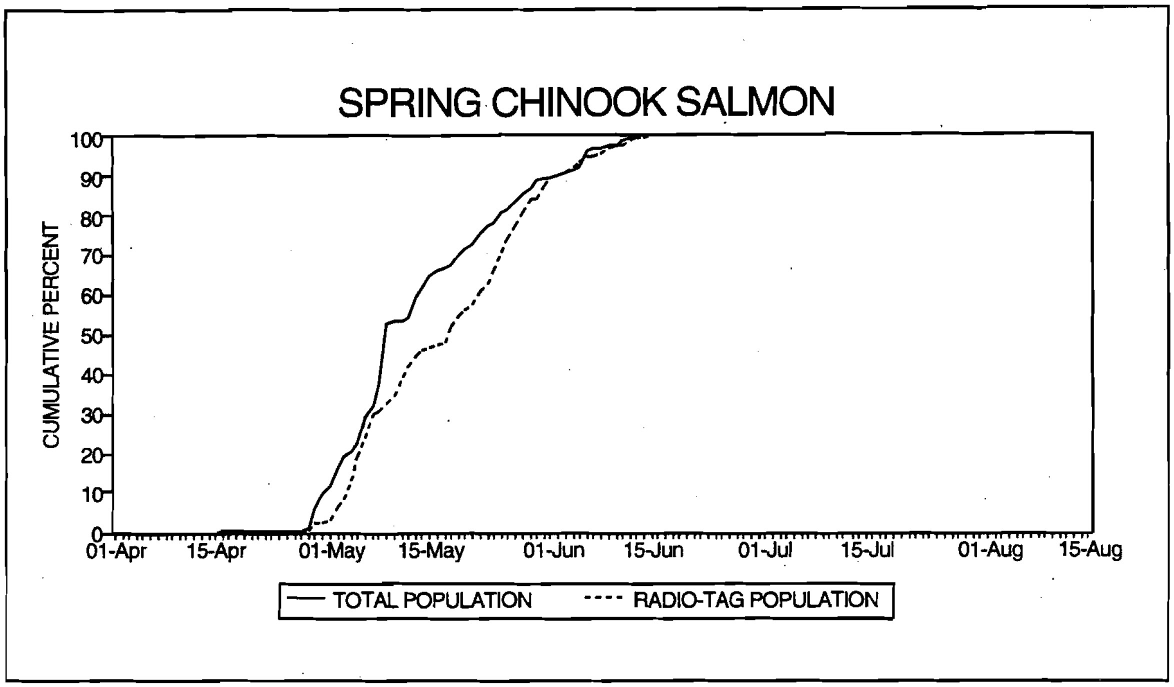


Figure 6.--Run timing at dams with adult trapping facilities for the radio-tagged spring chinook salmon that entered tributaries, 1993.



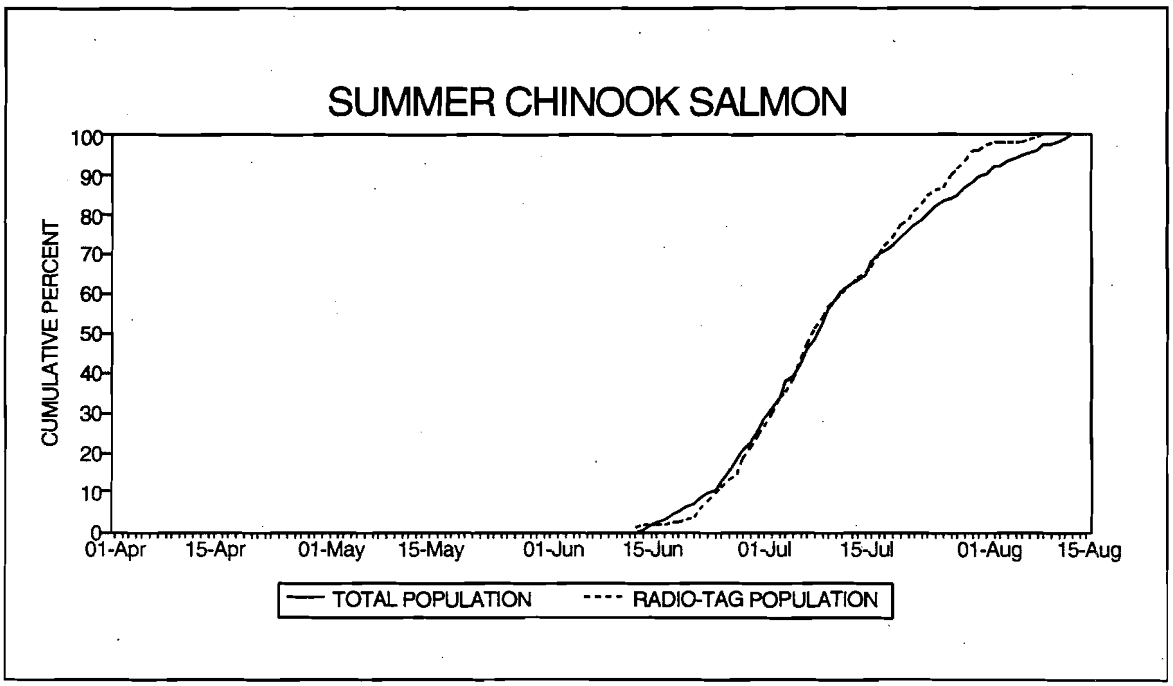


Figure 7.--Run timings of the total and radio-tagged populations at Priest Rapids Dam, 1993

started and the median run and tagging dates were 1 May and 11 May, respectively. Therefore, run timing of radio-tagged spring chinook salmon adults farther upstream may not be indicative of the population in general. Run timing of summer chinook salmon adults was similar for both tagged and observed fish (Fig. 7).

Fish arrived at the tailraces and collection channels throughout the day, with the highest numbers arriving during daylight hours (Appendix B, Figs. 1-20). Fish generally made their first collection-channel entries during daylight hours. Last collection-channel records (ladder entrances) and exits from fish ladders were almost completely limited to daylight hours, with the exception of Rocky Reach and Wells Dams.

Travel Time

The first radio-tagged spring chinook salmon passed McNary Dam on 27 April. Median migration time from McNary Dam to Priest Rapids Dam was 95.8 hours for spring chinook salmon and 87.2 hours for summer chinook salmon (Table 3).

Priest Rapids Dam

Upon arrival in the tailrace of Priest Rapids Dam, fish moved directly to the collection channel. The first collection-channel records at Priest Rapids Dam were made 1.4 and 0.7 hours (median) after the first downstream monitor records for spring and summer chinook salmon, respectively.

Table 3.--Travel time (hours) of radio-tagged spring and summer chinook salmon passing Priest Rapids Dam, 1993.

		N	Median	Max.	Min.
<u>Spring chinook salmon</u>					
McNary Dam to tailrace (Priest Rapids Dam)		161	95.8	1,802	54.3
Tailrace to arrival (at Priest Rapids Dam)		154	1.4	1,076	0.1
Arrival to entry		216	14.4	415	<0.1
	Fate below Priest Rapids Dam	30	3.6	330	<0.1
	Fate above Priest Rapids Dam	159	16.4	415	<0.1
First entry to last channel exit		226	8.9	487	<0.1
Ladder time	right	12	2.0	20	1.5
	left	184	3.1	105	1.8
Total passage time at Priest Rapids Dam		197	44.9	2,084	2.6
<u>Summer chinook salmon</u>					
McNary Dam to tailrace (Priest Rapids Dam)		222	87.2	415	46.7
Tailrace to arrival (at Priest Rapids Dam)	233	0.7	81	0.1	
Arrival to entry		269	1.0	178	<0.1
First entry to last channel exit		269	25.5	1,416[1]	<0.1
Ladder time	right	21	2.3	26	1.4
	left	240	2.9	55	1.4
Total passage time at Priest Rapids Dam		261	29.4	682	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

Arrival-to-entry timing differed for spring and summer chinook salmon. Spring chinook salmon took a median of 14.4 hours to make their first collection-channel entry, while summer chinook salmon moved into the collection channel in 1 hour (Table 3). Spring chinook salmon with final records upstream from Priest Rapids Dam had longer median arrival-to-entry times (16.4 hours) than those below the dam (3.6 hours). Analysis with the Wilcoxon Signed Rank test (Bickel and Doksum, 1977) indicated that the difference between the two groups was not statistically different (P = 0.9483).

Median duration of entry to last collection channel record was 8.9 hours for spring chinook salmon and 25.5 hours for summer chinook salmon (Table 3). Median ladder times for spring chinook salmon were 2.0 and 3.1 hours for the right and left fish ladders, respectively. Median ladder times for summer chinook salmon were 2.3 and 2.9 hours, respectively. Total passage time (median) at Priest Rapids Dam for spring and summer chinook salmon was 44.9 and 29.4 hours, respectively (Appendix Figure D1).

The median migration time from Priest Rapids Dam to Wanapum Dam was 15.8 hours for spring chinook salmon, 13.6 hours for summer chinook salmon, and 62.4 hours for fall chinook salmon (Table 4). Spring chinook salmon tagged at Priest Rapids Dam took significantly more time (32.4 hours) (P = 0.0108) to reach Wanapum Dam than fish tagged at John Day Dam (16.9 hours), suggesting a handling-associated effect.

Table 4.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Wanapum Dam, 1993.

	N	Median	Max.	Min.
Spring chinook salmon				
Priest Rapids Dam to tailrace (Wanapum Dam)	54	15.8	1,314	6.8
Priest Rapids Dam to collection channel (Wanapum)				
Tagged at John Day Dam	174	16.9	1,314	5.7
Tagged at Priest Rapids Dam	30	32.4	466	14.8
Tailrace to arrival (at Wanapum Dam)	65	1.5	197	<0.1
Arrival to entry	226	8.9	486	<0.1
First entry to last channel exit	226	2.0	1,104	<0.1
Ladder time right	7	4.2	23	1.7
left	203	2.8	67	1.4
Total passage time at Wanapum Dam	211	36.6	1,108	2.0
Tagged at John Day Dam	185	35.7	1,108	2.6
Tagged at Priest Rapids Dam	26	46.0	496	2.0
Summer chinook salmon				
Priest Rapids Dam to tailrace (Wanapum Dam)	38	13.6	415	46.7
Tailrace to arrival (at Wanapum Dam)	38	0.9	81	0.1
Arrival to entry	255	1.9	178	<0.1
First entry to last channel exit	255	20.2	1,416[1]	<0.1
Ladder time right	44	2.3	26	1.4
left	160	2.7	55	1.4
Total passage time at Wanapum Dam	209	22.9	682	2.4
Fall chinook salmon				
Priest Rapids Dam to tailrace (Wanapum Dam)	19	62.4	288	16.8
Tailrace to arrival (at Wanapum Dam)	19	2.4	29	<2.4
Arrival to entry	57	<2.4	362	<2.4
First entry to last channel exit	58	24.0	684	<2.4
Ladder time right	7	4.8	14	2.4
left	33	2.4	17	<2.4
Total passage time at Wanapum Dam	40	40.7	689	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

Wanapum Dam

Upon arrival at the Wanapum Dam tailrace, fish moved directly into the collection channel. Median times from the tailrace to arrival were 1.5, 0.9, and 2.4 hours for spring, summer, and fall chinook salmon, respectively (Table 4). Similar to the behavior they exhibited at Priest Rapids Dam, spring chinook salmon at Wanapum Dam had longer median first collection-channel entry (8.9 hours) than summer chinook salmon (1.9 hours) or fall chinook salmon (2.4 hours), but spent less time from entry to last collection-channel records (2.0 hours for spring chinook salmon vs. 20.2 hours for summer chinook salmon and 24.0 hours for fall chinook salmon).

Spring chinook salmon median ladder times were 4.2 and 2.8 hours for the right and left fish ladders, respectively. Ladder times were 2.3 (right fish ladder) and 2.7 (left fish ladder) hours for summer chinook salmon and 4.8 (right fish ladder) and 2.4 (left fish ladder) hours for fall chinook salmon.

Median total passage times at Wanapum Dam were 36.6, 22.9, and 40.7 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D2). No Wanapum Dam total passage time differences were observed between spring chinook salmon tagged at John Day Dam and those tagged at Priest Rapids Dam after arrival at Wanapum Dam (Table 4). Median passage time for spring chinook salmon tagged at Priest Rapids Dam was longer (46.0 hours) than passage time for fish tagged at John Day Dam

(35.7 hours). The difference, however, was not significant (P = 0.3878).

The median migration time from Wanapum Dam to Rock Island Dam was 22.6 hours for spring chinook salmon, 24.3 hours for summer chinook salmon, and 36.0 hours for fall chinook salmon (Table 5).

Rock Island Dam

Fish moved directly from the tailrace to the collection channel at Rock Island Dam. Median tailrace to arrival times were 0.9, 0.8, and less than 2.4 hours for spring, summer, and fall chinook salmon, respectively.

Median tailrace-to-arrival and arrival-to-entry times were consistent throughout the migration. First entries occurred quickly (spring chinook salmon, 0.9 hours; summer chinook salmon, 0.5 hours; and fall chinook salmon, <2.4 hours). Durations between entry into the collection channel and last record in the collection channel were 10.7, 8.0, and 14.4 hours for spring, summer, and fall chinook salmon, respectively.

Median ladder times for spring chinook salmon were 0.5, 2.6, and 3.1 hours for the right, center, and left fish ladders, respectively. Ladder times were 1.8 (right fish ladder), 2.5 (center fish ladder), and 1.4 (left fish ladder) hours for summer chinook salmon, and 4.8 (right fish ladder), 2.4 (center fish ladder), and 2.4 hours (left fish ladder) for fall chinook salmon. Median total passage times at Rock Island Dam were 20.3,

Table 5.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Rock Island Dam, 1993.

		N	Median	Max.	Min.
Spring chinook salmon					
Wanapum Dam to tailrace (Rock Island Dam)		138	22.6	172	16.0
Tailrace to arrival (at Rock Island Dam)		145	0.9	588	0.1
Arrival to entry		206	0.9	105	<0.1
First entry to last channel exit		205	10.7	770	<0.1
Ladder time	right	145	0.5	17	0.1
	center	44	2.6	46	0.4
	left	5	3.1	26	1.1
Total passage time at Rock Island Dam		195	20.3	779	1.2
Summer chinook salmon					
Wanapum Dam to tailrace (Rock Island Dam)		189	24.3	115	14.2
Tailrace to arrival (at Rock Island Dam)		236	0.8	42	0.1
Arrival to entry		255	0.5	283	<0.1
First entry to last channel exit		255	8.0	1,891[1]	0.1
Ladder time	right	214	1.8	1,760	0.6
	center	17	2.5	800	9.8
	left	17	1.4	12	0.5
Total passage time at Rock Island Dam		250	14.6	1,768	1.2
Fall chinook salmon					
Wanapum Dam to tailrace (Rock Island Dam)		23	36.0	598	12.0
Tailrace to arrival (at Rock Island Dam)		34	<2.4	10	<2.4
First entry to collection channel		53	<2.4	10	<2.4
First entry to last channel exit		53	14.4	775	<2.4
Ladder time	right	30	4.8	1,334	<2.4
	center	2	2.4	2	<2.4
	left	6	2.4	2	<2.4
Total passage time at Rock Island Dam		38	19.2	1,366	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

14.6, and 19.2 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D3).

Wenatchee River

The median travel time from the exit of Rock Island Dam to entry of the Wenatchee River was 36.0 hours for spring chinook salmon and 53.2 hours for summer chinook salmon (Table 6). The median Wenatchee River entry dates for spring and summer chinook salmon were 2 June and 17 July, respectively (Appendix C, Fig. 1).

Rocky Reach Dam

The first spring chinook salmon arrived at Rocky Reach Dam on 7 May. Median migration time from Rock Island Dam to Rocky Reach Dam was 13.5 hours for spring chinook salmon, 14.3 hours for summer chinook salmon, and 14.4 hours for fall chinook salmon (Table 6). Median tailrace to arrival times were 0.7, 0.9, and 2.4 hours for spring, summer, and fall chinook salmon, respectively. Fall chinook salmon took over three times longer than spring and summer chinook salmon between arrival and entry (4.8 vs. 1.4 hours for spring and summer chinook salmon). The median time between entry into the collection channel and the last record (spring chinook salmon, 25.6 hours; summer chinook salmon, 10.4 hours; and fall chinook salmon, 38.4 hours) made up the longest portion of the total dam-passage time. The median ladder times were 3.3, 2.8, and 4.8 hours for spring, summer, and fall chinook salmon, respectively. Median total passage times at

Table 6.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Rocky Reach Dam, 1993.

	N	Median	Max.	Min.
Spring chinook salmon				
Rock Island Dam to Wenatchee River entry	148	36.0	343.6	14.1
Rock Island Dam to tailrace (Rocky Reach Dam)	28	13.5	400	8.6
Tailrace to arrival (Rocky Reach Dam)	58	0.7	96	0.1
Arrival to entry	100	1.4	159	<0.1
First entry to last channel exit	100	25.6	835	<0.1
Ladder time	89	3.3	85	1.8
Total passage time at Rocky Reach Dam	211	36.6	1,108	2.0
Summer chinook salmon				
Rock Island Dam to Wenatchee River entry	156	53.2	2,174	13.3
Rock Island Dam to tailrace (Rocky Reach Dam)	107	14.3	1,605	9.5
Tailrace to arrival (Rocky Reach Dam)	142	0.9	743	0.1
Arrival to entry	158	1.4	262	<0.1
First entry to last channel exit	158	10.4	1,321[1]	<0.1
Ladder time	127	2.8	26	1.4
Total passage time at Rocky Reach Dam	209	22.9	682	2.4
Fall chinook salmon				
Rock Island Dam to tailrace (Rocky Reach Dam)	22	14.4	118	9.6
Tailrace to arrival (Rocky Reach Dam)	27	2.4	112	<2.4
Arrival to entry	37	4.8	105	<2.4
First entry to last channel exit	37	38.4	571	<2.4
Ladder time	34	4.8	247	2.4
Total passage time at Rocky Reach Dam	38	60.0	609	2.4

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

Rocky Reach Dam were 36.6, 22.9, and 60.0 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D4).

Entiat River

The median migration time between exiting Rocky Reach Dam and entering the Entiat River was 37.8 hours for spring and 150 hours for summer chinook salmon (Table 7). The median Entiat River entry dates were 12 June and 31 July for spring and summer chinook salmon, respectively (Appendix C, Fig. 2).

Wells Dam

The median migration time from Rocky Reach Dam to Wells Dam was 22.7 hours for spring chinook salmon, 25.8 hours for summer chinook salmon, and 40.8 hours for fall chinook salmon (Table 7). The fish moved directly from the tailrace to the collection channel as determined by short median tailrace to arrival times of 1.4, 1.8, and 2.4 hours for spring, summer, and fall chinook salmon, respectively. Median time from arrival to entry of the collection channel ranged from 0.4 hours for summer chinook salmon to less than 2.4 hours for fall chinook salmon. Median time between entry into the collection channel and the last record in the collection channel made up the longest portion of the total dam passage time (26.8, 33.3, and 31.2 hours for spring, summer, and fall chinook salmon, respectively).

Median ladder times were 2.2 (right fish ladder) and 2.1 (left fish ladder) hours for spring chinook salmon, 2.6 (right

Table 7.--Travel time (hours) of radio-tagged spring, summer, and fall chinook salmon passing Wells Dam, 1993.

	N	Median	Max.	Min.
Spring chinook salmon				
Rocky Reach Dam to Entiat River entry	20	37.8	560	11.8
Rocky Reach Dam to tailrace (Wells Dam)	63	22.7	97	17.9
Tailrace to arrival (Wells Dam)	66	1.4	96	0.6
Arrival to entry	72	0.9	29	<0.1
First entry to last channel exit	73	26.8	1,383	<0.1
Ladder time				
right	27	2.2	52	1.2
left	28	2.1	22	0.6
Total passage time at Wells Dam	56	28.5	1,396	2.9
Wells Dam to Methow River entry	41	30.9	1,178	17.8
Wells Dam to Okanogan River entry	7	270.4	531	103.2
Summer chinook salmon				
Rocky Reach Dam to Entiat River entry	10	150.0	1,803	15.3
Rocky Reach Dam to tailrace (Wells Dam)	111	25.8	50	15.4
Tailrace to arrival (Wells Dam)	112	1.8	1,610	0.5
Arrival to entry	123	0.4	646	<0.1
First entry to last channel exit	123	33.3	1,698[1]	<0.1
Ladder time				
right	10	2.6	32	1.5
left	87	2.7	28	1.3
Total passage time at Wells Dam	97	46.9	1,108	2.0
Wells Dam to Methow River entry	16	434.2	2,025	73.3
Wells Dam to Okanogan River entry	50	24.6	1,631	13.4
Fall chinook salmon				
Rocky Reach Dam to tailrace (Wells Dam)	33	40.8	180	7.2
Tailrace to arrival (Wells Dam)	36	2.4	36	<2.4
Arrival to entry	52	<2.4	823	<2.4
First entry to last channel exit	51	31.2	749	<2.4
Ladder time				
right	20	2.4	100	<2.4
left	32	2.4	19	2.4
Total passage time at Wells Dam	52	45.6	828	4.8

[1]First entry to last channel exit times greater than max total passage time are associated with non-passage fish.

fish ladder) and 2.7 (left fish ladder) hours for summer chinook salmon, and 2.4 hours for both right and left fish ladders for fall chinook salmon. Median total passage times at Wells Dam were 28.5, 46.9, and 45.6 hours for spring, summer, and fall chinook salmon, respectively (Appendix Figure D5).

Methow and Okanogan Rivers

Migration times for spring chinook salmon from Wells Dam to the Methow River and from Wells Dam to the Okanogan River were 30.9 and 270.4 hours, respectively (Table 7). The median Methow River entry date for spring chinook salmon was 13 June, and the median Okanogan River entry date was 16 June. Median migration times for summer chinook salmon from Wells Dam to the Methow River (Appendix C, Fig. 3) and from Wells Dam to the Okanogan River (Appendix C, Fig. 4) were 434.2 and 24.7 hours, respectively. For summer chinook salmon, the median date of entry to the Methow River was 31 August and the median date of entry to the Okanogan River was 2 August.

Fate of Radio-Tagged Fish

Spring Chinook Salmon

Most radio-tagged spring chinook salmon migrating above Priest Rapids Dam terminated their migration in tributaries (Fig. 8). The Wenatchee River was the final destination of the largest proportion of radio-tagged fish (57.4%), with lesser

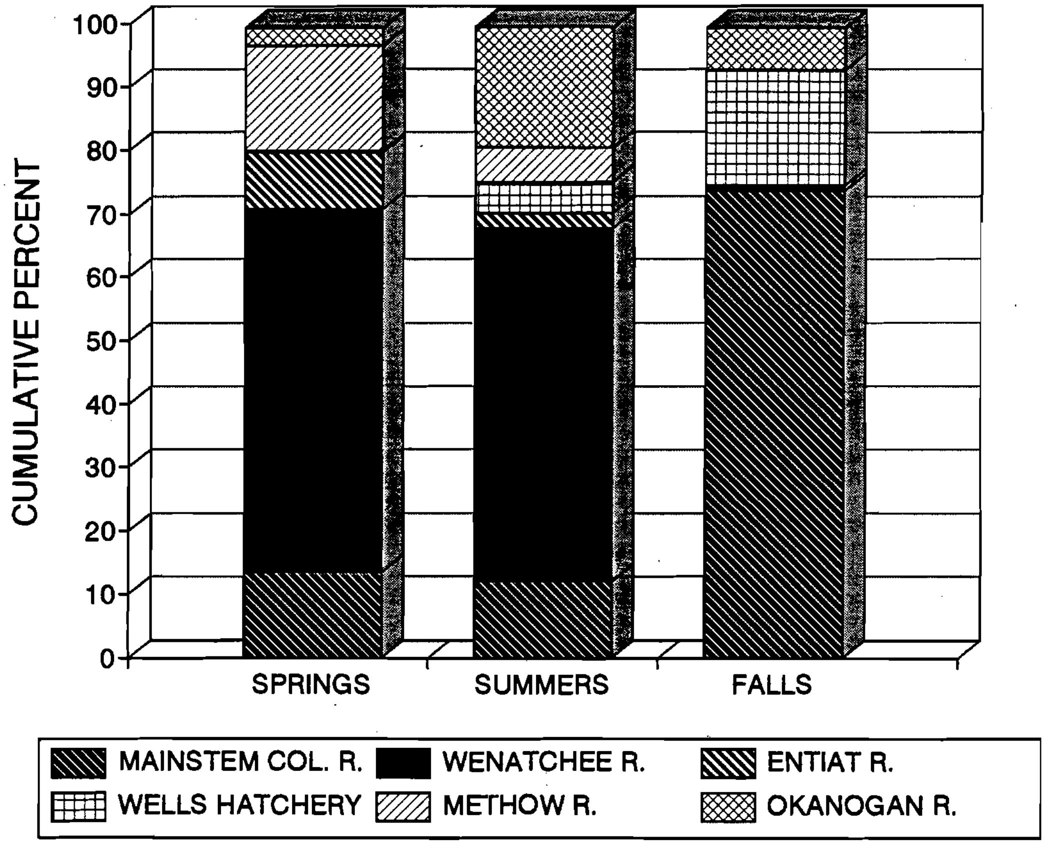


Figure 8.--Distribution of radio-tagged spring, summer, and fall chinook salmon upstream from Priest Rapids Dam, 1993.

numbers in the Entiat (9.0%), Methow (16.8%), and Okanogan (3.0%) Rivers (Table 8). Tags detected in the mainstem Columbia River above Priest Rapids Dam that remained stationary for long periods were assigned to pre-spawning mortality or tag regurgitations. We assumed tags that disappeared during the spring chinook migration period were related to harvest or tag failures. Below Priest Rapids Dam, the mainstem population consisted of fallbacks from above Priest Rapids Dam, and in some instances, Wanapum Dam. Some fallbacks eventually moved into the Ringold Spring Chinook Salmon Facility (RM 353). Other radio-tagged spring chinook salmon never passed Priest Rapids Dam but milled below the dam until after they should have spawned. We suspect most of these fish were adult returns that were a product of juvenile releases from the Ringold Facility.

Some mortalities below Priest Rapids may have been fallbacks that should have migrated to areas upstream from Priest Rapids Dam. It is also very likely that some of the mainstem mortalities above Priest Rapids Dam were fish from the Ringold Facility that were trying to move downstream. We estimated that the maximum mortality of spring chinook salmon in the study area (excludes all fish entering spawning areas) was 22.2%. If all of the fish with unknown fates below Priest Rapids Dam (N = 38) were fish from the Ringold Facility, the mortality estimate would have decreased to 11.1%.

Table 8.--Summary of last locations of radio-tagged spring and summer chinook salmon in the mid-Columbia River study area.

Last recorded location	Spring chinook salmon PR[1]	Spring chinook salmon RR[2]	Spring chinook salmon TOTAL	Summer chinook salmon RR[2]	Summer chinook salmon TOTAL
Columbia River near Walla Walla River			2		0
Yakima River			3		2
Ringold Facility	4	2	25		2
Unknown, downstream Priest Rapids Dam	5		38		7
Priest Rapids trap	1		6		1
Below Priest Rapids Dam			1		2
Priest Rapids Dam fishery			0		1
Unknown, upstream Priest Rapids Dam	2		2		0
Wanapum Dam fishery			1		0
Columbia River near Wanapum Dam	1		1		0
Unknown, Downstream Wanapum Dam			7		0
Unknown, Wanapum Dam			2		0
Unknown, upstream Wanapum Dam	1		1		1
Unknown, downstream Rock Island Dam			3	4	7
Stationary, Rock Island Dam			1		0
Unknown, upstream Rock Island Dam			0		3
Wenatchee River	18		154		171
Unknown, downstream Rocky Reach Dam		1	3		2
Entiat River	2	11	24	2	8
Chelan River	1		1		0
Unknown, downstream Wells Dam		3	8	1	2
Wells Hatchery		1	1	7	15
Wells Dam fishery			0		1
Unknown, upstream Wells Dam	1	4	6		2
Methow River	2	23	45	6	17
Okanogan River		3	8	21	59
Chief Joseph Dam fishery			0		12
Unknown, below Chief Joseph Dam			0		3
TOTAL	38	48	343	49	318

PR[1] Fish tagged at Priest Rapids Dam
RR[2] Fish tagged at Rocky Reach Dam

Summer Chinook Salmon

The majority of radio-tagged summer chinook salmon passing above Priest Rapids Dam also terminated their migrations in tributaries. The largest number of fish was last recorded in the Wenatchee River (56.4%), and smaller numbers were last recorded in the Entiat (2.6%), Methow (5.6%), and Okanogan (19.5%) Rivers. An additional 5.0% of radio-tagged fish entered the Wells Hatchery.

Mainstem fish above Priest Rapids Dam were fish that did not move for long periods (pre-spawning mortality or tag regurgitations), and fish that disappeared during the summer chinook salmon migration period (harvest or tag failures). The fishery in the tailrace of Chief Joseph Dam removed at least 12, and possibly up to 15, radio-tagged summer chinook salmon. We estimated that the maximum mortality (which includes all fish not entering spawning areas) of summer chinook salmon in the study area was 13.5%. It is highly likely that some of the radio-tagged fish with last locations downstream from Wanapum, Rock Island, Rocky Reach and Wells Dams were also spawners.

Fall Chinook Salmon

Final detections of fall chinook salmon above Priest Rapids Dam were recorded predominantly in the main stem (72.9%) and in Wells Hatchery (17.9%) (Table 9). The largest number of mainstem fish were detected in the Wells Dam tailrace (61), with smaller

Table 9.--Summary of last locations of radio-tagged fall chinook salmon in the mid-Columbia River study area.

Last recorded location	PR[1]	RR[2]
Below Vernita Bridge	6	0
Columbia River sport fish harvest	1	0
Priest Rapids Salmon Hatchery	8	0
Priest Rapids Dam tailrace	2	0
Priest Rapids Reservoir (PR vicinity)	3	0
Priest Rapids Reservoir (wildlife area)	3	0
Priest Rapids Reservoir (mouth of Crab Creek)	7	0
Columbia River sport fish harvest	1	0
Wanapum Dam tailrace	36	0
Wanapum Dam Reservoir (Crescent Bar area)	1	1
Rock Island Dam tailrace	3	3
Rock Island Reservoir (RI vicinity)	0	1
Rock Island Reservoir (Wenatchee River mouth)	0	1
Wenatchee River (lower)	1	1
Wenatchee River sportfish harvest	0	1
Rocky Reach Dam tailrace	17	9
Rocky Reach Reservoir (RR vicinity)	0	4
Rocky Reach Reservoir (Entiat River mouth)	0	4
Entiat River	0	0
Rocky Reach Reservoir (Chelan River mouth)	0	7
Chelan River	0	2
Wells Salmon Hatchery	13	34
Wells Dam tailrace	13	48
Wells Dam Reservoir (Wells Dam vicinity)	3	4
Methow River	0	0
Wells Dam Reservoir (Okanogan River mouth)	1	0
Okanogan River	2	15
Similkameen River	1	3
Wells Dam Reservoir (Bridgeport Bar area)	0	7
Chief Joseph Dam tailrace	0	2
Chief Joseph Dam snag fishery	0	2
Priest Rapids Dam area	1	0
Rocky Reach Dam area	0	5
Wells Dam area	0	2
TOTAL	123	156

[1] Fish tagged at Priest Rapids Dam

[2] Fish tagged at Rocky Reach Dam

groups observed below Priest Rapids (16), Wanapum (36), Rock Island (6), and Rocky Reach Dams (26). A major exception to this pattern was observed in 21 fish that migrated into the Okanogan River. A few fish were last detected at the confluences of the Columbia River and its tributaries: two were detected at the mouth of the Wenatchee River; four at the Entiat River; nine at the Chelan River; and one at the mouth of the Okanogan River. We could not estimate maximum mortality for fall chinook salmon, because pre-spawning mortalities could not be separated from spawners. However, a fraction of the fish that fell back but did not reascend the fishways were probably pre-spawning mortalities.

Adult Collection Channel Efficiency

Priest Rapids Dam

Spring chinook salmon at Priest Rapids Dam had net positive entries (number of entries higher than number of exits) at 8 of the 11 powerhouse collection-channel openings (Fig. 9). Locations of their last powerhouse collection-channel entry were spread across the collection channel (Fig. 10). Fish moved both directions in the channel but tended to move toward the fish ladder (Fig. 11). Fish entering at 6 of the 11 openings had a greater than 50% probability of reaching the base of the fish ladder before exiting the channel either downstream or via the fish ladder (Fig. 12). All of the openings where fish had less than a 50% chance of being at the base of the ladder before exiting were orifice gate openings.

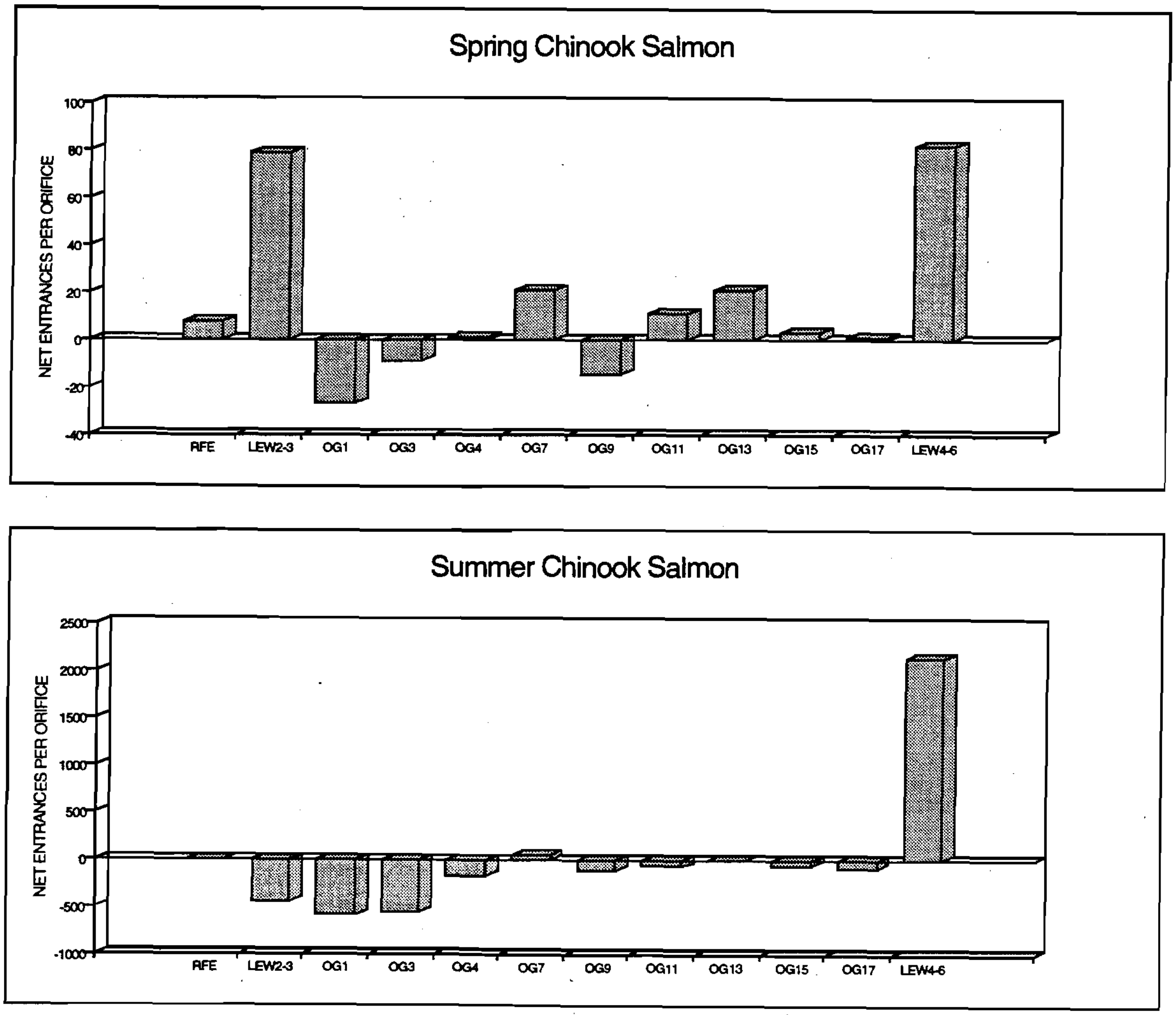


Figure 9.--Net passage per collection-channel opening at Priest Rapids Dam, 1993; RFE (Right Fishway Entrance), LEW (Left Entrance Weir), and OG (Orifice Gates).

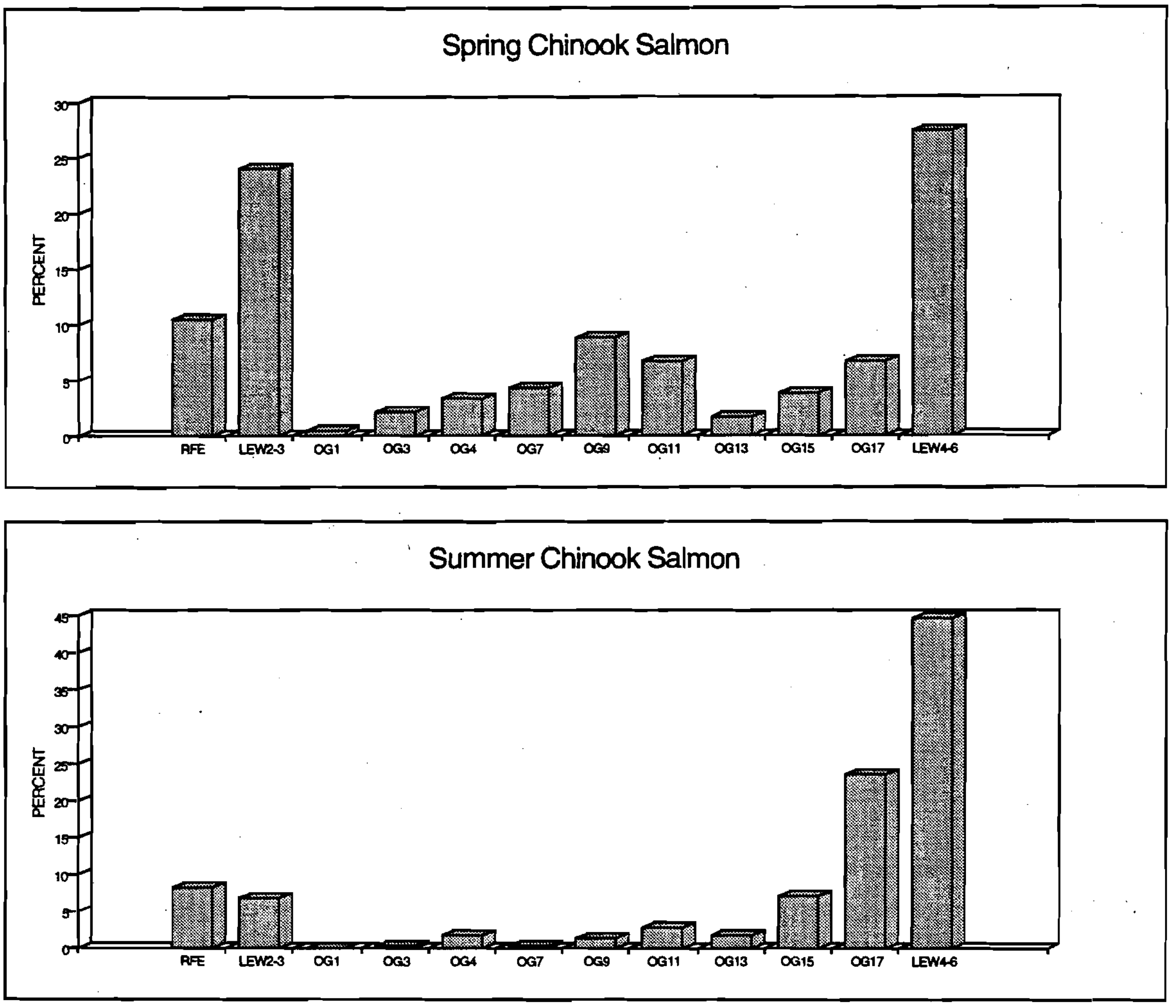
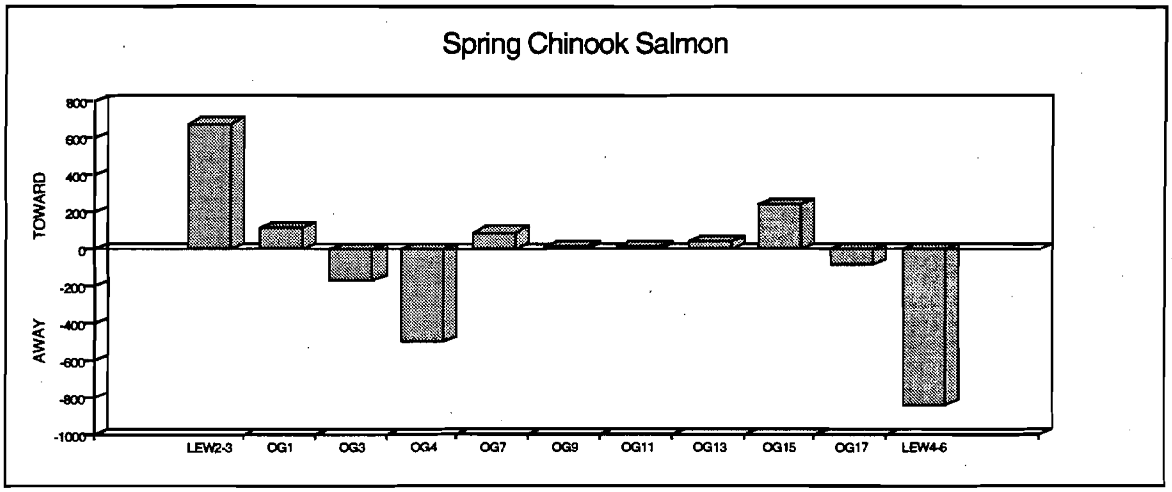


Figure 10.--Percent of last entrances per collection-channel opening at Priest Rapids Dam, 1993; RFE (Right Fishway Entrance), LEW (Left Entrance Weir), and OG (Orifice Gates).



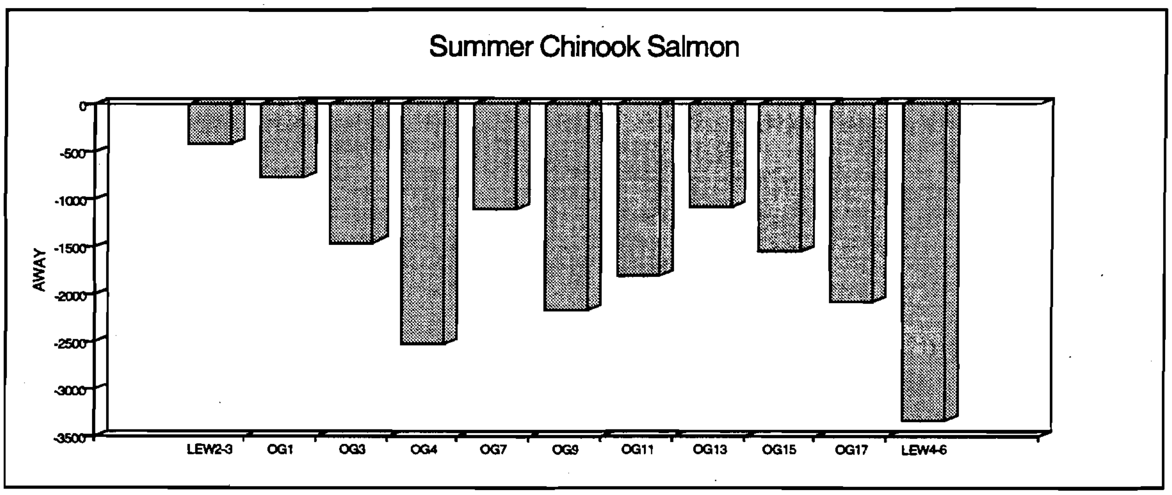


Figure 11.--Net movement toward the fish ladder per collection-channel opening in the Priest Rapids Dam collection channel, 1993; RFE (Right Fishway Entrance), LEW (Left Entrance Weir), and OG (Orifice Gates).

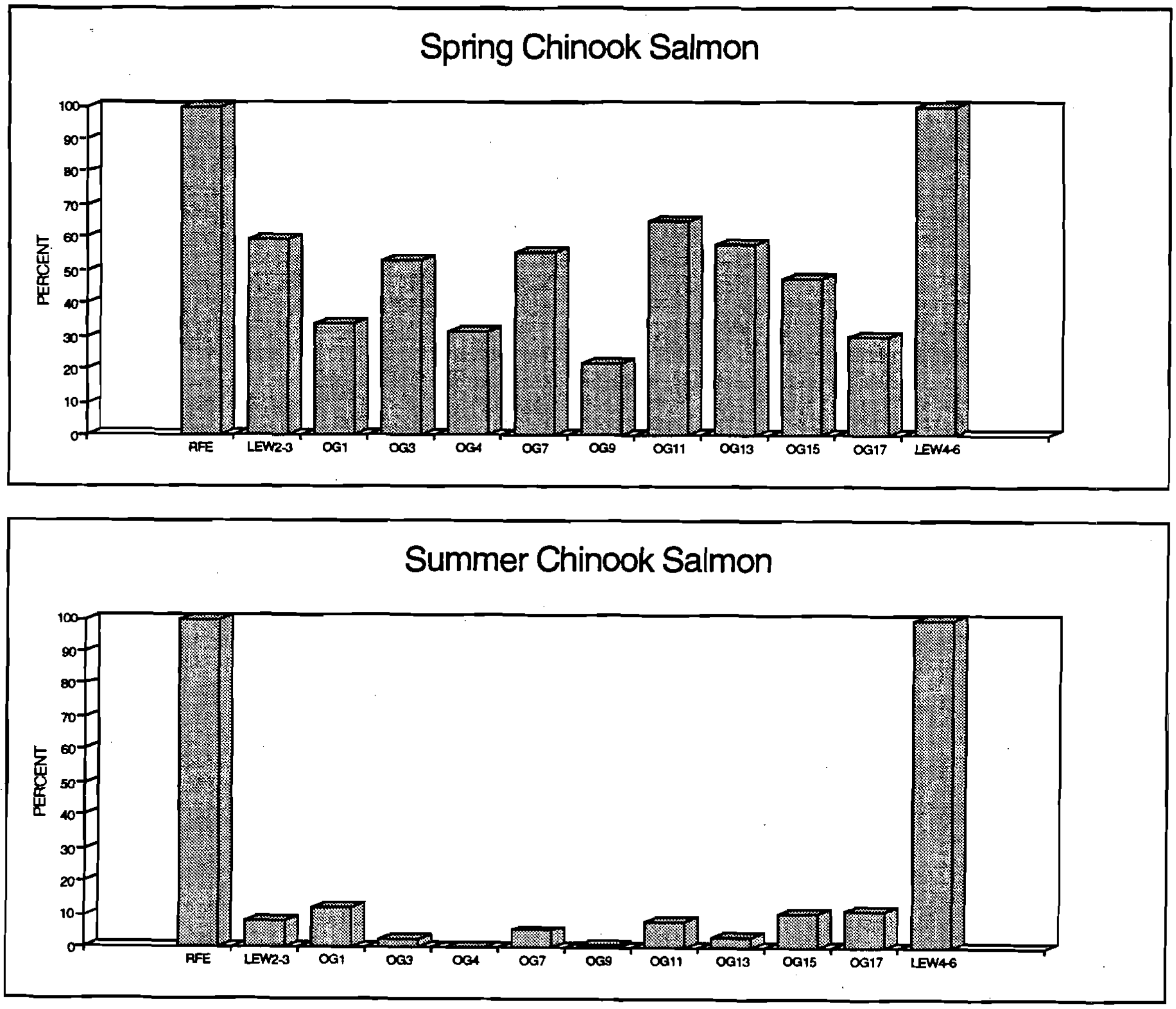


Figure 12.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Priest Rapids Dam, 1993.

Summer chinook salmon behavior was different at the powerhouse collection channel openings and within the channel compared to spring chinook salmon. Net entries at most of the openings were negative (Fig. 9), and last entry locations were concentrated at the base of the fish ladder (Fig. 10). Also, summer chinook salmon movement in the channel was away from the fish ladder (Fig. 11), and less than 10% of the entries at most openings produced a record on the antenna at the base of the fish ladder before the fish fell out of the collection channel (Fig. 12).

Wanapum Dam

At Wanapum Dam, spring and summer chinook salmon detections yielded net positive entries at most of the powerhouse collection channel openings with the exception of the highly negative net entrance rate of fish at Slotted Entrance 3 (SE3) (results for SE3 are the sum of observations for SE3 and Orifice Gate 20 (OG20)) (Fig. 13). However, nearly half of the spring chinook salmon that entered the channel at SE3 traversed to the base of the fish ladder (Fig. 14). Nearly 25% of spring chinook salmon passing the fish ladder and 13% of summer chinook salmon passing the fish ladder (Fig. 15) made their last powerhouse collection-channel entry at SE3.

In contrast, fall chinook salmon had a positive net entry at SE3 (Fig. 13), where 20% of their last channel entrances were recorded (Fig. 15).

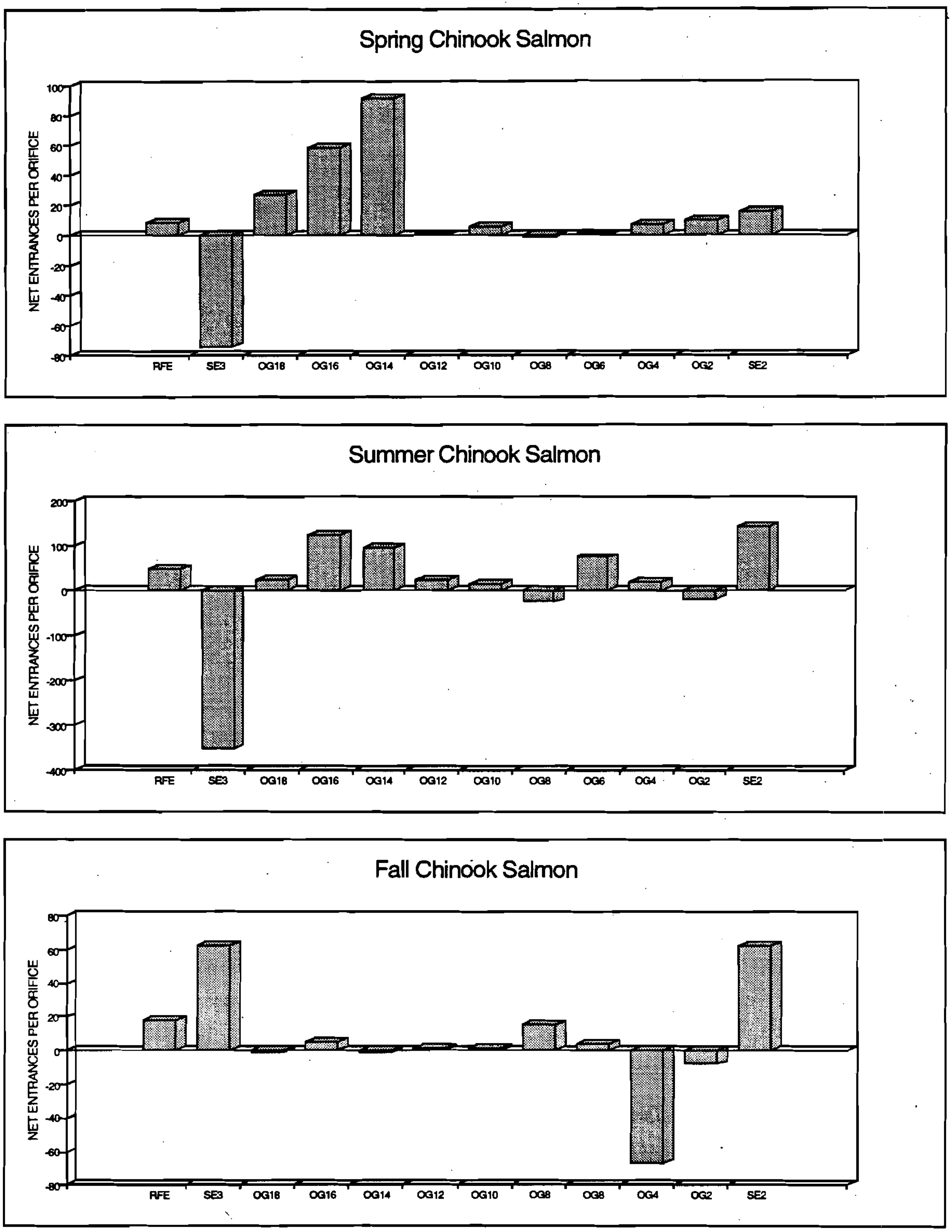
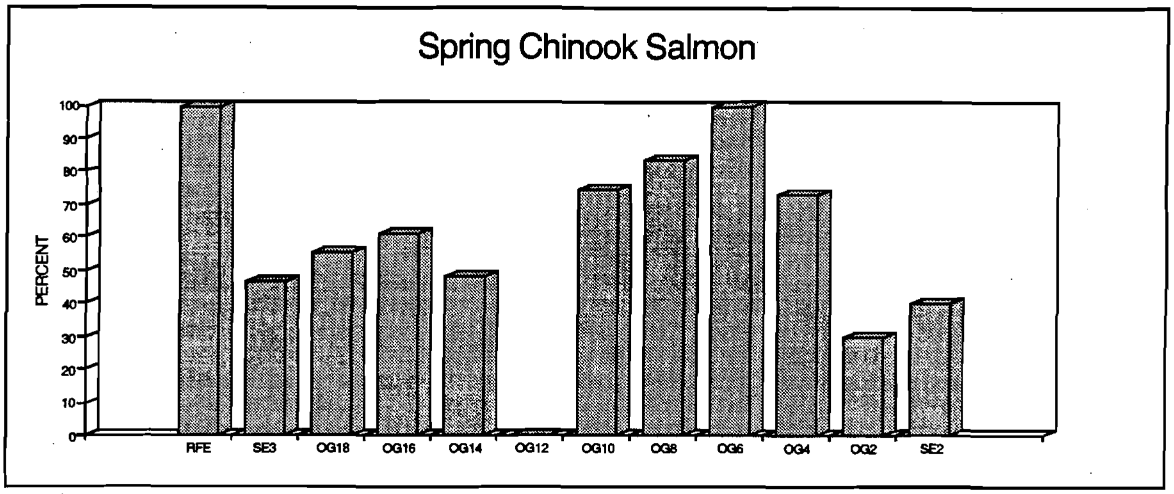


Figure 13.--Net passage per collection-channel opening at Wanapum Dam, 1993; RFE (Right Fishway Entrance), SE (Slotted Entrance), and OG (Orifice Gates).



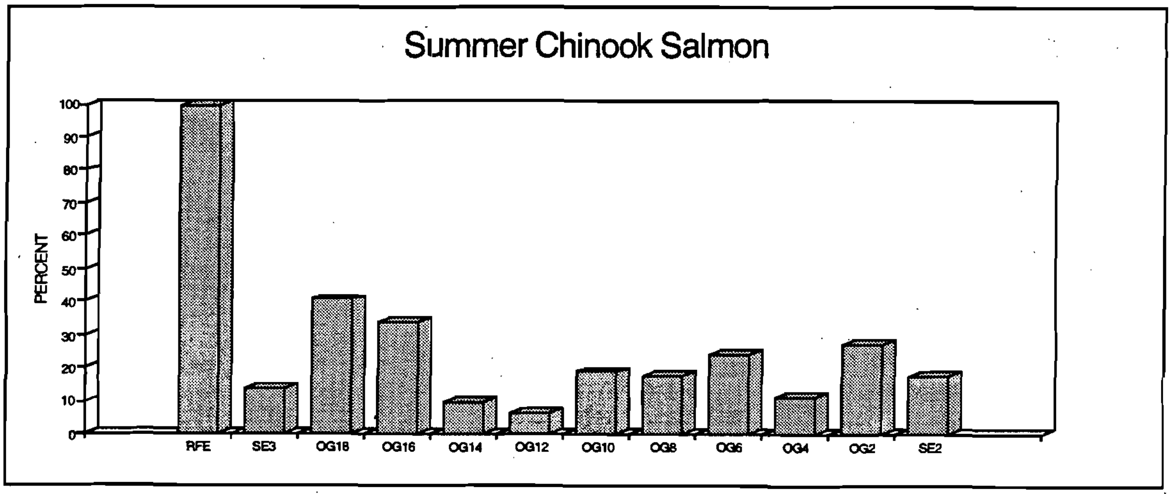


Figure 14.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Wanapum Dam, 1993.

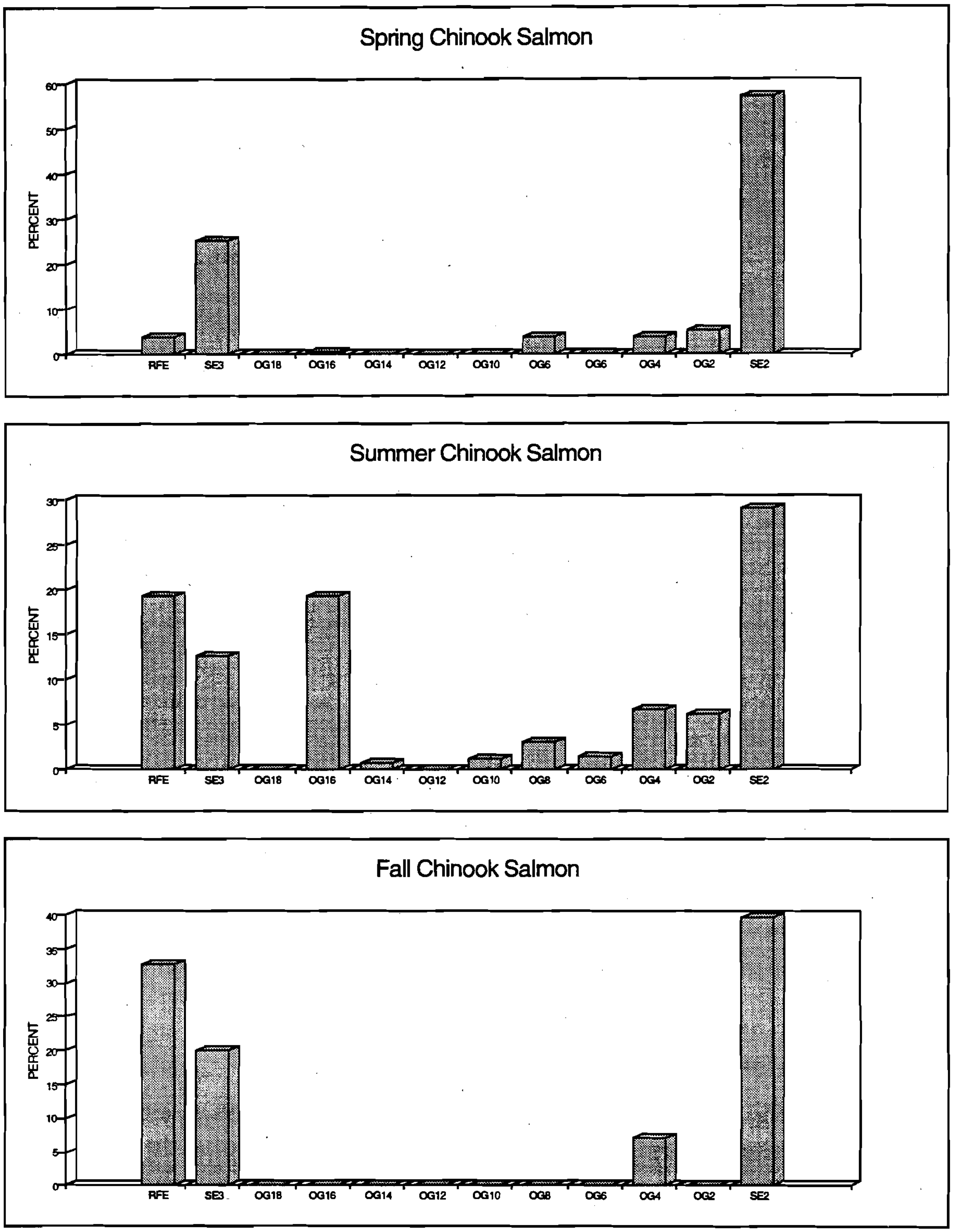


Figure 15.--Percent of last entrances per collection-channel opening at Wanapum Dam, 1993; RFE (Right Fishway Entrance), SE (Slotted Entrance), and OG (Orifice Gates).

Fish moved mostly in the channel toward the fish ladder during the spring run and away from the fish ladder during the summer run (Fig. 16).

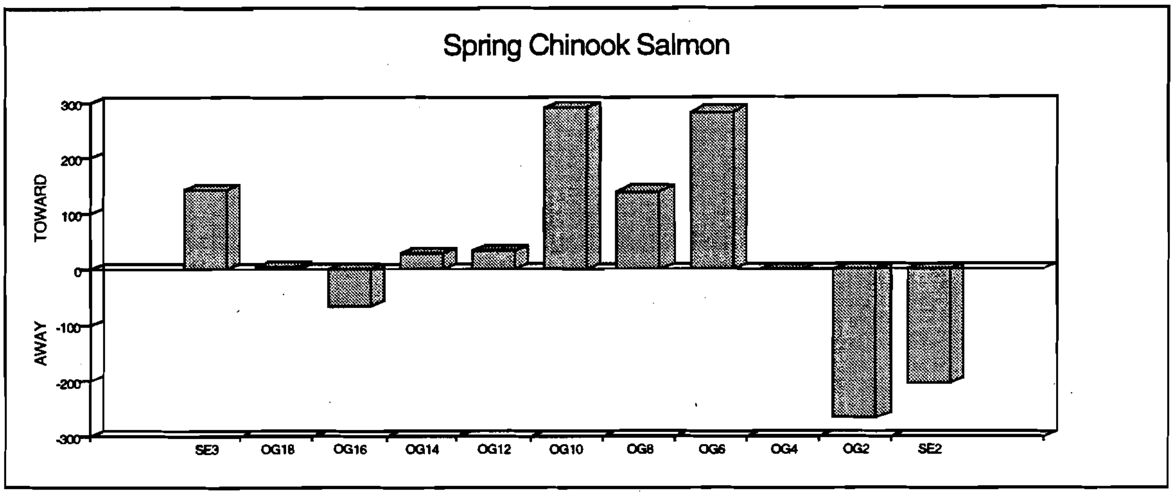
Rock Island Dam

At Rock Island Dam, spring and summer chinook salmon had positive net entries at two collection channel openings: the Right Powerhouse Right Entrance (RPRE), and the Right Powerhouse Left Entrance (RPLE) (Fig. 17). One collection channel opening, the Right Powerhouse Downstream (RPDS), had a negative net entry, and the Right Bank Left Powerhouse Entrance (RBLPE) was ineffective for fish passage. For fall chinook salmon, the RPDS opening produced the highest net entry. Entries into the fish ladder were made from all of the right powerhouse collection-channel openings (Fig. 18), with RBLPE used the least. The proportion of spring and summer chinook salmon reaching the base of the fish ladder were nearly equal (Fig. 19).

At the Center (CLAD) and Left Powerhouse Entrance (LPHE) net entrances were slightly positive yet they provide a significant percentage of the total last entrances.

Rocky Reach Dam

Net entries for spring and summer chinook salmon at the Rocky Reach Dam collection-channel openings were very similar (Fig. 20). The majority of positive entries occurred through Orifice Passage Entrance 18 (OPE18) and LPE while the collection-channel openings at RPE-OPE20 (combined) and the Spill Entrance



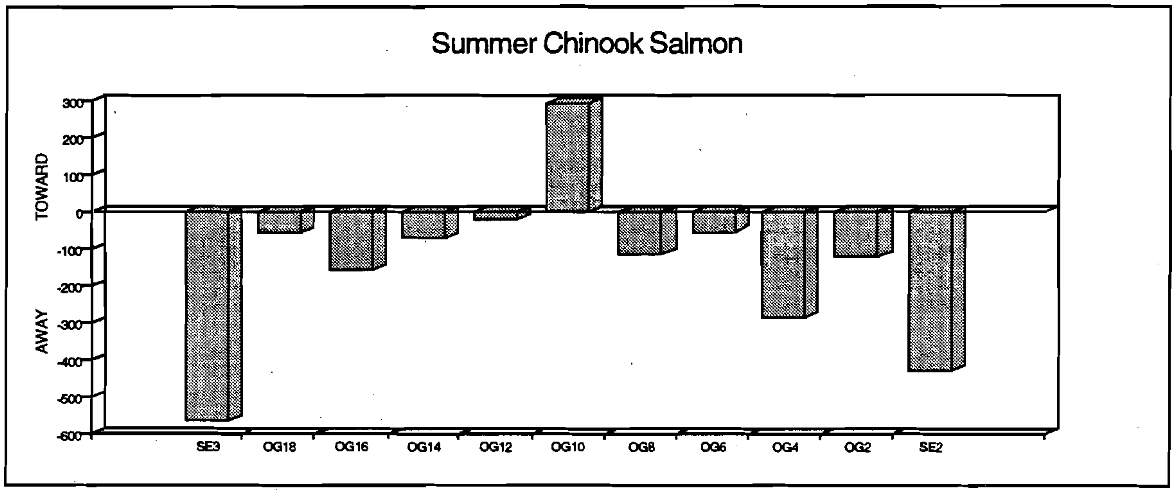


Figure 16.--Net movement toward the fish ladder per collection-channel opening in the Wanapum Dam collection channel, 1993; RFE (Right Fishway Entrance), SE (Slotted Entrance), and OG (Orifice Gates).

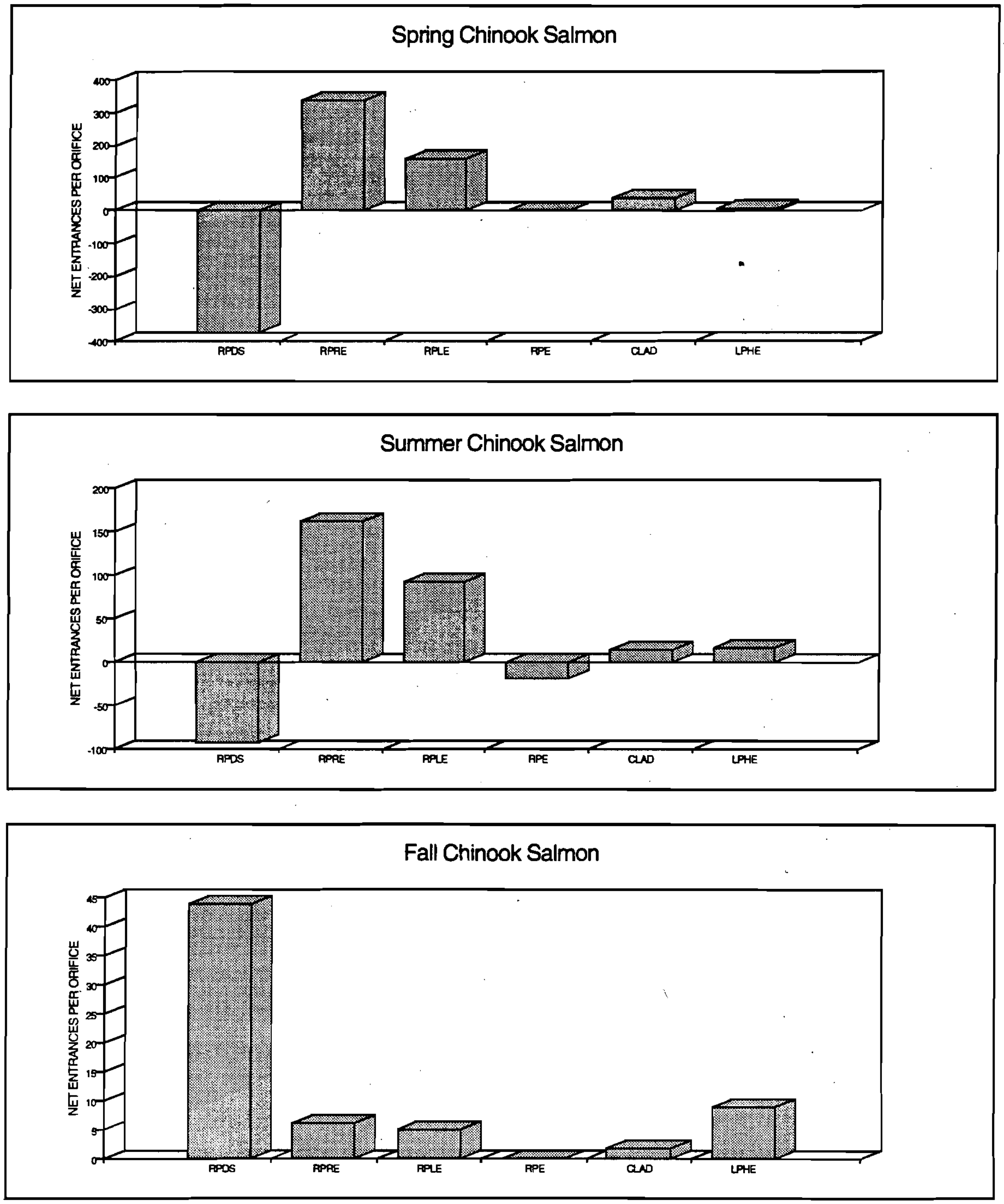


Figure 17.--Net passage per collection-channel opening Rock Island Dam, 1993; RPDS (Right Powerhouse Downstream), RPRE (Right Powerhouse Right Entrance), RPLE (Right Powerhouse Left Entrance), RBLPE (Right Bank Left Powerhouse Entrance), CLAD (Center Ladder Entrance), and LPHE (Left Powerhouse Entrance).

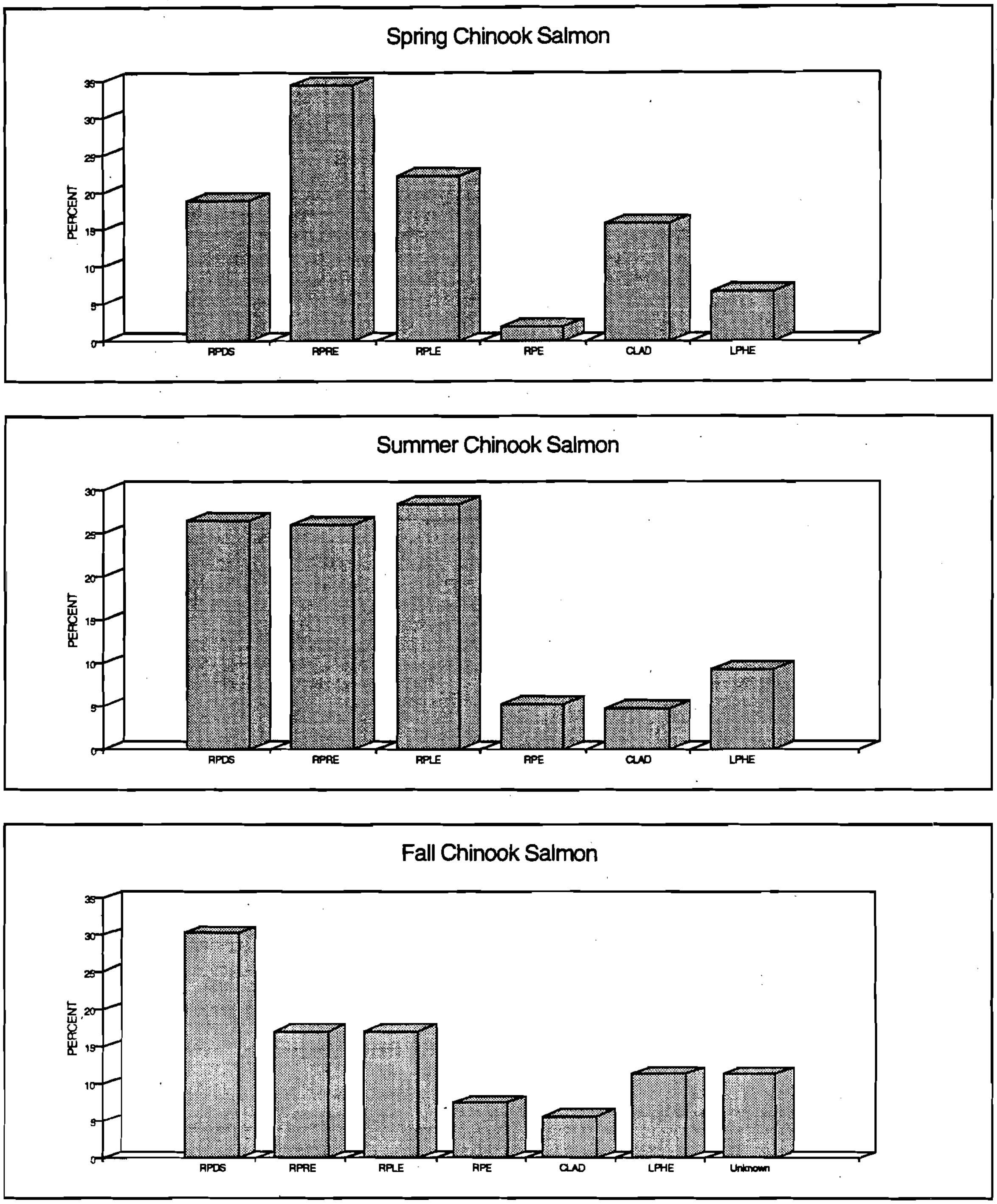


Figure 18.--Percent of last collection-channel opening per entrance at Rock Island Dam, 1993; RPDS (Right Powerhouse Downstream), RPRE (Right Powerhouse Right Entrance), RPLE (Right Powerhouse Left Entrance), RBLPE (Right Bank Left Powerhouse Entrance), CLAD (Center Ladder Entrance), and LPHE (Left Powerhouse Entrance).

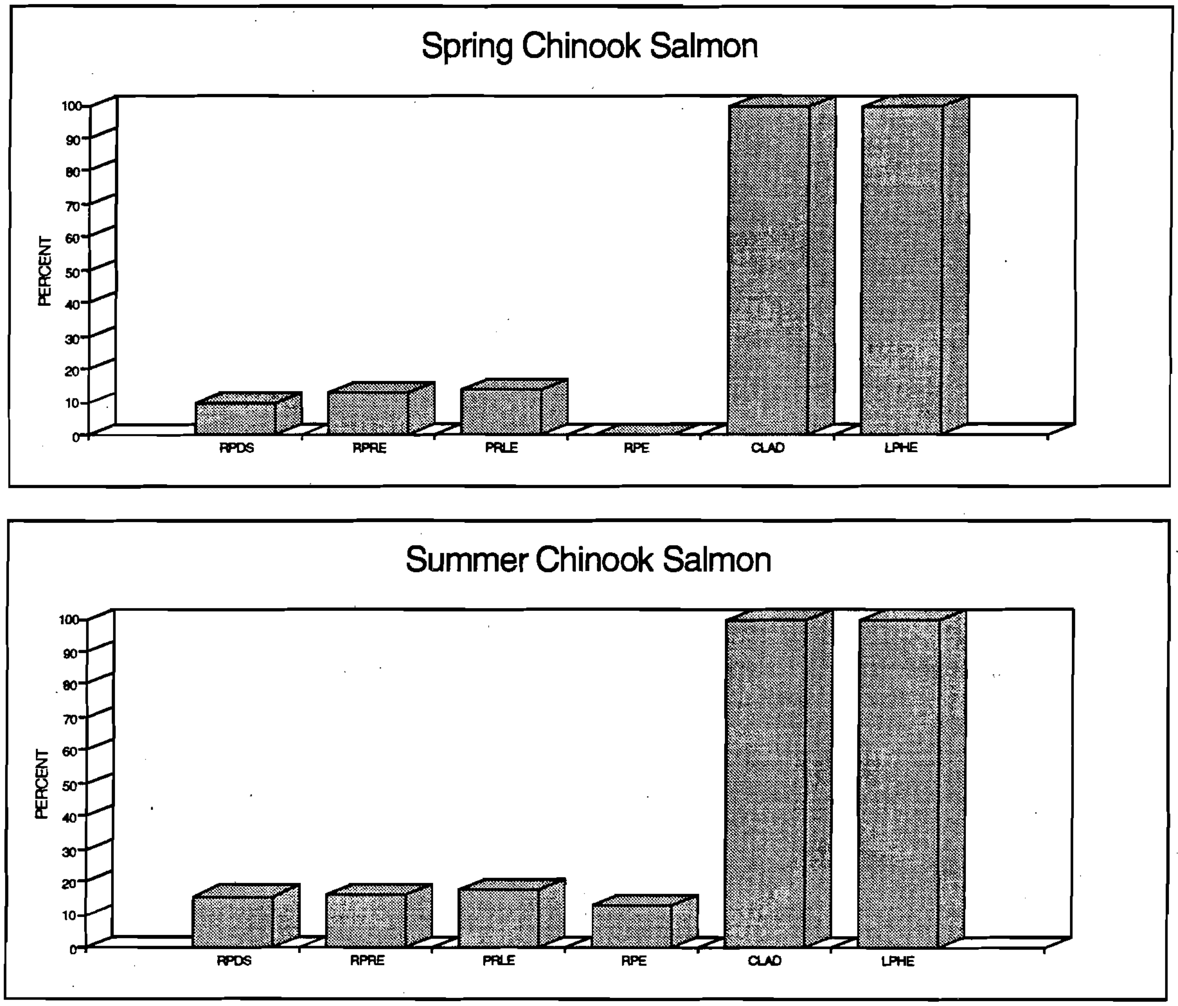


Figure 19.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Rock Island Dam, 1993.

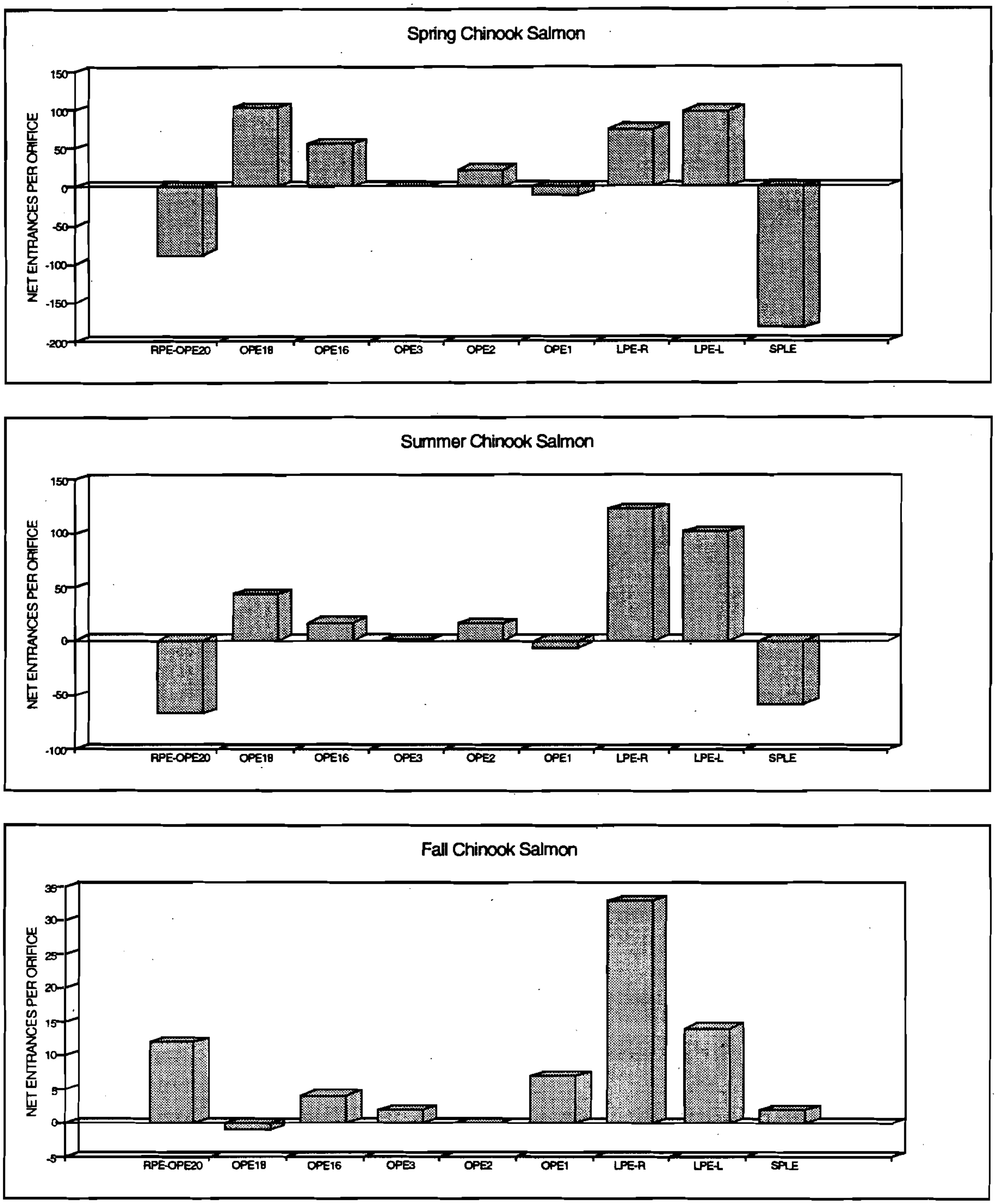


Figure 20.--Net passage per collection-channel opening at Rocky Reach Dam, 1993; RPE (Right Powerhouse Entrance), OPE (Orifice Passage Entrance), LPE (Left Powerhouse Entrance), and SPLE (Spill Entrance).

(SPLE) were ineffective. Fall chinook salmon had positive net entries through almost all collection-channel openings, including the combined RPE-OPE20 and the SPLE. The OPE18 opening was a minor exception.

The majority of last collection-channel entrances were made near the base of the fish ladder at OPE1 and LPE for spring, summer, and fall chinook salmon (Fig. 21). Movement in the collection channel was distinctly toward the fish ladder during the spring run and somewhat less so during the summer run (Fig. 22). The high rate of movement away from the fish ladder through LPE was caused by large numbers of fish moving to the junction pool after entry at LPE and then back down the channel to exit through the LPE. The probability of reaching the base of the fish ladder was dependent on opening location, and was higher for spring chinook salmon than summer chinook salmon, with the exception of the combined RPE-OPE20 (Fig. 23).

Wells Dam

Low net entries or low negative net entrances were recorded for spring and summer chinook salmon at the Wells Dam collection-channel openings facing the powerhouse/spill channel (RSE and LSE) (Fig. 24). For fall chinook salmon, positive net entries were recorded at three collection channel openings: the Left Side Entrance (LSE), the Left Downstream Entrance (LDSE), and the Right Side Entrance (RSE). Each of these collection channel openings was used to access the fish-ladders, with the LDSE as

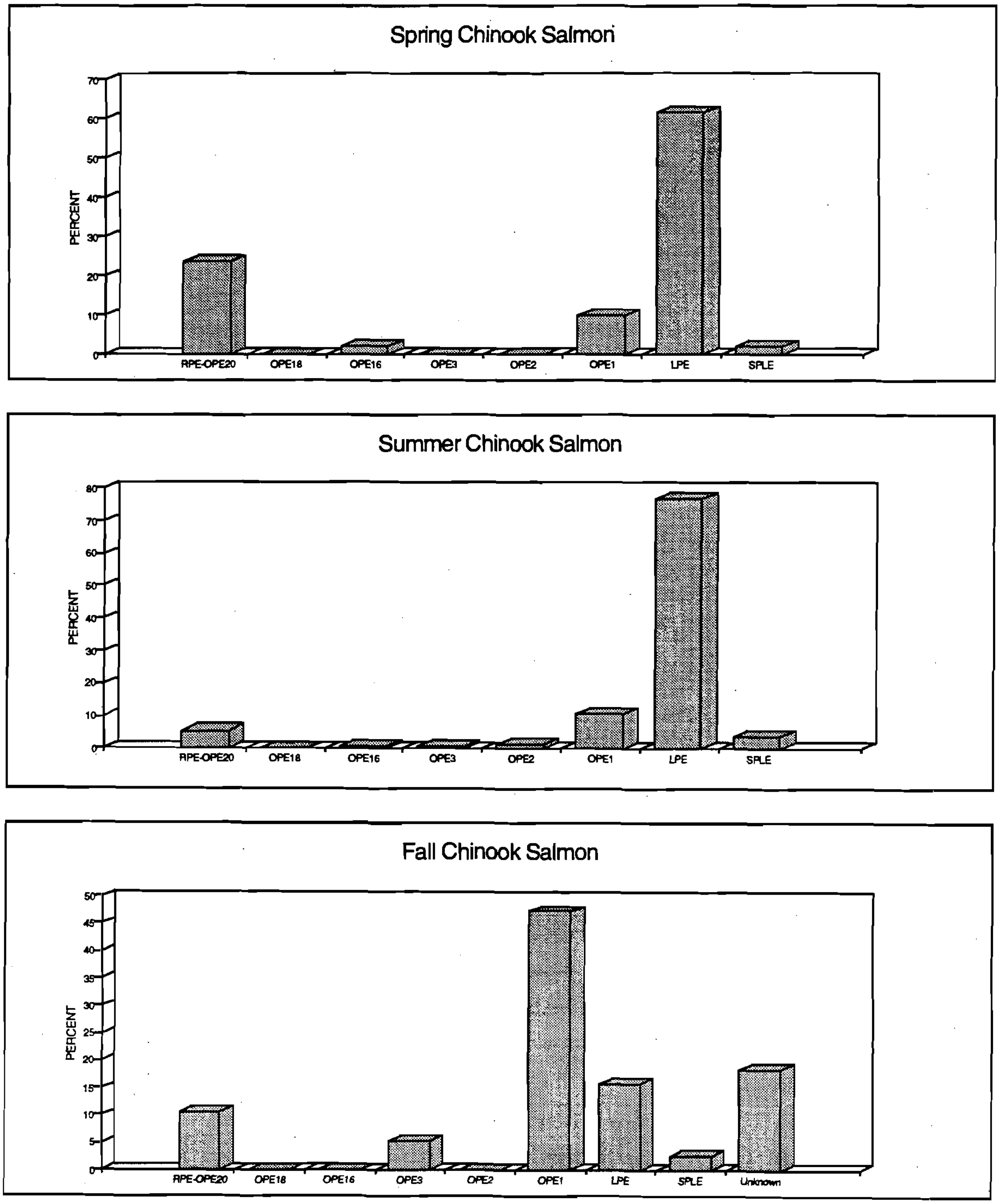
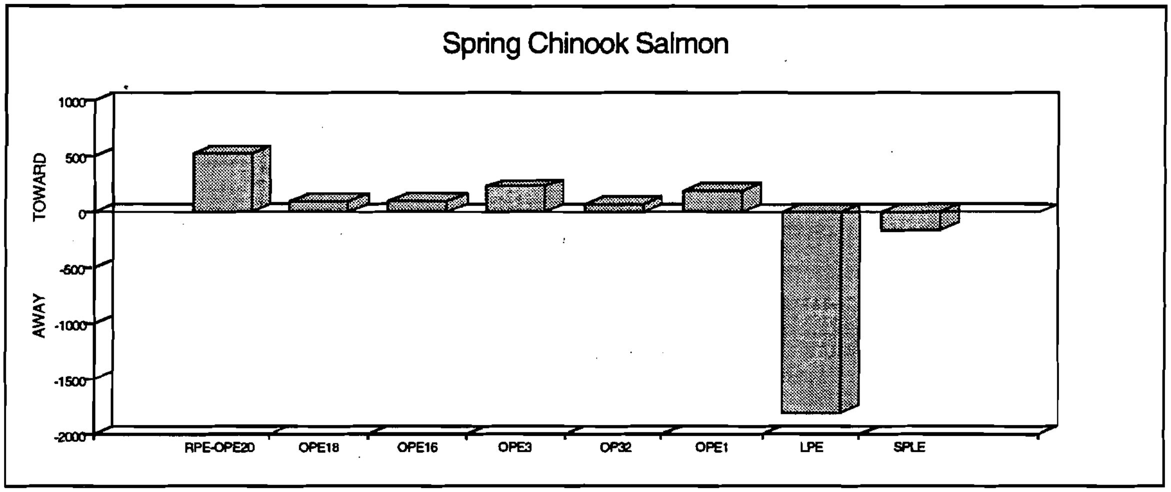


Figure 21.--Percent of last entrances per collection-channel opening at Rocky Reach Dam, 1993; RPE (Right Powerhouse Entrance), OPE (Orifice Passage Entrance), LPE (Left Powerhouse Entrance), and SPLE (Spill Entrance).



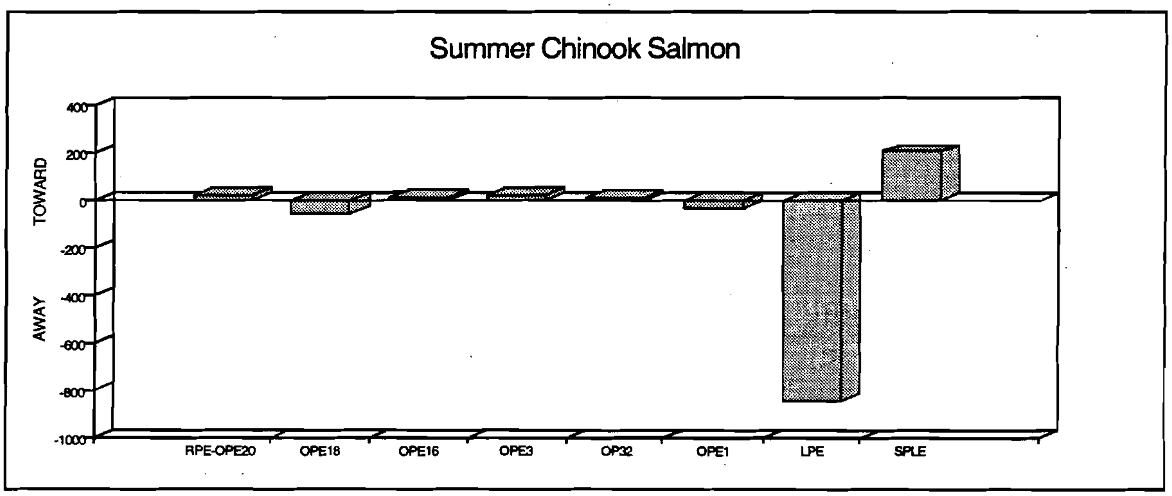


Figure 22.--Net movement toward the fish ladder per collection-channel opening in the Rocky Reach Dam collection channel, 1993; RPE (Right Powerhouse Entrance), OPE (Orifice Passage Entrance), LPE (Left Powerhouse Entrance), and SPLE (Spill Entrance).

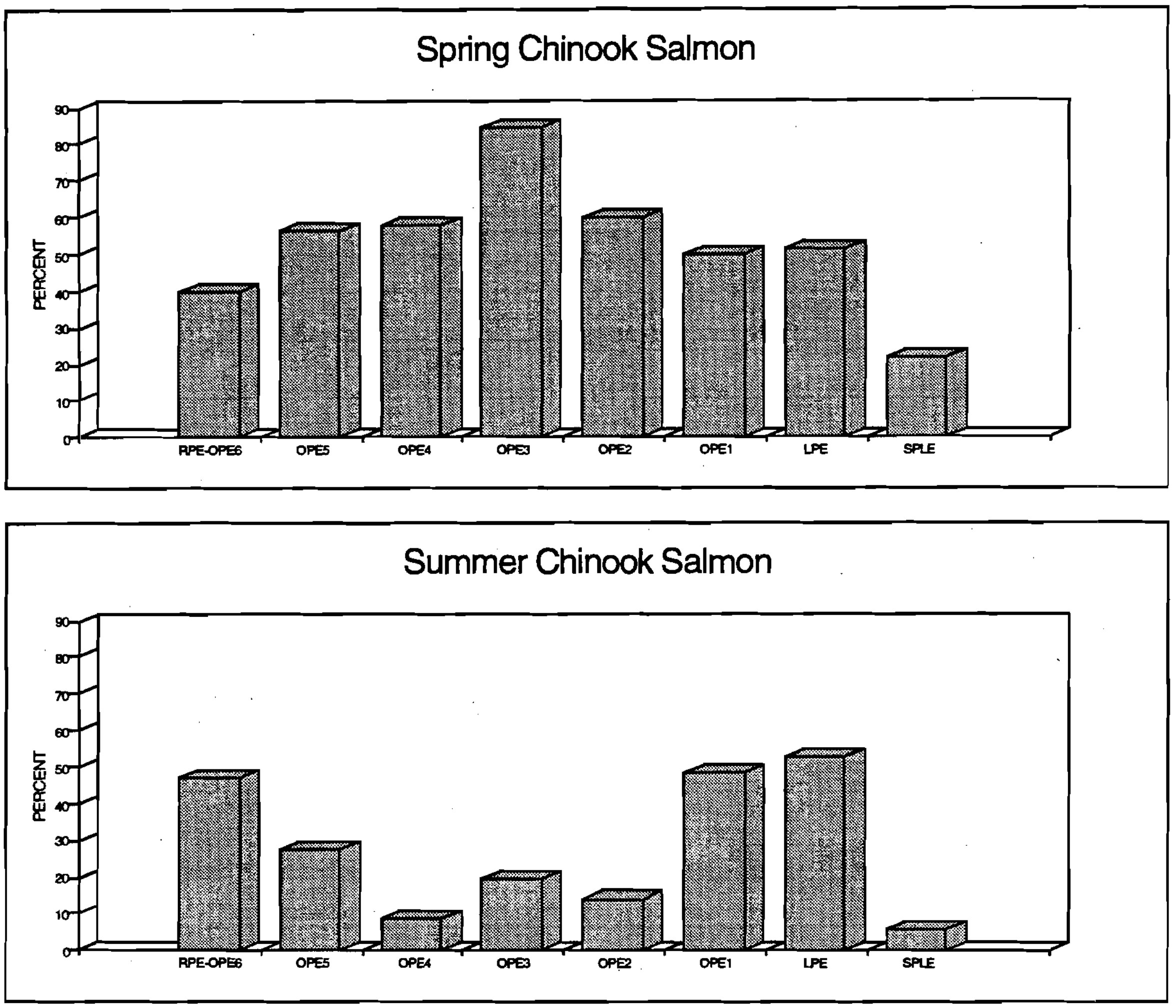


Figure 23.--Percent of total entries per collection-channel opening that reached the base of the fish ladder at Rocky Reach Dam, 1993.

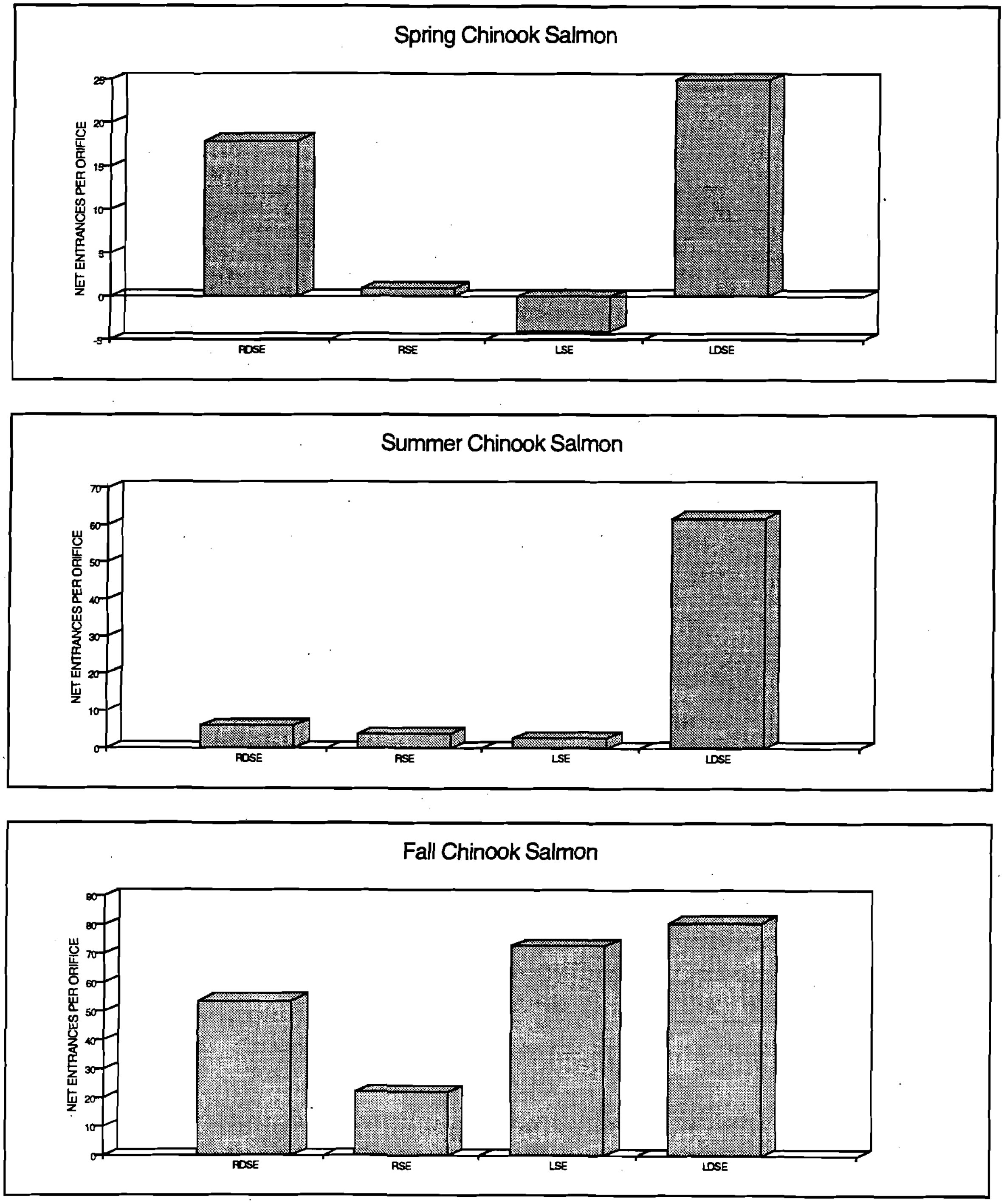


Figure 24.--Net passage per collection-channel opening at Wells Dam, 1993; RDSE (Right Downstream Entrance), RSE (Right Side Entrance), LDSE (Left Downstream Entrance), and LSE (Left Side Entrance).

the most frequently used (Fig. 25). During the summer chinook salmon migration, the highest entry rate observed at Wells Dam was at the LSE.

Fish-Ladder Selection

At Priest Rapids Dam, 93.9 and 92.0% of the spring and summer chinook salmon favored the left-bank fish ladder (Table 10). Additional fish may have passed the right-bank fish ladder without detection, as all detections were made by a single antenna at the top of the fish ladder. For example, 17 spring and 9 summer chinook salmon that were recorded upstream from Priest Rapids Dam were not recorded by the fish-ladder exit monitors at Priest Rapids Dam; neither were they transported to the forebay from the Priest Rapids Hatchery trap.

At Wanapum Dam, radio-tagged fish also preferred the left-bank fish ladder (spring chinook salmon, 96.7%; summer chinook salmon, 78.5%; and fall chinook salmon, 82.5%). However, the efficiency of the right-bank fish-ladder exit monitor may have been reduced by radio-frequency noise. Based on upstream monitors, 9 spring and 48 summer chinook salmon were not recorded and apparently passed the right-bank fish ladder.

Fish at Rock Island Dam favored the right-bank fish ladder (spring chinook salmon, 74.6%; summer chinook salmon, 87.0%; and fall chinook salmon, 78.9%). At Wells Dam, the majority of radio-tagged fish chose the left-bank fish ladder (spring chinook salmon, 51.8%; summer chinook salmon, 89.8%; fall chinook salmon, 61.5%).

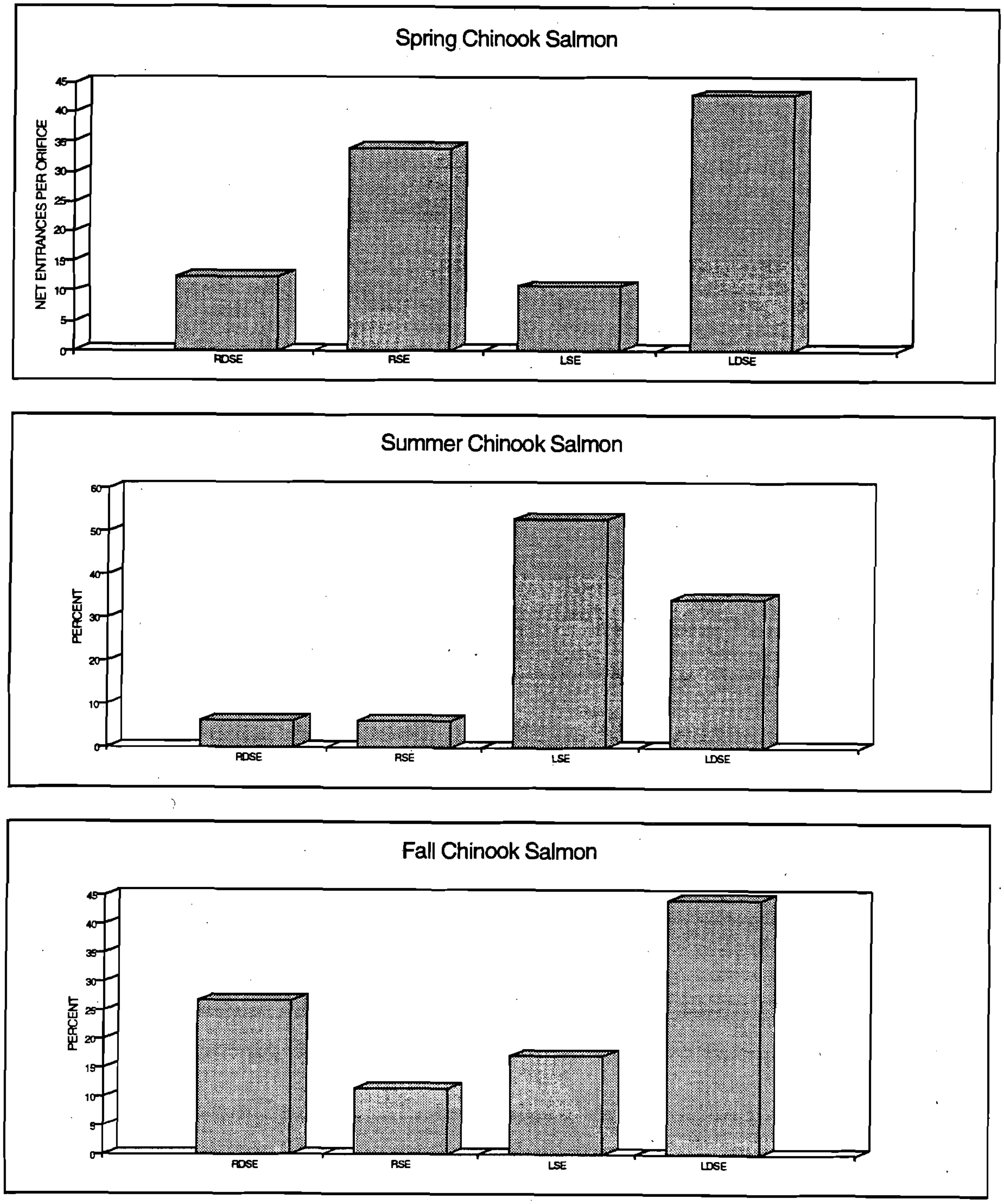


Figure 25.--Percent of last entrances per collection-channel opening per entrance at Wells Dam, 1993; RDSE (Right Downstream Entrance), RSE (Right Side Entrance), LDSE (Left Downstream Entrance), and LSE (Left Side Entrance).

Table 10.--Fish-ladder selection by radio-tagged spring, summer, and fall chinook salmon at the mid-Columbia River dams, 1993.

	Left	Center	Right
Spring Chinook Salmon			
Priest Rapids Dam	185	-	12
Wanapum Dam	204	-	7
Rock Island Dam	5	5	147
Rocky Reach Dam	-	-	89
Wells Dam	29	-	27
Summer Chinook Salmon	Left	Center	Right
Priest Rapids Dam	241	-	21
Wanapum Dam	165	-	44
Rock Island Dam	17	15	215
Rocky Reach Dam	-	-	128
Wells Dam	88	-	10
Fall Chinook Salmon	Left	Center	Right
Wanapum Dam	33	-	7
Rock Island Dam	6	2	30
Rocky Reach Dam	-	-	194
Wells Dam	32	-	20

Fallback and the Fate of Fallback Fish

Priest Rapids Dam

Of the 35 spring chinook salmon fallbacks (Table 11), 24 were last detected downstream (Table 12). Six of the 24 were recaptured at the Ringold Spring Chinook Salmon Facility, 2 strayed into the Priest Rapids Hatchery, and 16 displayed overshoot behavior or milling behavior in the McNary Reservoir similar to that of fish recovered at the Ringold Facility. Five of the 35 fallbacks entered the Wenatchee River, one entered the Okanogan River, and five were distributed in the mainstem Columbia River between Wanapum and Wells Dams. The fate of fallbacks that did not enter spawning tributaries or the Ringold Facility were potentially the same as all other fish last detected in the main stem: pre-spawning mortality, harvest, mainstem spawning, or tag failure.

Three of the four Priest Rapids Dam summer chinook salmon fallbacks were last detected upstream (two in the Wenatchee River and one at the Wells Hatchery). The fourth fallback was last detected downstream from Priest Rapids Dam in the Hanford Reach.

Eighteen fall chinook salmon tagged at Priest Rapids Dam were fallbacks (Table 11). One of these fish passed the dam twice and subsequently entered the Wells Salmon Hatchery (Table 12). The remainder stayed below the dam. One was harvested from the Hanford Reach, six were last recorded in the Hanford Reach, eight entered the Priest Rapids Salmon Hatchery, and two were last recorded in the Priest Rapids Dam tailrace.

Table 11.--Summary of fallbacks of radio-tagged spring, summer, and fall chinook salmon at mid-Columbia River dams.

Dam	Spring chinook salmon Number passing	Number of fallbacks	(%)	Summer chinook salmon Number passing	Number of fallbacks	(%)	Fall chinook salmon Number passing	Number of fallbacks	(%)
Priest Rapids	197	35	(17.7)	261	4	(1.5)	123	18	(14.6)
Wanapum	211	17	(8.1)	209	2	(1.0)	58	3	(5.2)
Rock Island	197	5	(2.5)	247	7	(2.8)	53	7	(13.2)
Rocky Reach	89	0	(0.0)	128	5	(3.9)	194	22	(11.3)
Tagged P.R. Dam							38	5	(13.2)
Tagged R.R. Dam							156	17	(10.9)
Wells	56	2	(3.6)	98	14	(14.3)	52	11	(21.2)

Table 12.--Fate of radio-tagged chinook salmon fallbacks at the mid-Columbia River dams, 1993.

Location of fallback	Number
Priest Rapids Dam	
Spring chinook salmon	
Ringold Spring Chinook Salmon Facility	6
Priest Rapids Hatchery	2
McNary Reservoir	16
Mainstem Columbia River upstream	5
Wenatchee River	5
Okanogan River	1
Summer chinook salmon	
Hanford Reach	1
Wenatchee River	2
Wells Hatchery	1
Fall chinook salmon	
Hanford Reach harvest	1
Hanford Reach	6
Priest Rapids Hatchery	8
Priest Rapids tailrace	2
Wells Hatchery	1
Wanapum Dam	
Spring chinook salmon	
Ringold Spring Chinook Salmon Facility	2
McNary Reservoir	4
Downstream from Wanapum Dam	2
Wenatchee River	8
Okanogan River	1
Summer chinook salmon	
Wenatchee River	1
Okanogan River	1
Fall chinook salmon	
Wanapum Dam tailrace	3
Rock Island Dam	
Spring chinook salmon	
Wenatchee River	4
Entiat River	1
Summer chinook salmon	
Rock Island Dam tailrace	5
Wenatchee River	1
Wells Hatchery	1
Fall chinook salmon	
Crescent Bar area	1
Rock Island Dam tailrace	6

Table 12.--Continued.

Location of fallback	Number
<u>Rocky Reach Dam</u>	
Spring chinook salmon	
Summer chinook salmon	
Rock Island Dam tailrace	1
Wenatchee River	4
Fall chinook salmon	
Rock Island Dam tailrace	3
Rock Island Reservoir harvest	1
Rock Island Reservoir	4
Rocky Reach Dam tailrace	13
Wells Dam tailrace	1
<u>Wells Dam</u>	
Spring chinook salmon	
Entiat River	2
Summer chinook salmon	
Wenatchee River	1
Entiat River	1
Wells Dam tailrace	4
Wells Hatchery	2
Methow River	3
Okanogan River	2
Chief Joseph Dam harvest	1
Fall chinook salmon	
Rocky Reach Reservoir harvest	1
Wells Dam tailrace	6
Wells Hatchery	3
Okanogan River	1

Wanapum Dam

At Wanapum Dam, 6 of the 17 spring chinook salmon fallbacks (Table 11) returned to below Priest Rapids Dam. Two of these six fish were recaptured at the Ringold Spring Chinook Salmon Facility (Table 12). Eight of the 17 fallbacks terminated in the Wenatchee River, and one returned to the Okanogan River. The remaining two fish were last detected downstream from Wanapum Dam.

Two summer chinook salmon fallbacks were last detected upstream from Wanapum Dam: one in the Wenatchee River and one in the Okanogan River.

Only three fall chinook salmon fallbacks were observed at Wanapum Dam and they remained in the Wanapum Dam tailrace.

Rock Island Dam

All five spring chinook salmon fallbacks (Table 11) survived to enter spawning tributaries: four entered the Wenatchee River and one entered the Entiat River (Table 12).

Five of the seven summer chinook salmon fallbacks were last detected in the tailrace near the dam. The remaining two fish entered either the Wenatchee River or the Wells Hatchery. Of the five fallbacks last detected below the dam, four were detected above the Wenatchee River confluence before returning to below Rock Island Dam.

The fall chinook salmon fallbacks at Rock Island Dam (Table 13) were last recorded in the Rock Island Dam tailrace or in the Crescent Bar area (Table 12).

Rocky Reach Dam

No spring chinook salmon and five summer chinook salmon were fallbacks at Rocky Reach Dam (Table 11). Four of the five summer chinook salmon fallbacks were apparent overshoots from the Wenatchee River (Table 12), and the fifth was last detected just upstream from Rock Island Dam.

Twenty-two fall chinook salmon fallbacks were observed (Table 11). Thirteen of these remained in the tailrace (Table 12), three continued downstream to the Rock Island Dam tailrace, four were last recorded in the Rock Island Dam reservoir, one was harvested from the Rock Island Dam reservoir, and one passed a second time and was last detected in the Wells Dam tailrace.

Wells Dam

Two spring chinook salmon fallbacks were observed at Wells Dam (Table 11), and both subsequently entered the Entiat River (Table 12).

Fourteen summer chinook salmon fallbacks were observed at Wells Dam (Table 11): six were last detected upstream and eight were last detected downstream from Wells Dam (Table 12). Three of the upstream fish were last monitored in the Methow River, two in the Okanogan River, and one was captured below Chief Joseph Dam. The eight downstream fish were last detected in the Wenatchee River, the Entiat River, Wells Hatchery (2), and Wells Dam tailrace (4).

Eleven (21.2%) fall chinook salmon fallbacks were observed at Wells Dam (Table 12). Six remained in the tailrace, three entered the Wells Salmon Hatchery, one was harvested downstream from the dam, and one passed a second time and entered the Okanogan River.

SUMMARY

A total of 742 spring, 426 summer, and 279 fall chinook salmon were trapped, radio tagged, and released from John Day, Priest Rapids, and Rocky Reach Dams to determine migration characteristics. These characteristics included run timing and travel time, passage success, and dam-passage behavior. Final destinations in the main stem and tributaries of the Columbia River were also recorded.

Run Timing

Run timing for fish destined for lower-river locations (Wenatchee River, Priest Rapids Dam, Wanapum Dam, and Rock Island Dam) was advanced relative to run timing for fish that passed Rocky Reach and Wells Dams.

Individual spring chinook salmon stocks, destined for the tributaries, could not be separated on the basis of arrival time at Priest Rapids, Rocky Reach, or Wells Dams.

Most fish arrived at the dams during daylight hours. Similarly, most activity into and out of the fish ladders occurred during daylight hours.

Travel Time

In general, median passage-time estimates at individual mid-Columbia River dams ranged from 14.6 to 60 hours. The longest travel times were associated with fall chinook salmon. Total passage times at dams, depending on the stock of fish, were similar to estimates made with radio-telemetry techniques at dams in the lower Columbia and Snake Rivers (Bjornn and Peery 1992).

After arriving at the tailraces of dams, most radio-tagged fish moved rapidly to the vicinity of the collection channel and, with the exception of spring chinook salmon at Priest Rapids and Wanapum Dams, quickly made a first entry into the collection channel. Most radio-tagged fish also spent only a few hours passing through the fish ladders, and fish-ladder passage times were comparable to those recorded at lower Columbia and Snake River dams (Bjornn and Peery 1992).

Fate of Radio-Tagged Fish

The majority of radio-tagged spring and summer chinook salmon terminated their migration in tributaries. The Wenatchee River was the final destination for 44.9% of spring and 53.9% of summer chinook salmon.

Fall chinook salmon, in contrast, terminated their migration in the main stem (likely spawners) of the Columbia River either downstream from Priest Rapids Dam, in the tailraces of dams, or in Priest Rapids or Wells Hatcheries. Approximately 22, 13, and 9% of all radio-tagged adults were last detected in the Wells Dam, Wanapum Dam, and Rocky Reach Dam tailraces, respectively.

Adult Collection Channel Efficiency and Fish-Ladder Selection

At all dams, the longest passage period occurred at the collection channels. However, no major delays were observed between arrival at the tailrace, entrance at the collection channel, and passage through the fish ladders. Passage time was increased as a result of multiple collection-channel entries and exits, multiple trips up and down the inside and outside of the collection channel, multiple arrivals at the base of the fish ladders, and multiple entrances into the fish ladders.

Behavior of radio-tagged fish in the collection channels was species-specific and varied considerably as a result of the design of individual collection channels. In general, only a few collection-channel openings were effective at each dam, despite the total number available to fish.

Similarly, fish displayed distinct preferences between fish ladders. With the exception of Rock Island and Rocky Reach Dams, a large majority of fish chose the left-bank fish ladder at all dams. At Rocky Reach Dam the fish must orient to the left end of the powerhouse to enter the right-bank fish ladder.

Fallback and the Fate of Fallback Fish

The highest incidences of spring chinook salmon fallbacks occurred at Priest Rapids and Wanapum Dams. The majority of these fallbacks were last detected downstream from Priest Rapids Dam: these detections indicate that some fallbacks may result from overshoot of the dams.

Wells Dam had fourteen percent radio-tagged summer chinook salmon fallbacks. Approximately half of those fish terminated their migration downstream from the dam.

With the exception of fish passing Wanapum Dam, at least 10% fall chinook salmon fallbacks were observed at all the mid-Columbia River dams. As with spring chinook salmon at Priest

Rapids and Wanapum Dams, the majority of fall chinook salmon fallbacks were last detected downstream, indicating that some fallbacks may have overshot the dams.

RECOMMENDATIONS

Recommendations for further evaluations to improve adult passage at the mid-Columbia River Dams are as follows:

1) Close all collection-channel openings, with the exception of the openings with the highest activity closest to the base of the fish ladders. This recommendation is based on results obtained at Wells Dam where with only two openings per collection channel, first collection-channel entries were as fast or faster than at any other dam. Similarly, the right-bank adult passage facility at Rock Island has only three functional openings, yet first collection-channel entries were among the shortest, and total passage times were the shortest of all dams evaluated. In addition, positive behavior (movement toward the fish ladder) within the collection channels was not indicative of faster total passage time at dams. Positive behavior for spring chinook salmon at Priest Rapids and Wanapum Dams produced longer total passage times than did negative behavior during the summer chinook salmon run.

2) Modify flows between the openings and the base of the fish ladder to make them laminar, and move diffuser flows in the channels farther upstream, closer to the base of the fish ladder. At present, diffuser flows in the collection-channel/fish-ladder junction pools tend to obscure the flows from the fish ladders, and may confuse the fish.

3) Account for the high incidence of fallbacks and resulting over-counts at dams determining realistic and accurate passage survival and escapement estimates. Until such adjustments are made, estimates at individual dams will remain significantly biased upward. At Priest Rapids, the variability in the spring chinook fallback rates will depend on the program at the Ringold Facility.

ACKNOWLEDGMENTS

Funding and support for various aspects of this research came from the Public Utility Districts (PUDS) of Chelan, Douglas, and Grant Counties of Washington State. The National Marine Fisheries Service thanks the many PUD staff members who provided information and assistance. We especially acknowledge the assistance of Tom Hook and Sue Marcear at Wells Dam, operated by Douglas PUD, for permitting our use of their office and facilities.

We also thank the staff of PUD No. 1 of Chelan County, especially Steve Hays, Dick Nason, and Donald Brawley, for allowing the use of fish-trapping facilities at Rocky Reach Dam.

Chris Carlson of PUD No. 1 of Grant County provided valuable assistance in coordinating equipment acquisition and in the use and operation of the adult trapping facilities at Priest Rapids Dam.

We acknowledge the assistance of Donald Rapelje and the staff at Eastbank Salmon Hatchery for allowing the use of the facility as a base of operations in the Wenatchee area.

We thank the many other people whose assistance contributed greatly to the successful completion of this study. In particular, Dan Gebbers of Gebbers Farms, Inc.; Wayne Marsh; and Bob Whitehall, each of whom allowed us to install monitoring sites on their private property. Eric Hockersmith of NMFS provided technical assistance in reviewing data and developing graphics for this report.

Last, but of equal importance, we acknowledge the help of Cleo Moser, retired Washington Department of Fisheries, Hatchery Manager, for the benefit of his experience and knowledge of fish trapping and handling procedures.

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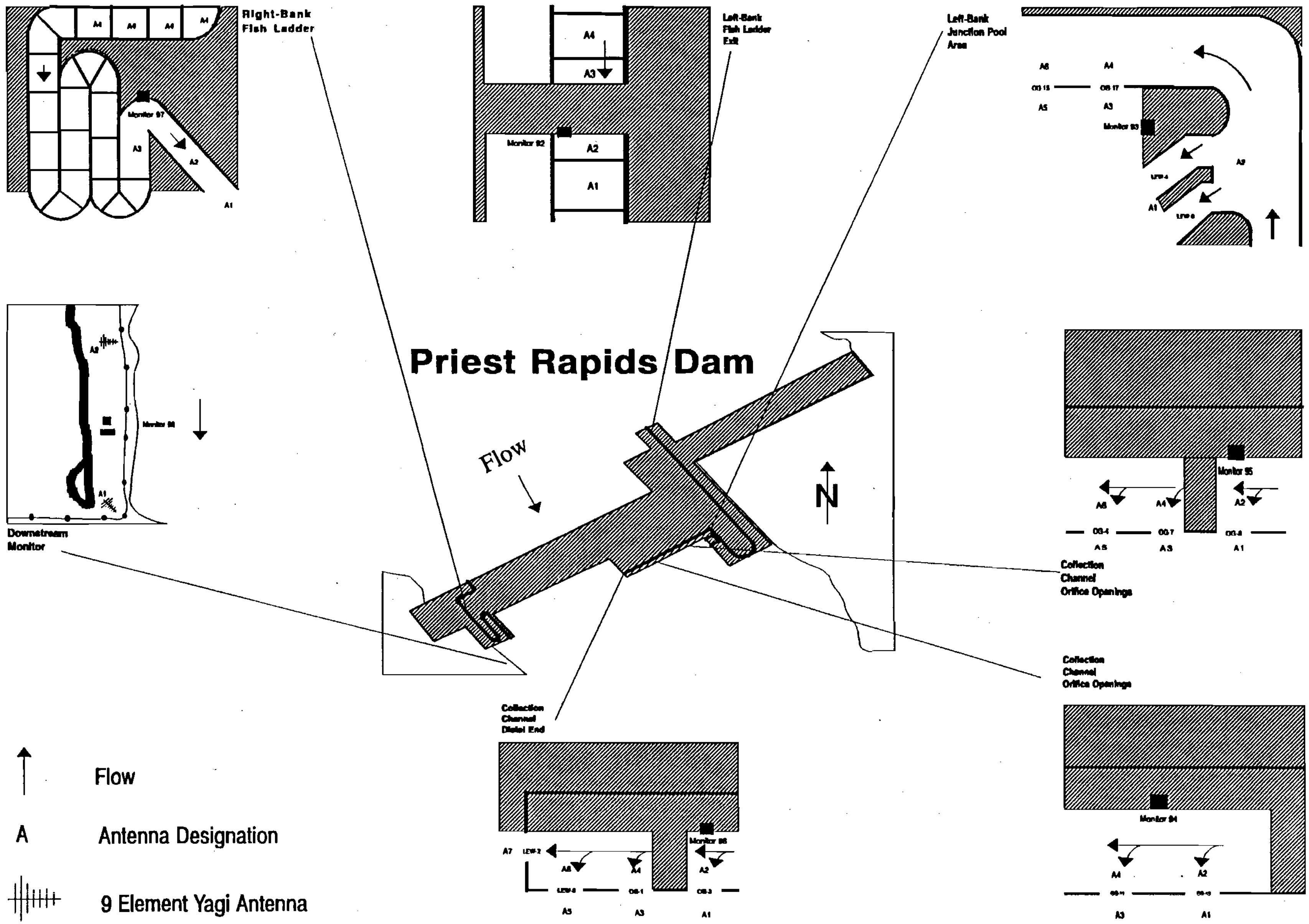
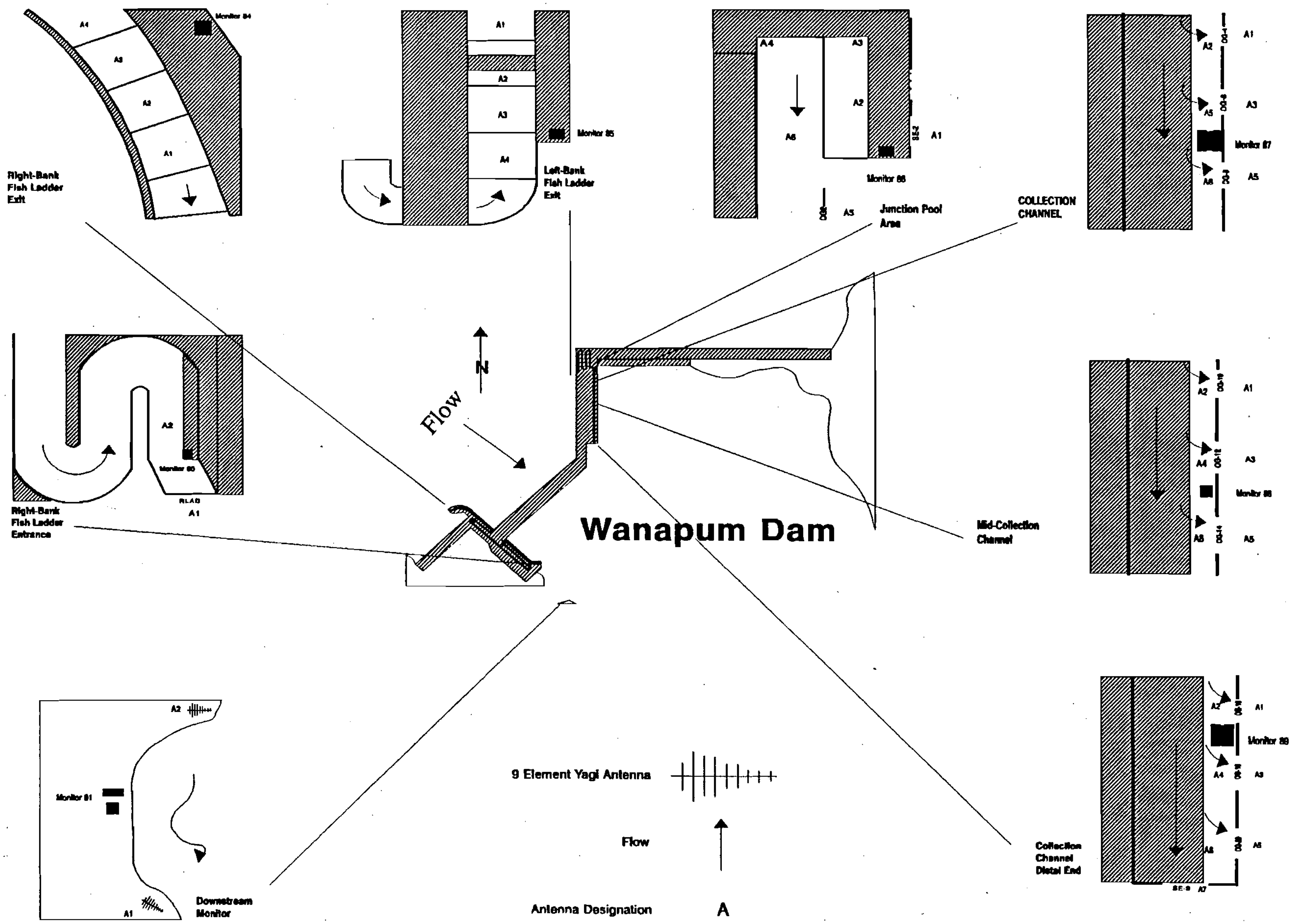
APPENDIX A

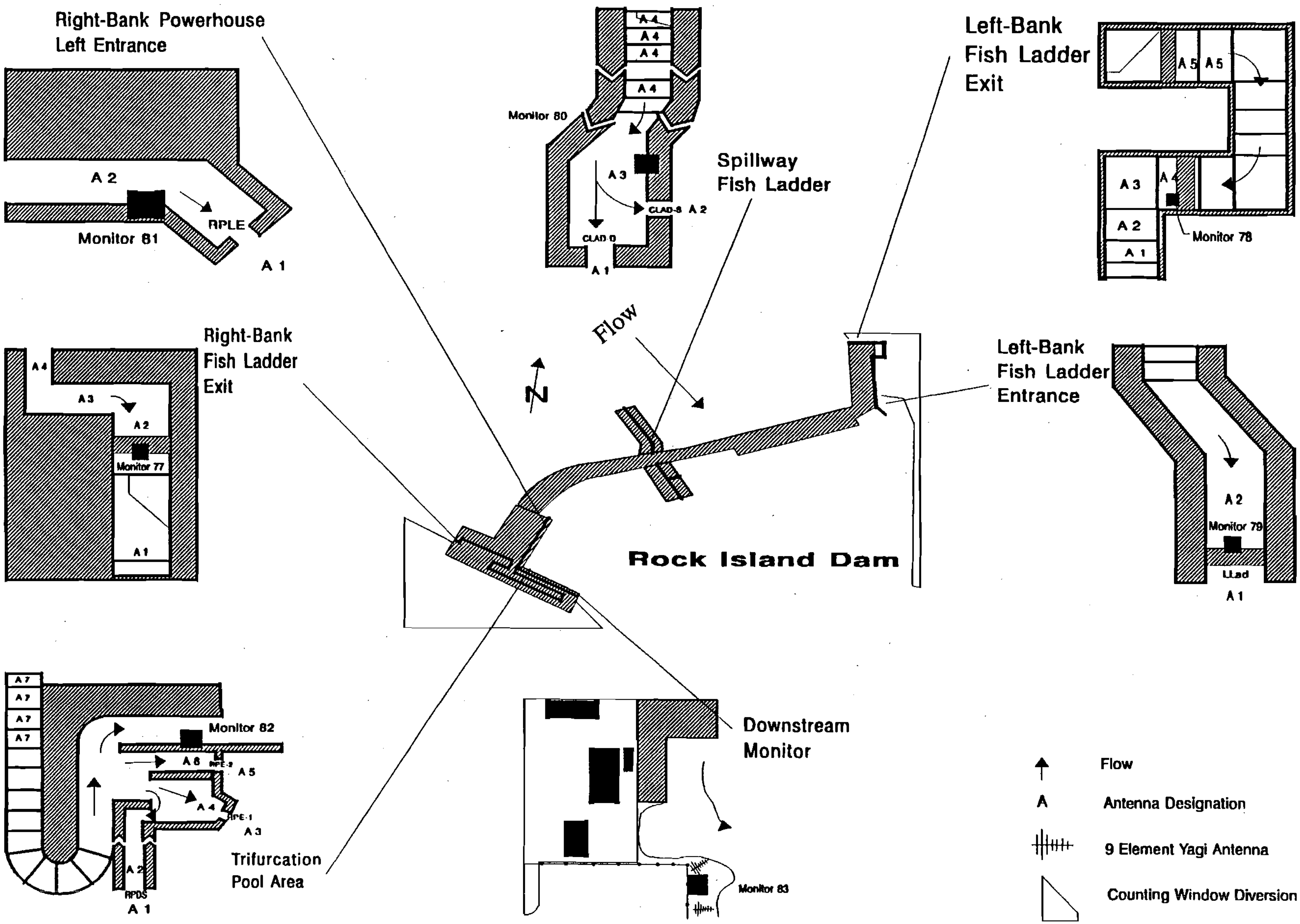
Monitor and Antennae Placement



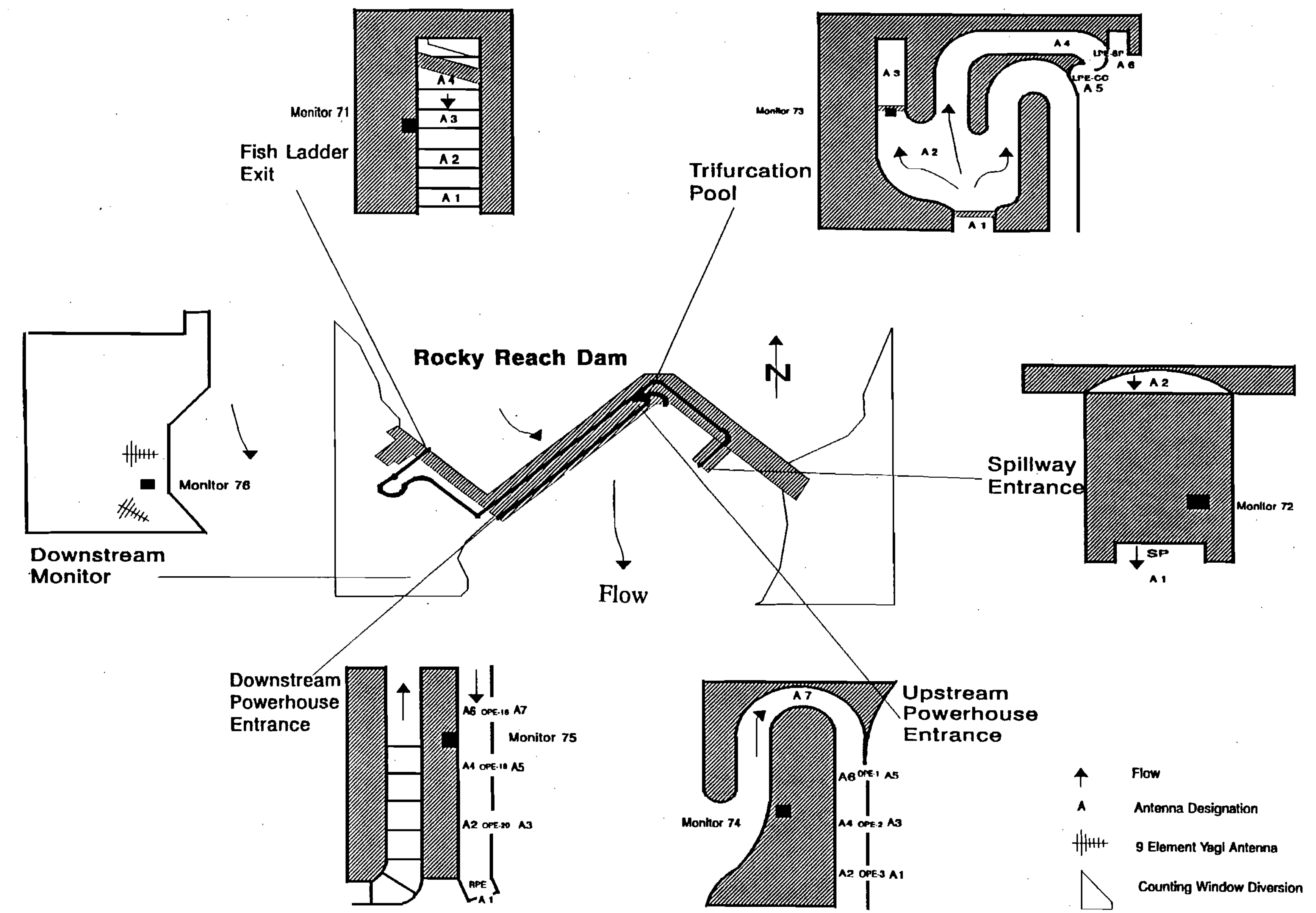
Appendix Figure A1.--Priest Rapids Dam monitor and antennae placement.



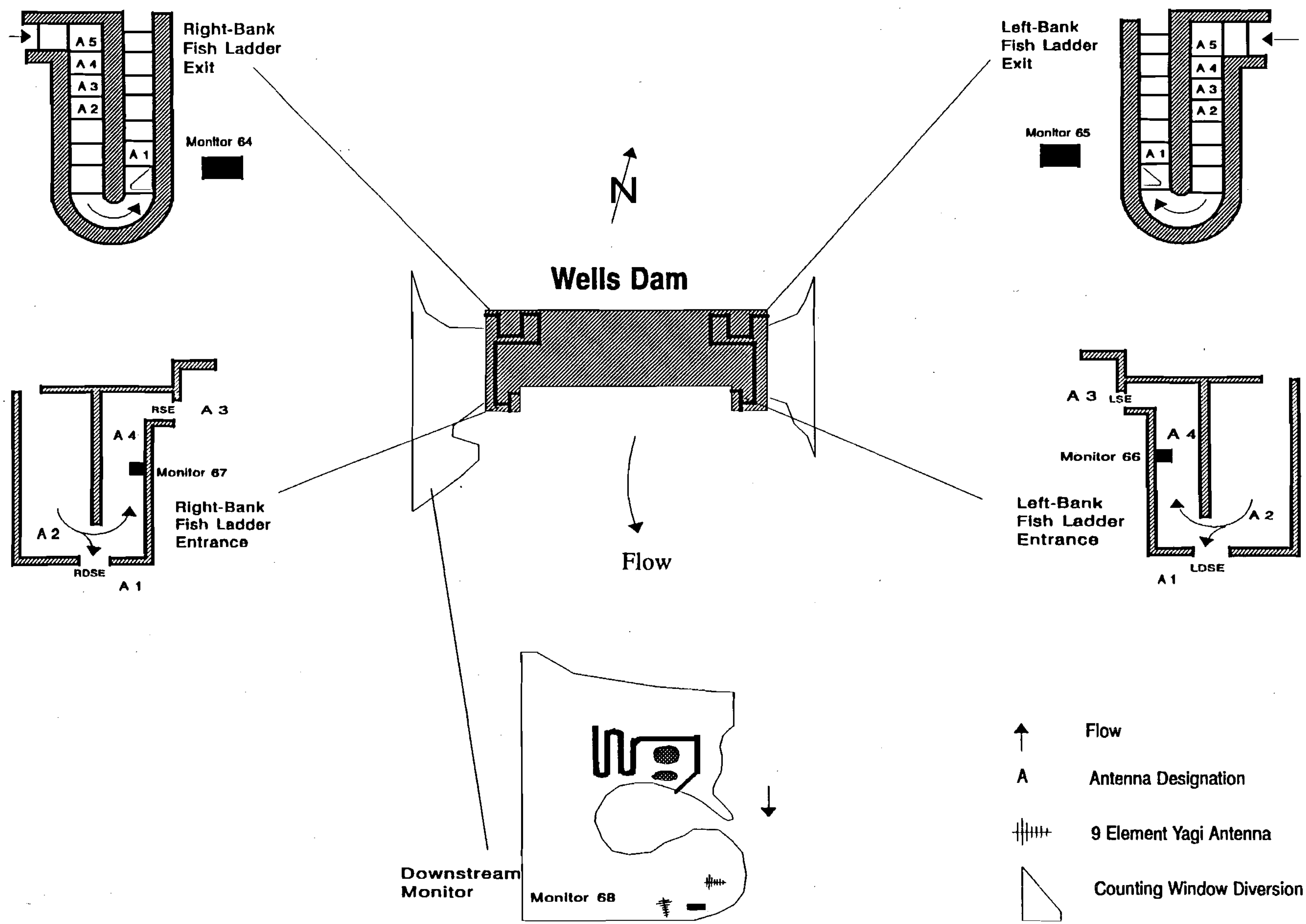
Appendix Figure A2.--Wanapum Dam monitor and antennae placement.



Appendix Figure A3.--Rock Island Dam monitor and antenna placement.



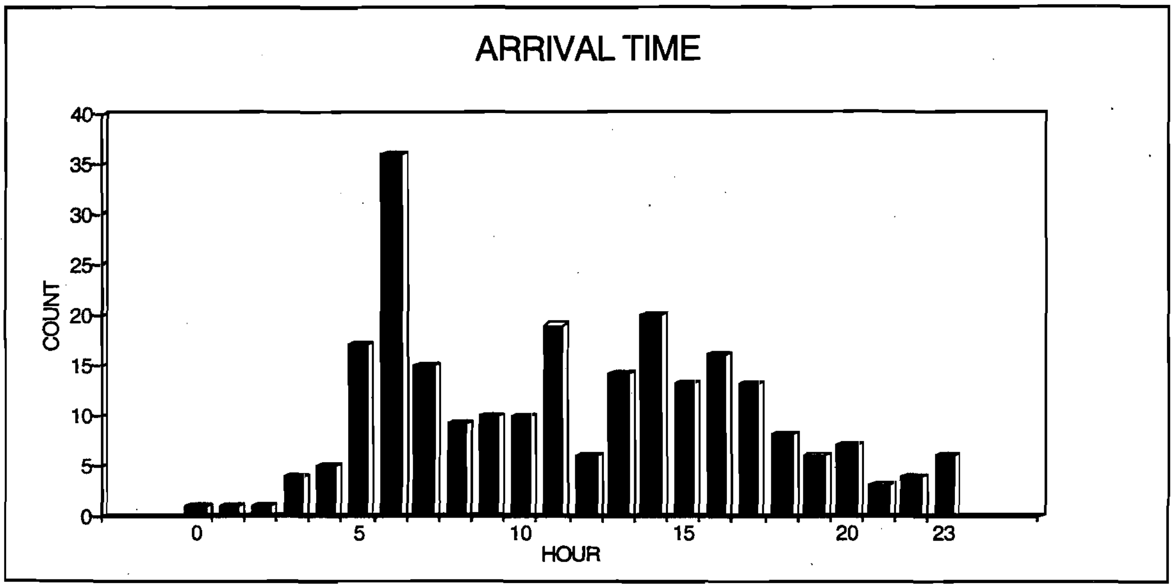
Appendix Figure A4.--Rocky Reach Dam monitor and antennae placement.

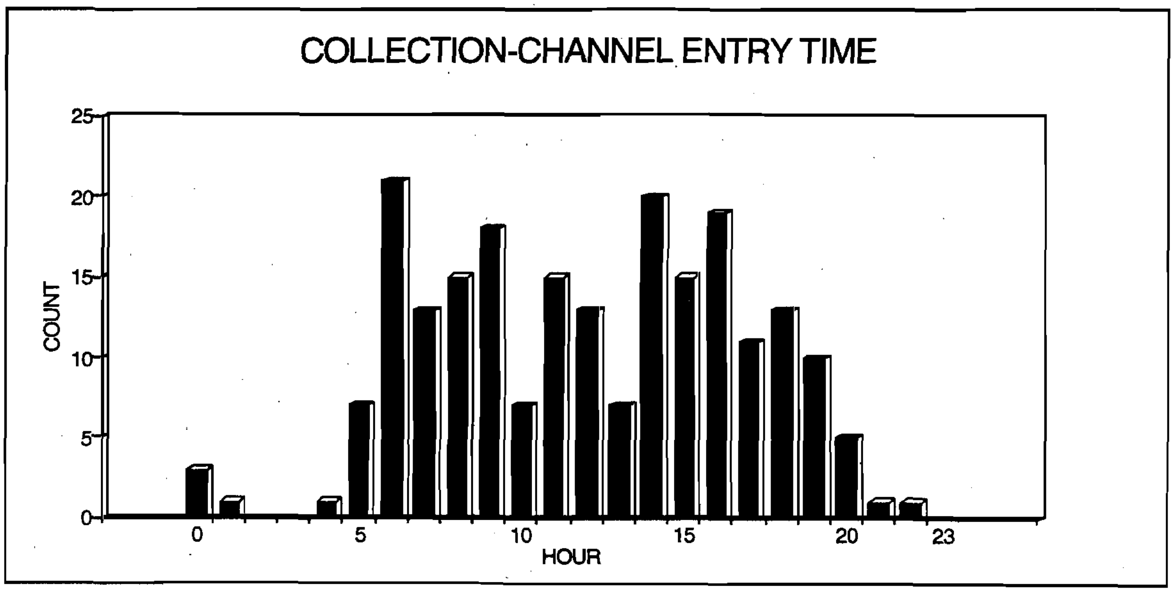


Appendix Figure A5.--Wells Dam monitor and antennae placement.

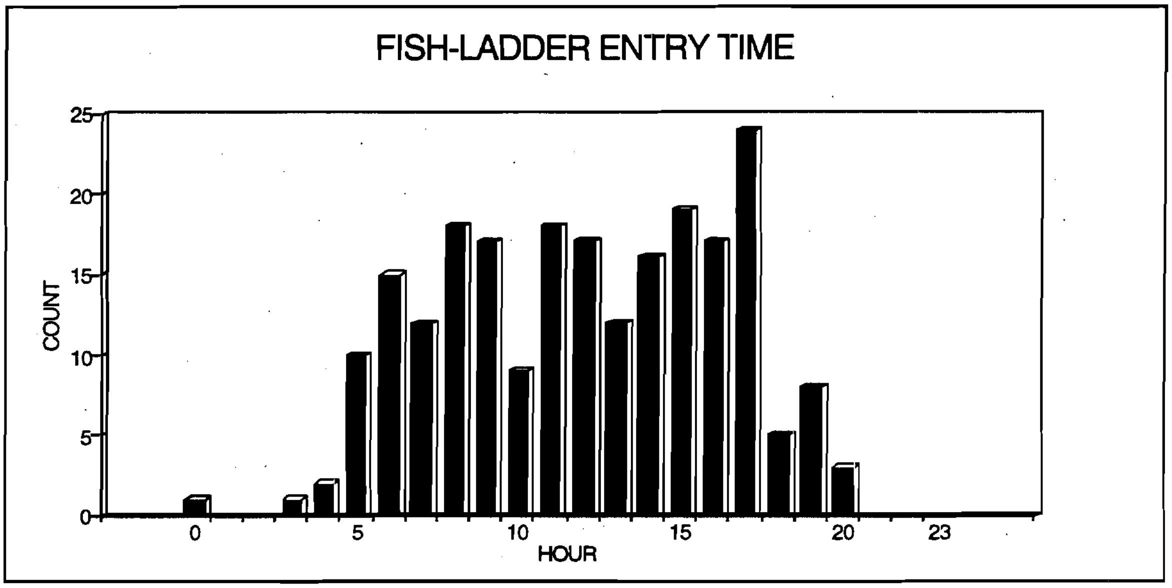
APPENDIX B

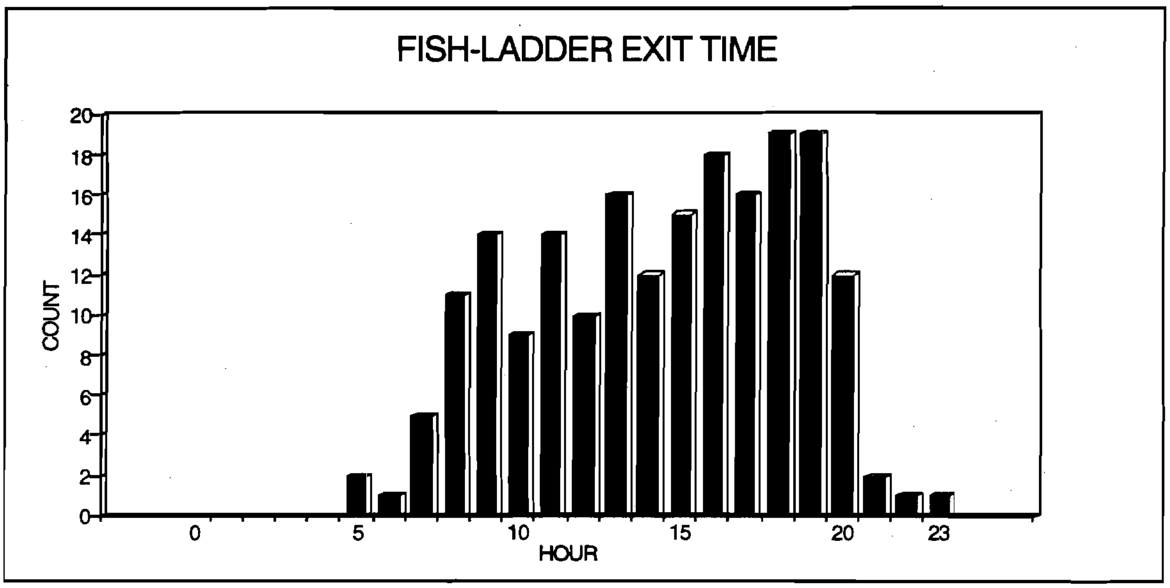
Diel Activity



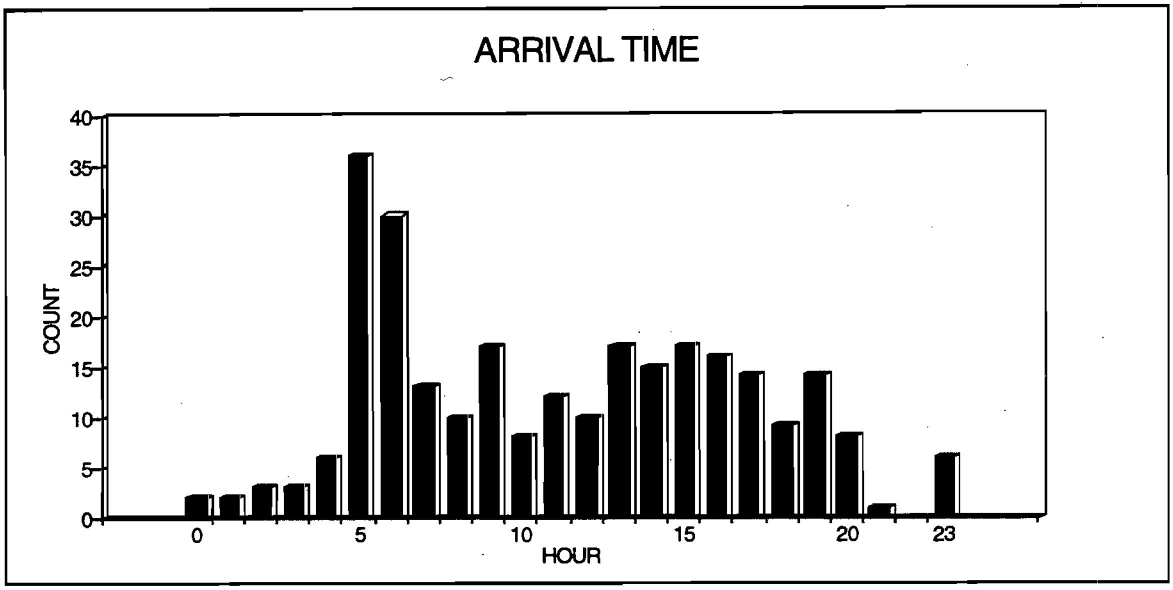


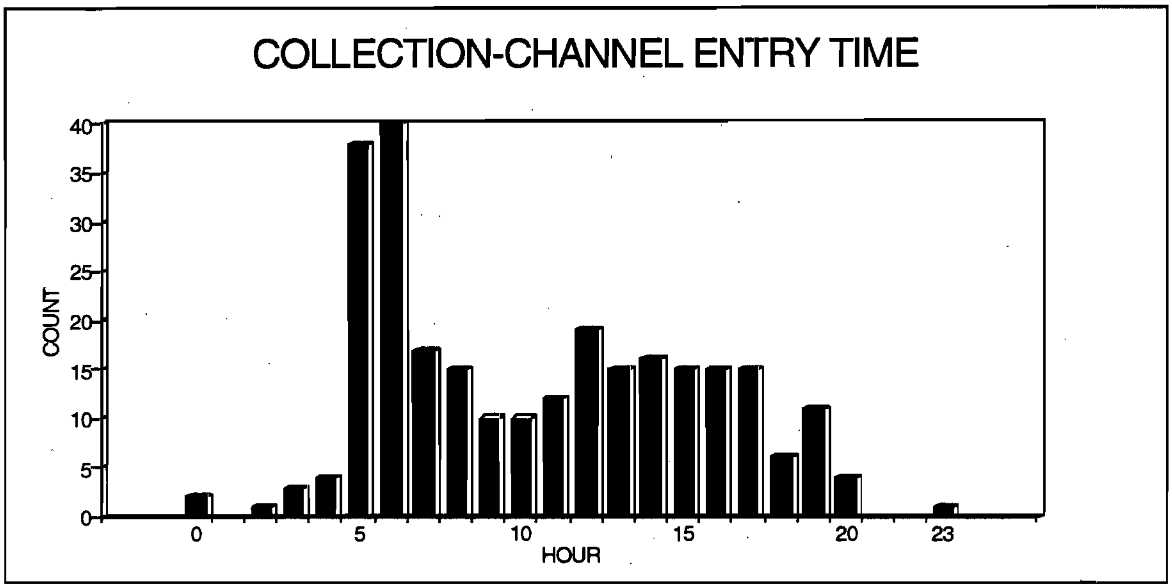
Appendix Figure B1.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Priest Rapids Dam, 4 May-28 July 1993.



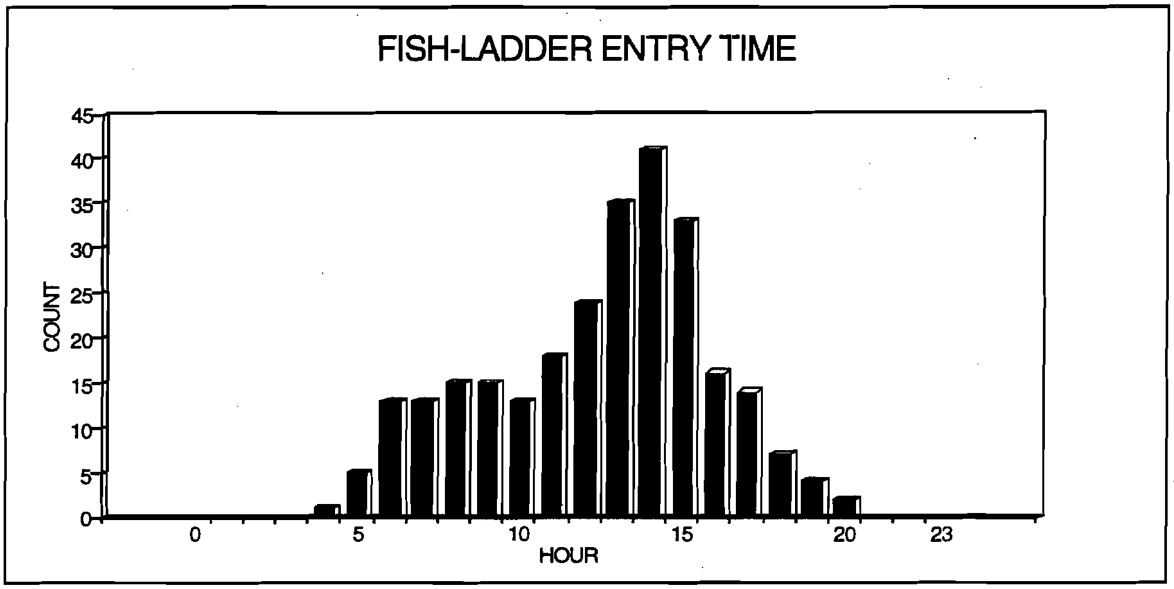


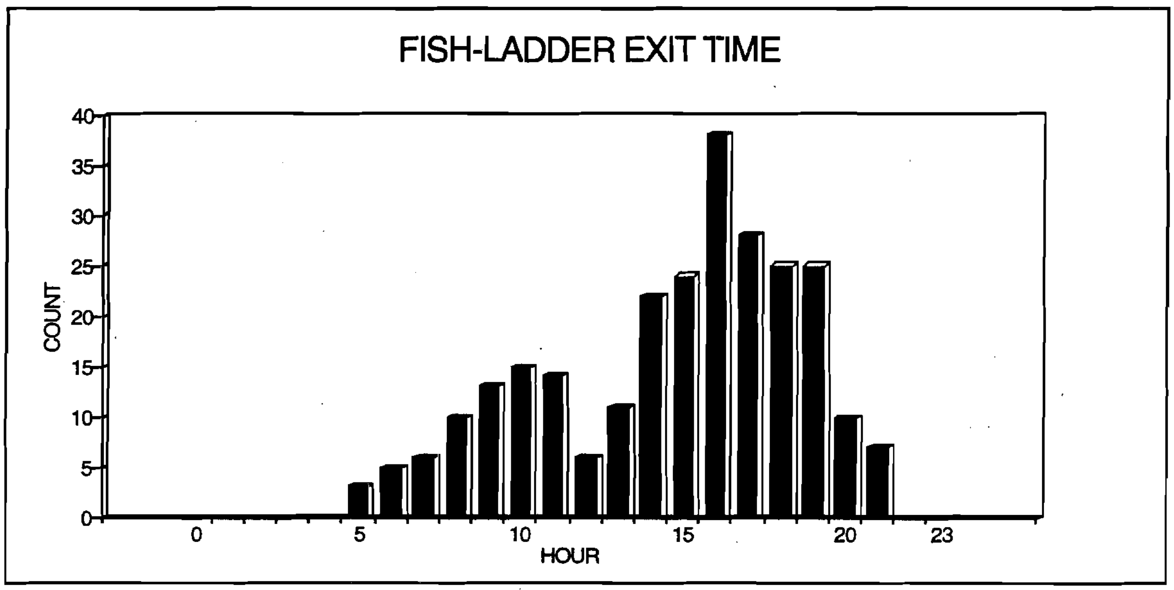
Appendix Figure B2.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Priest Rapids Dam, 4 May-28 July 1993.



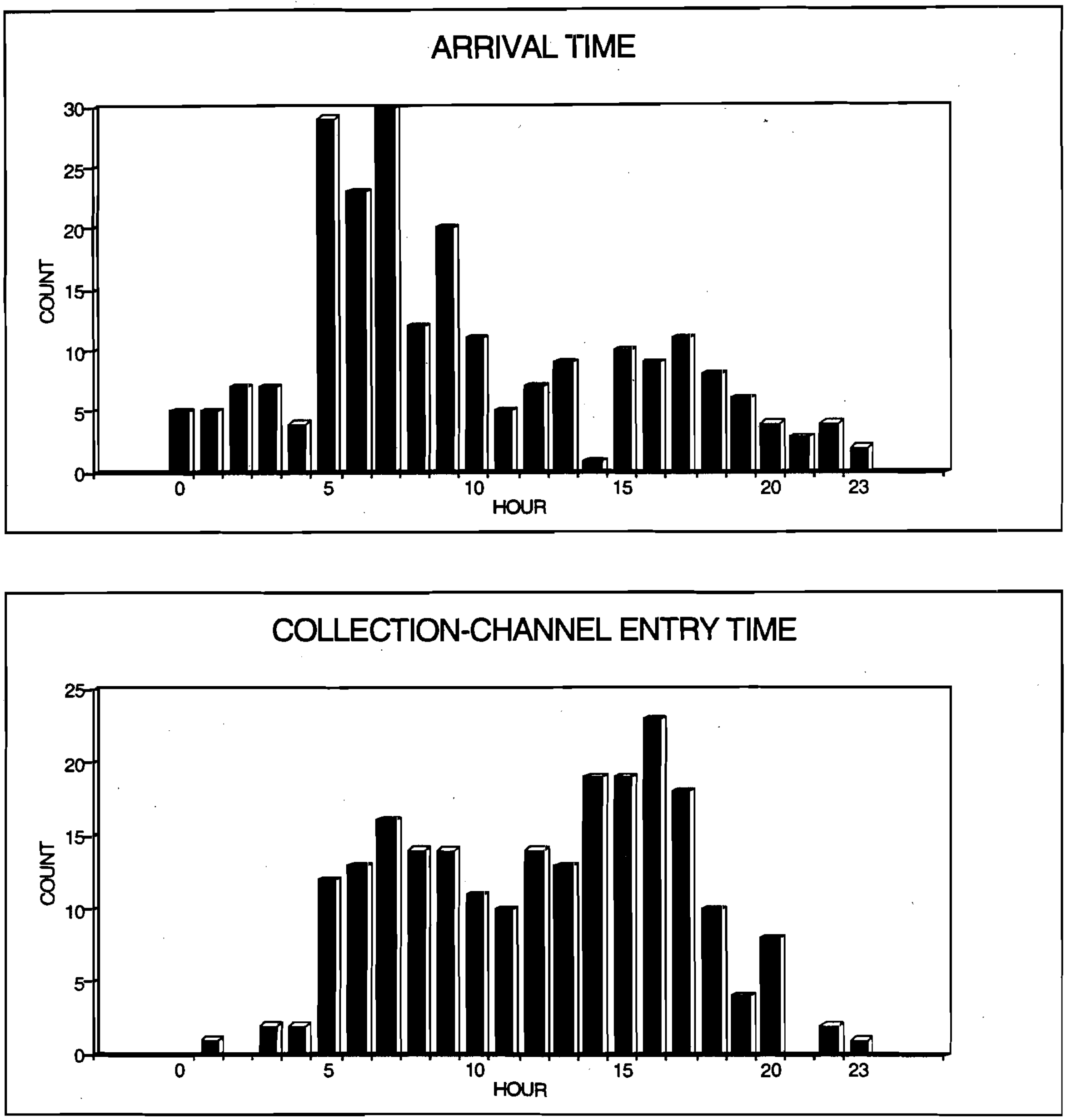


Appendix Figure B3.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Priest Rapids Dam, 13 June-21 August 1993.

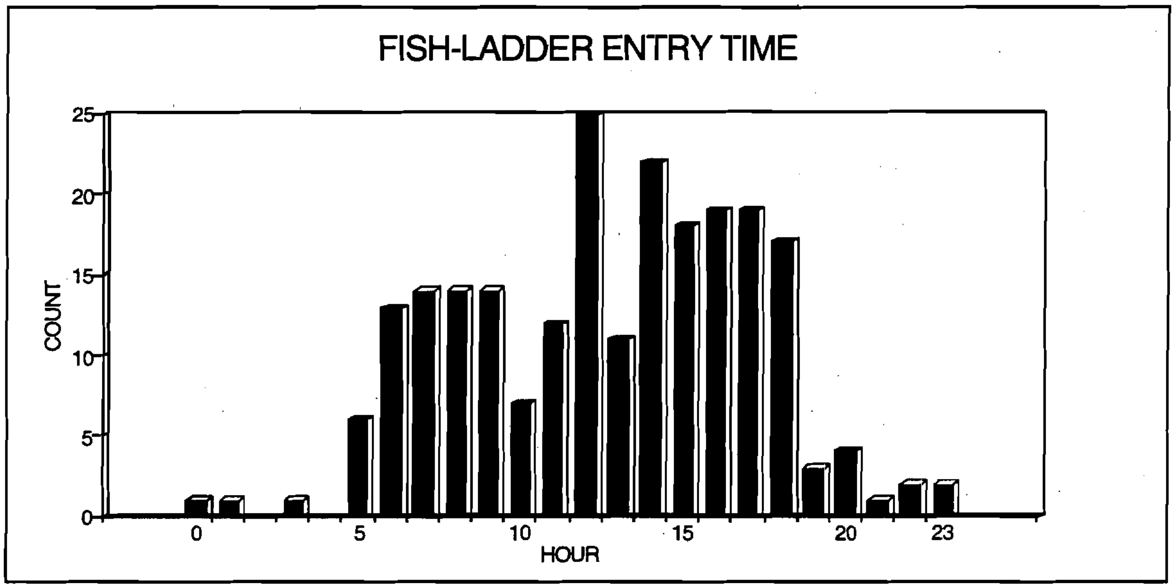


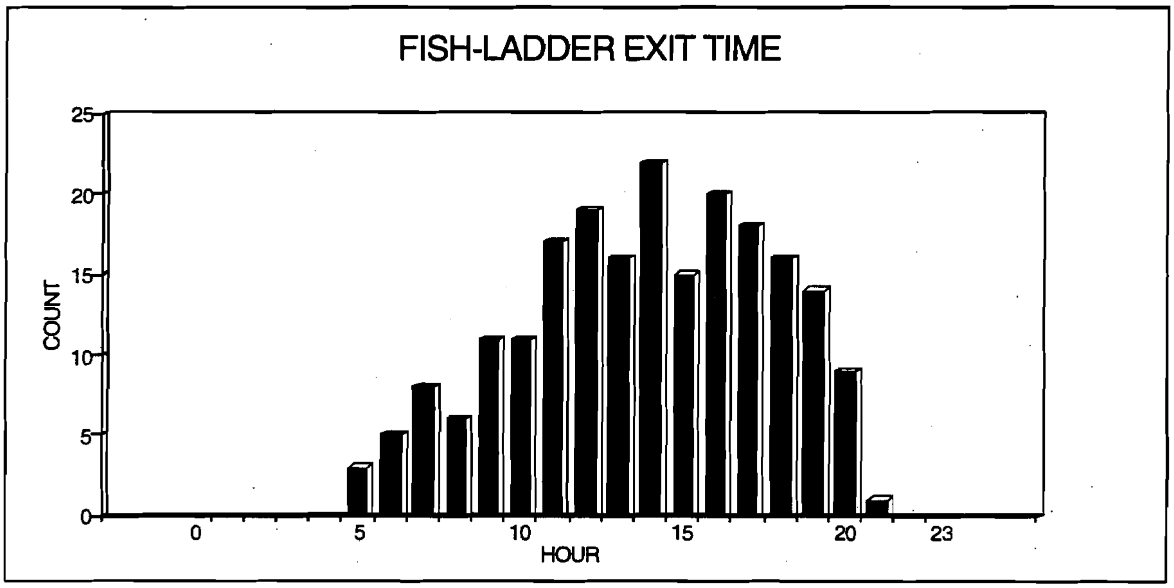


Appendix Figure B4.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Priest Rapids Dam, 13 June-21 August 1993.

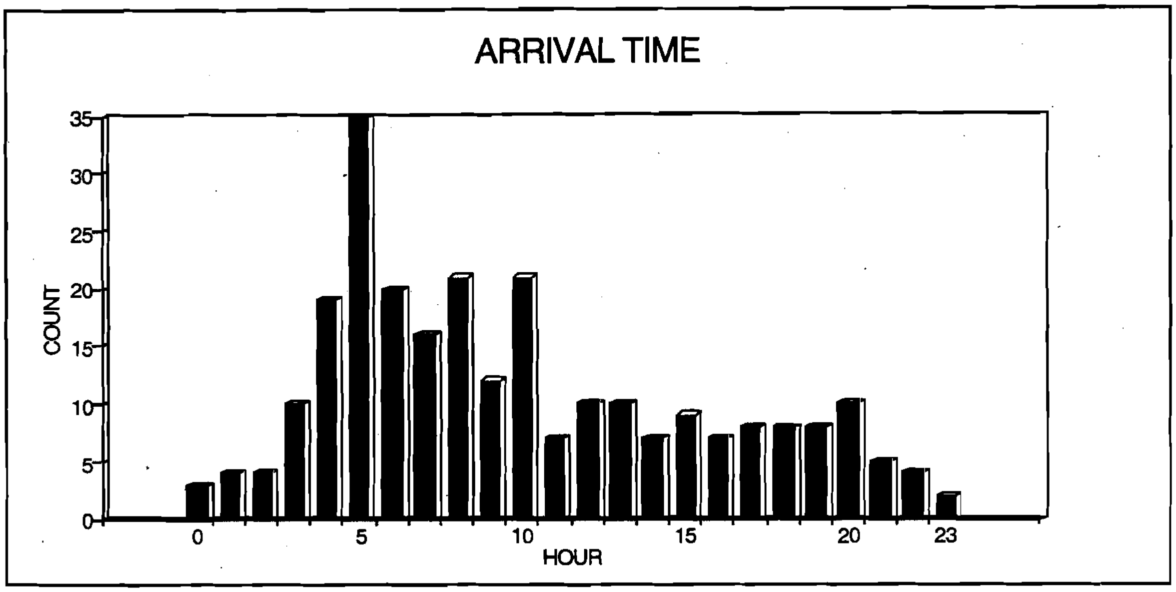


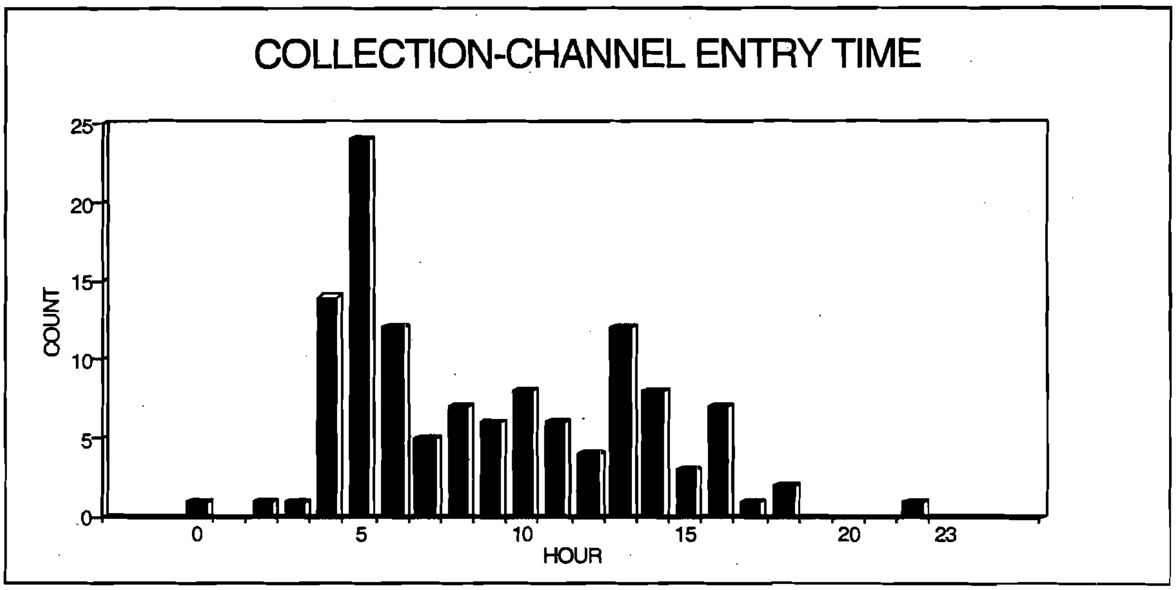
Appendix Figure B5.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Wanapum Dam, 7 May-31 July 1993.



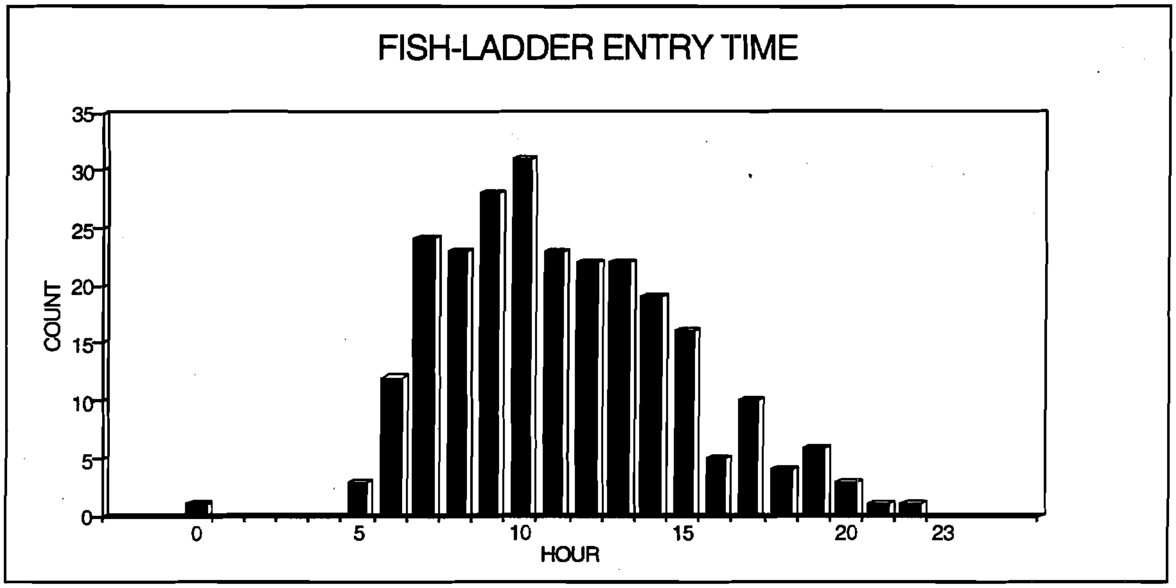


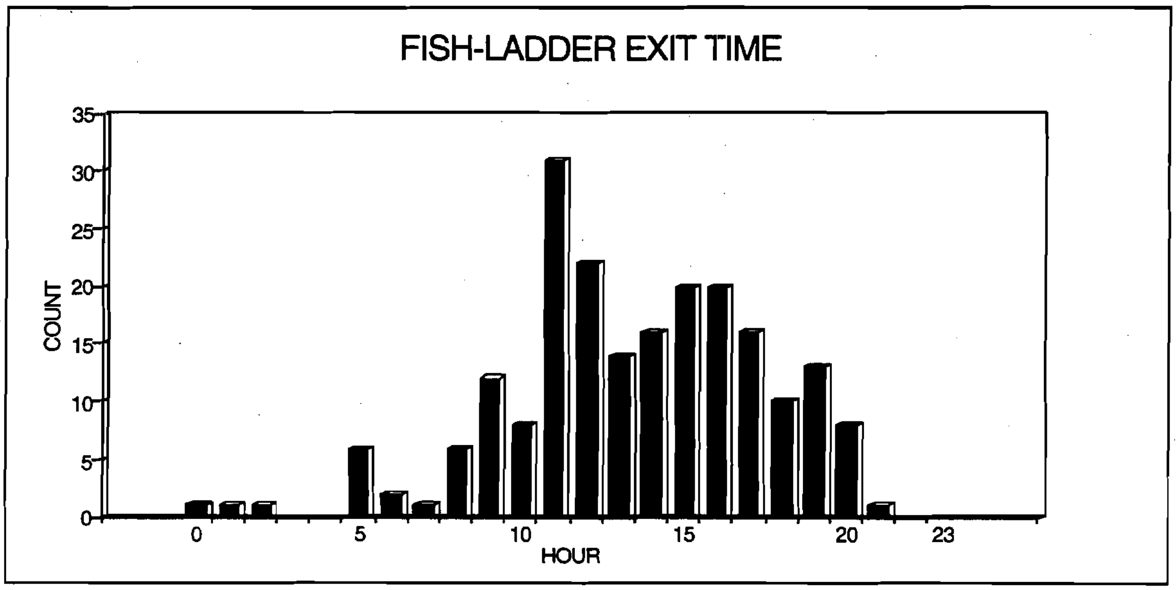
Appendix Figure B6.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Wanapum Dam, 7 May-31 July 1993.



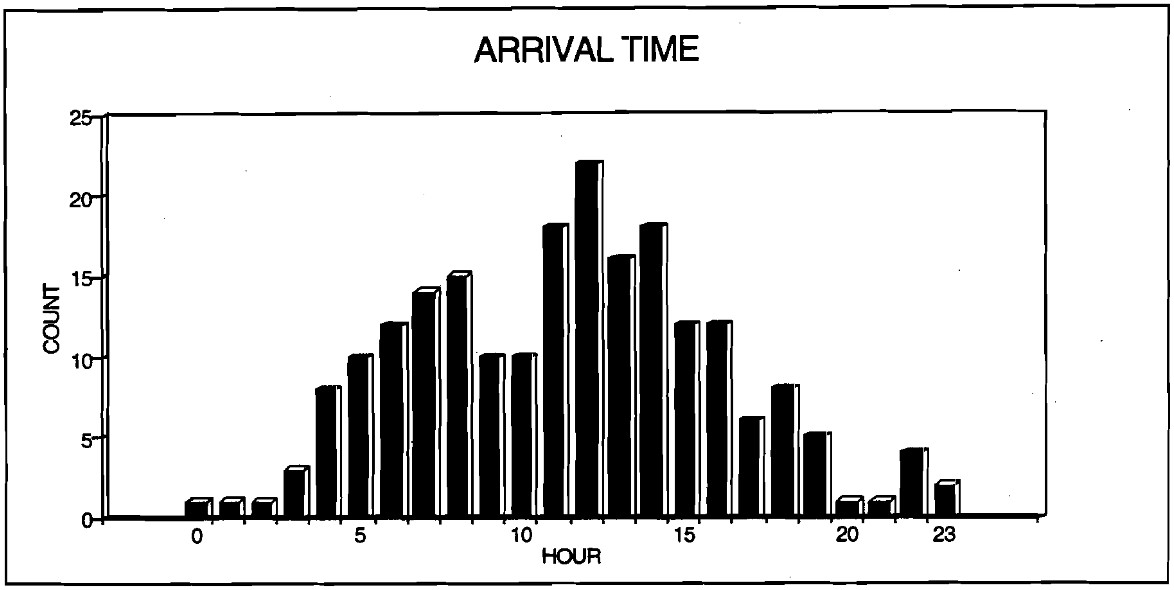


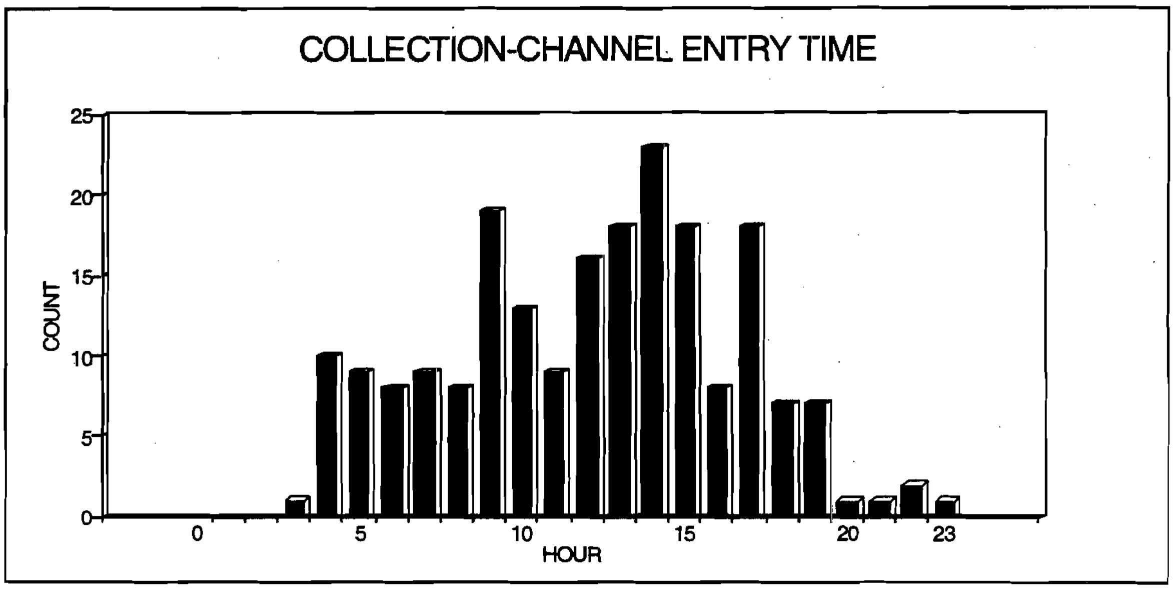
Appendix Figure B7.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Wanapum Dam, 14 June-25 August 1993.



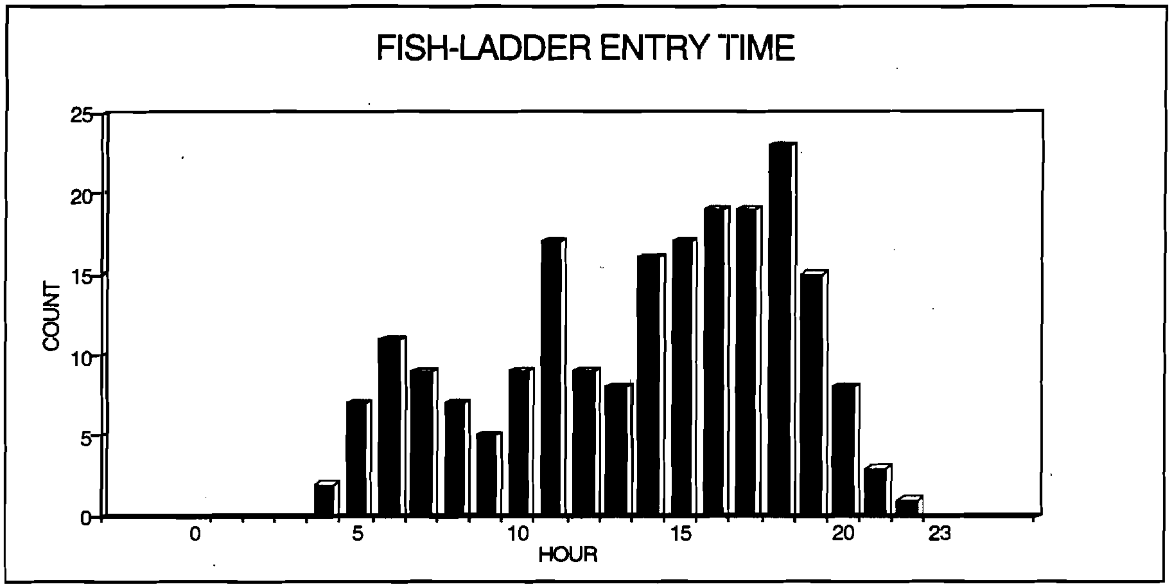


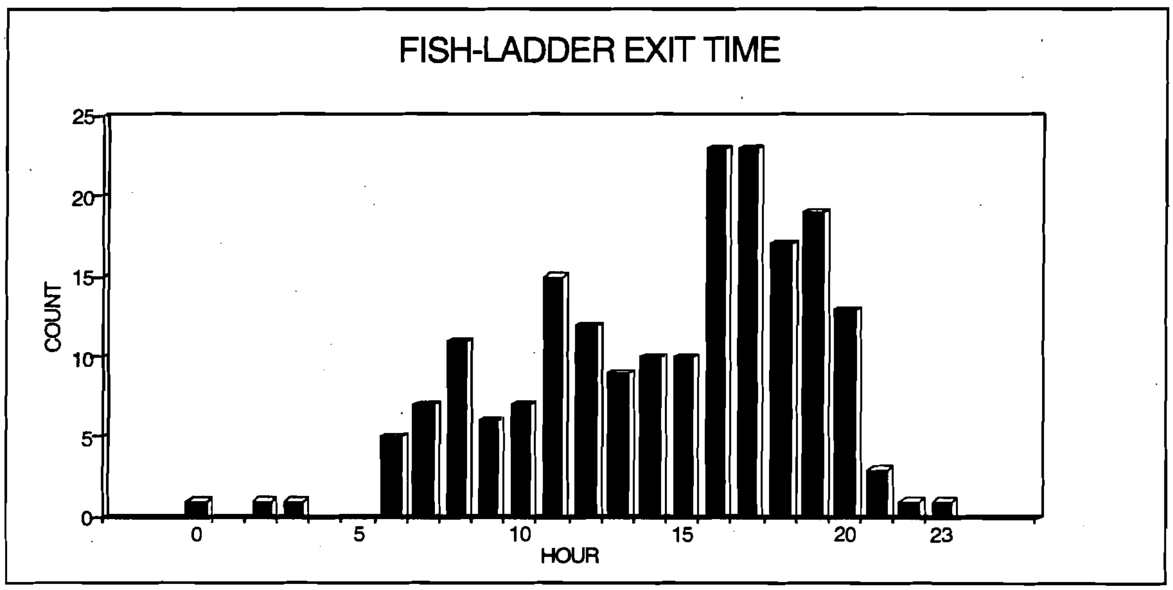
Appendix Figure B8.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Wanapum Dam, 14 June-25 August 1993.



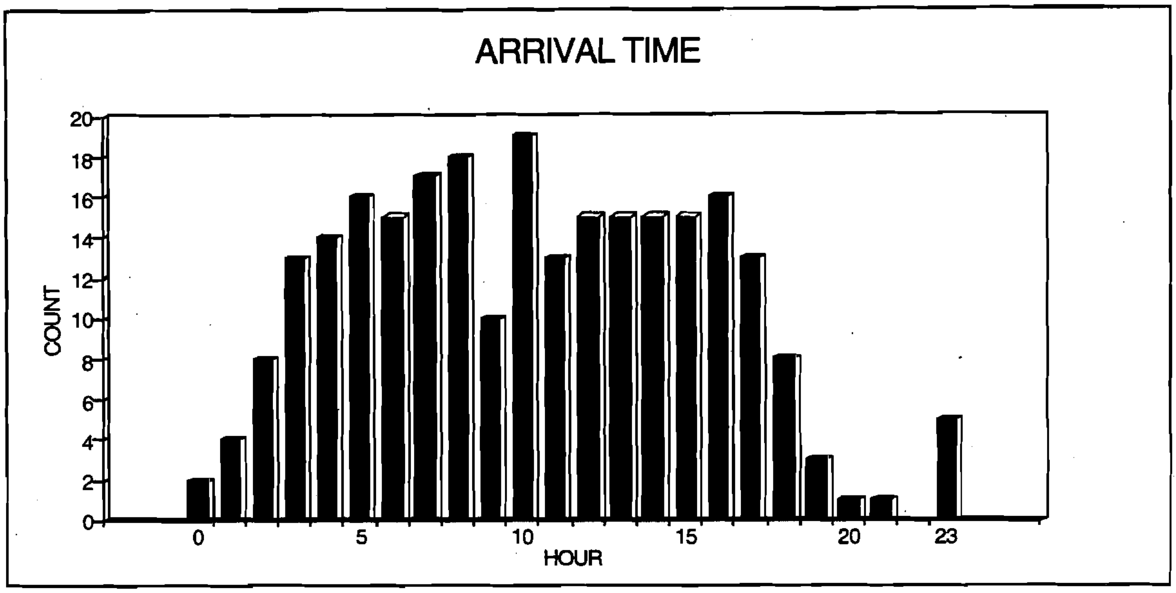


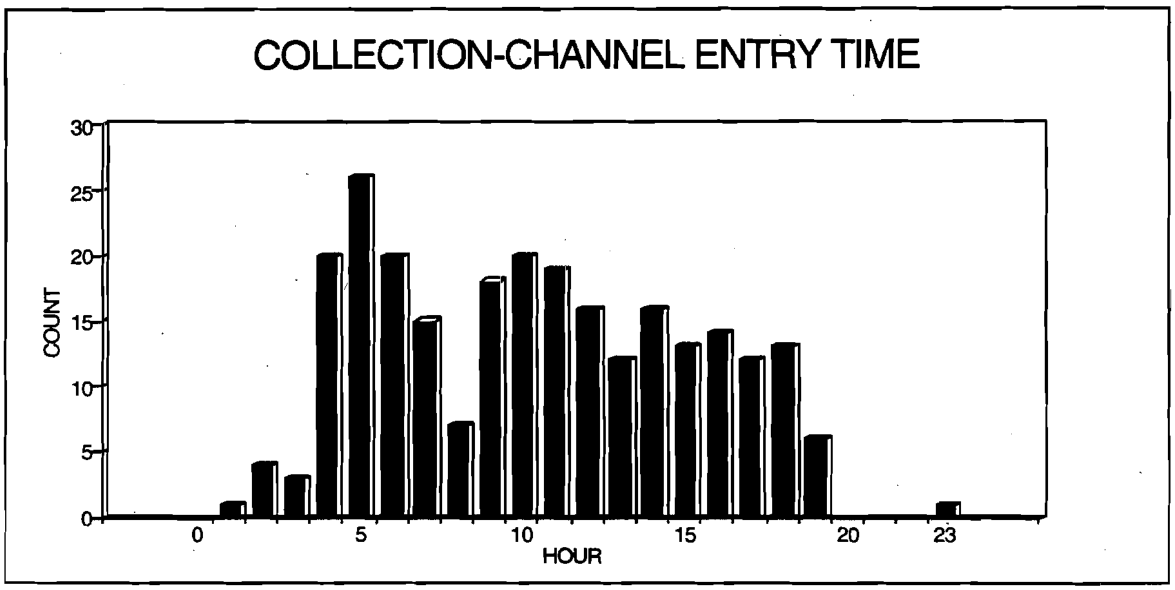
Appendix Figure B9.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Rock Island Dam, 6 May-2 July 1993.



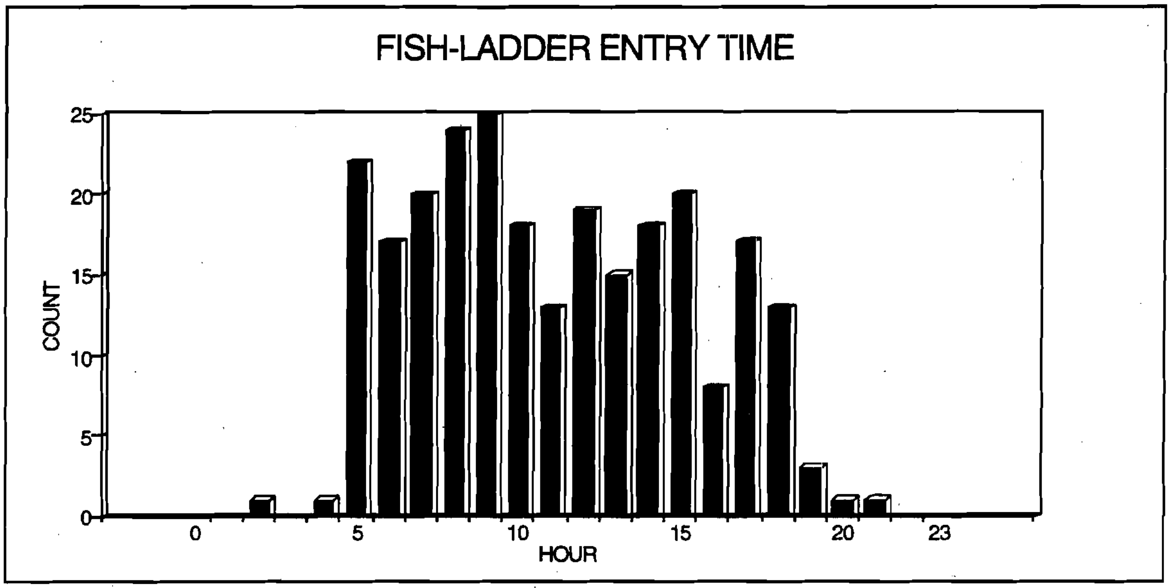


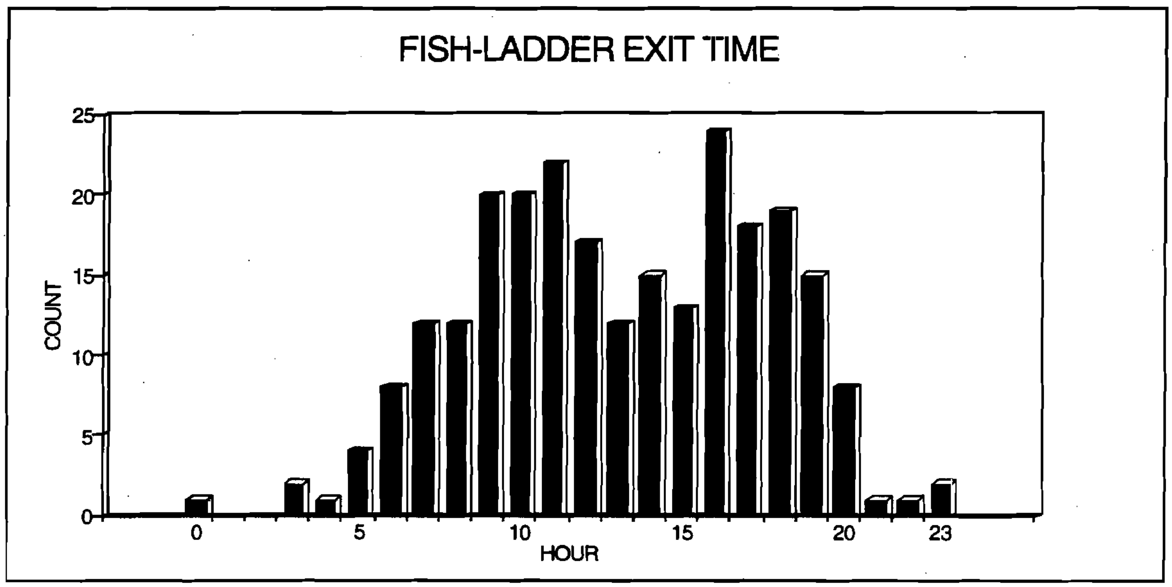
Appendix Figure B10.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Rock Island Dam, 6 May-2 July 1993.



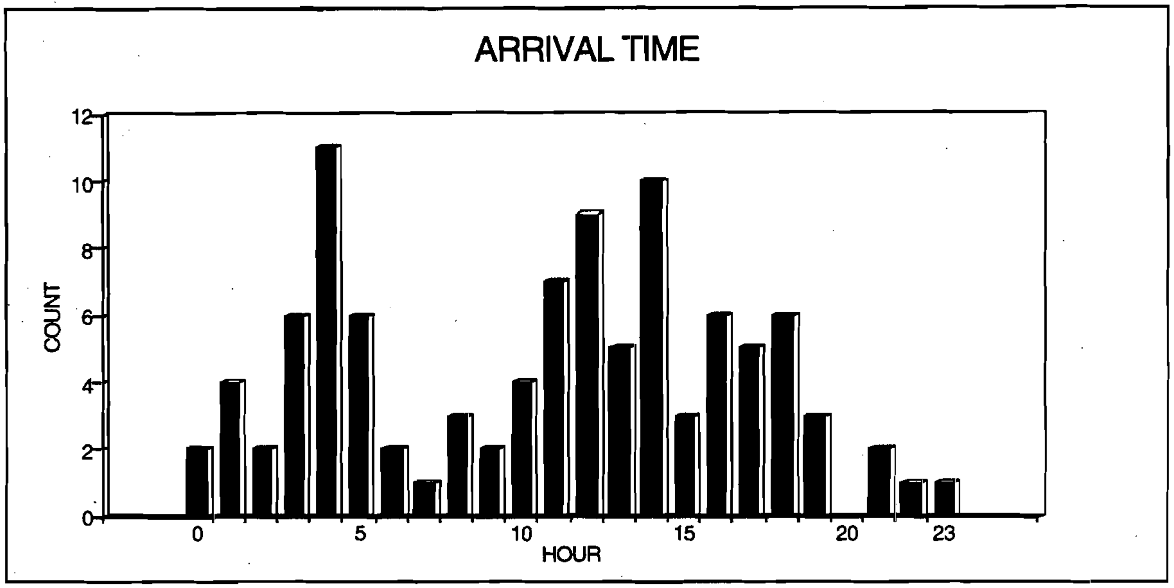


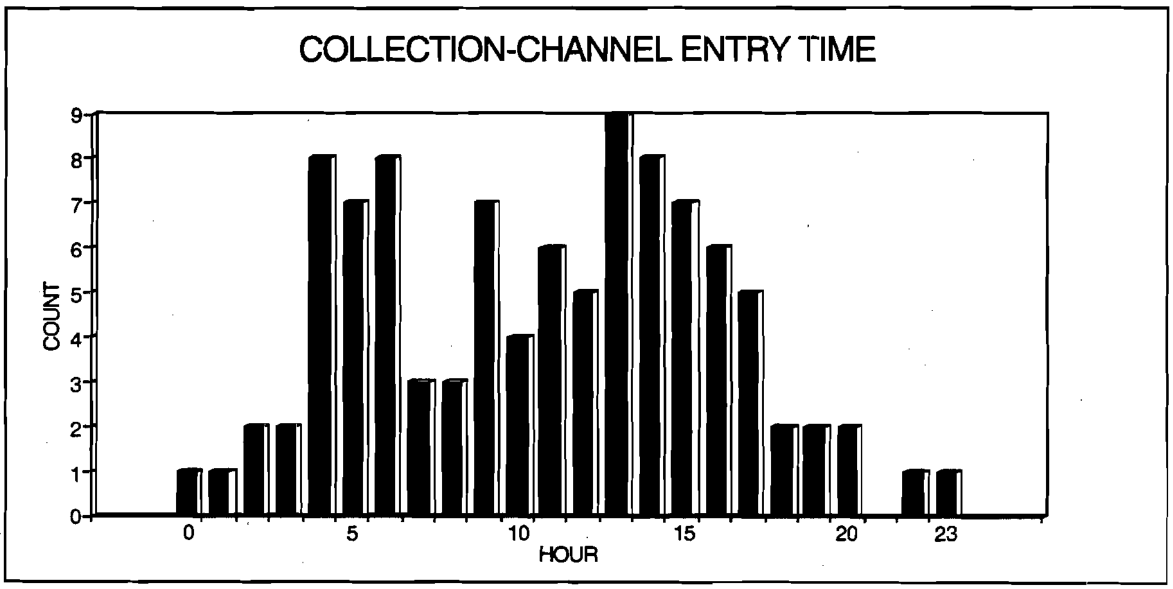
Appendix Figure B11.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Rock Island Dam, 16 June-8 September 1993.



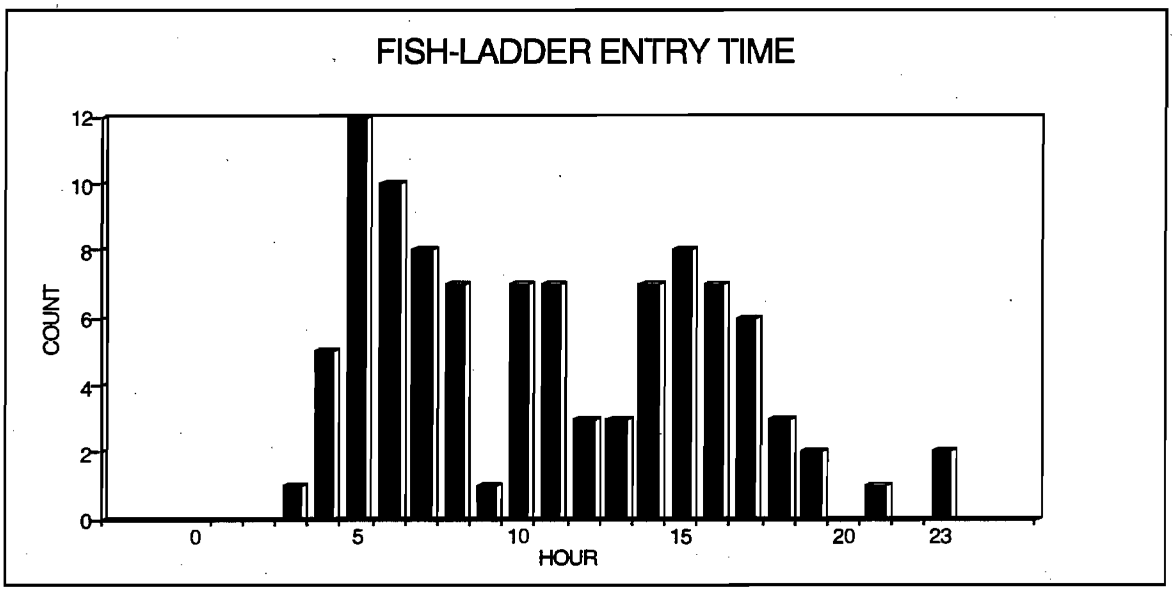


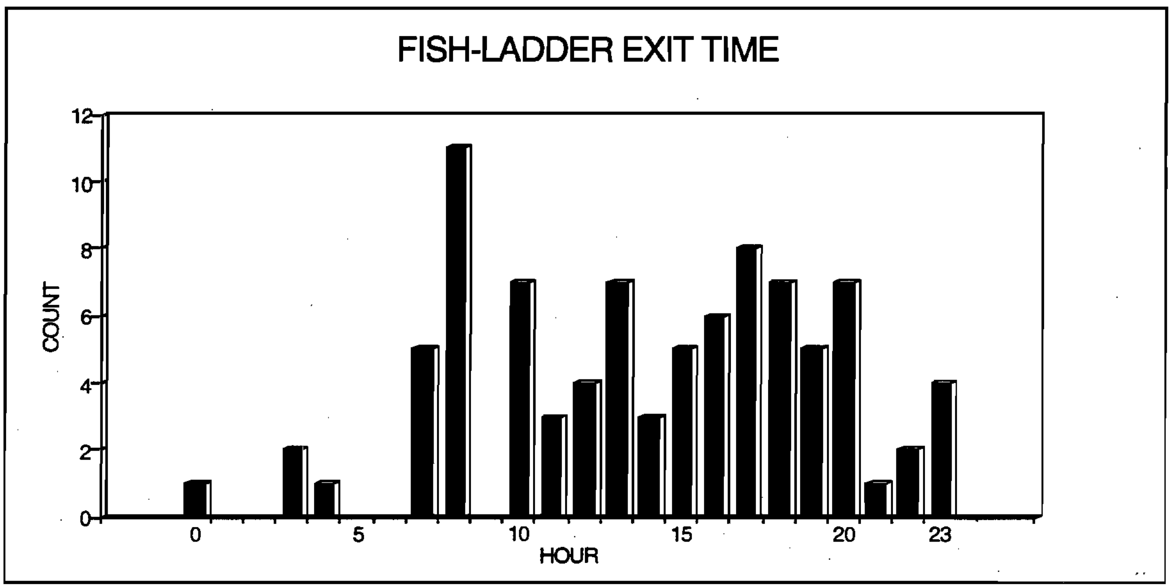
Appendix Figure B12.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Rock Island Dam, 16 June-8 September 1993.



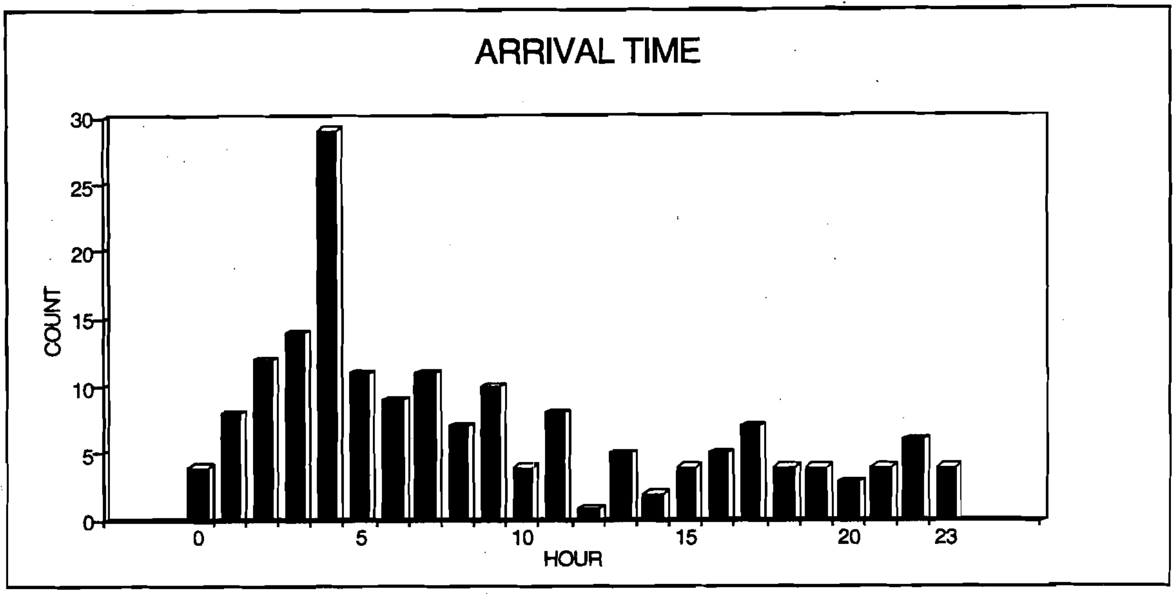


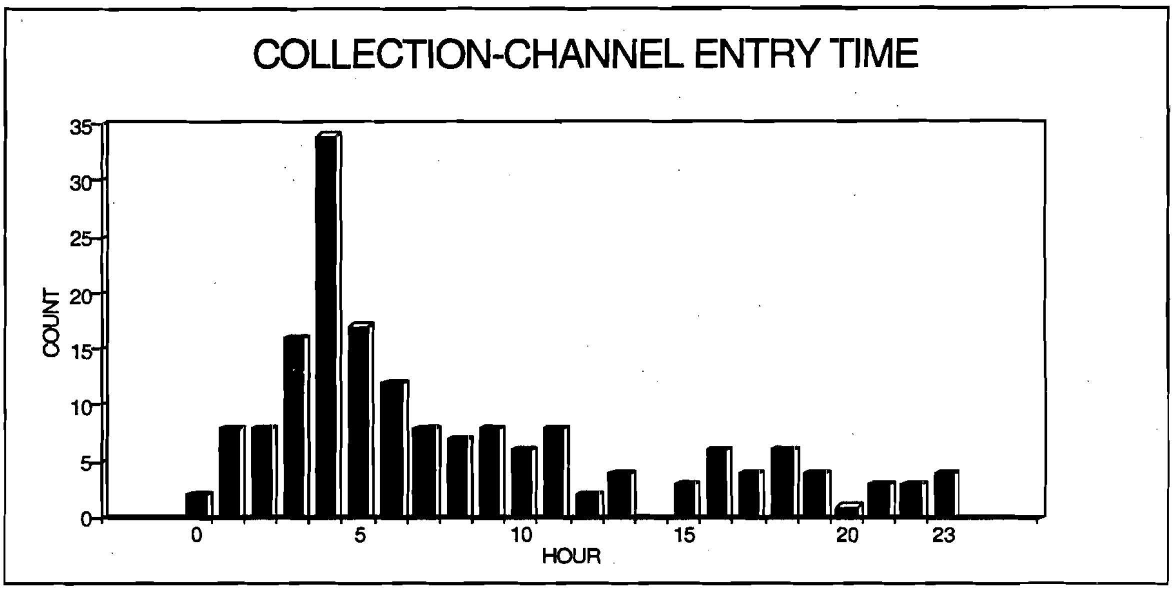
Appendix Figure B13.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Rocky Reach Dam, 7 May-3 July 1993.



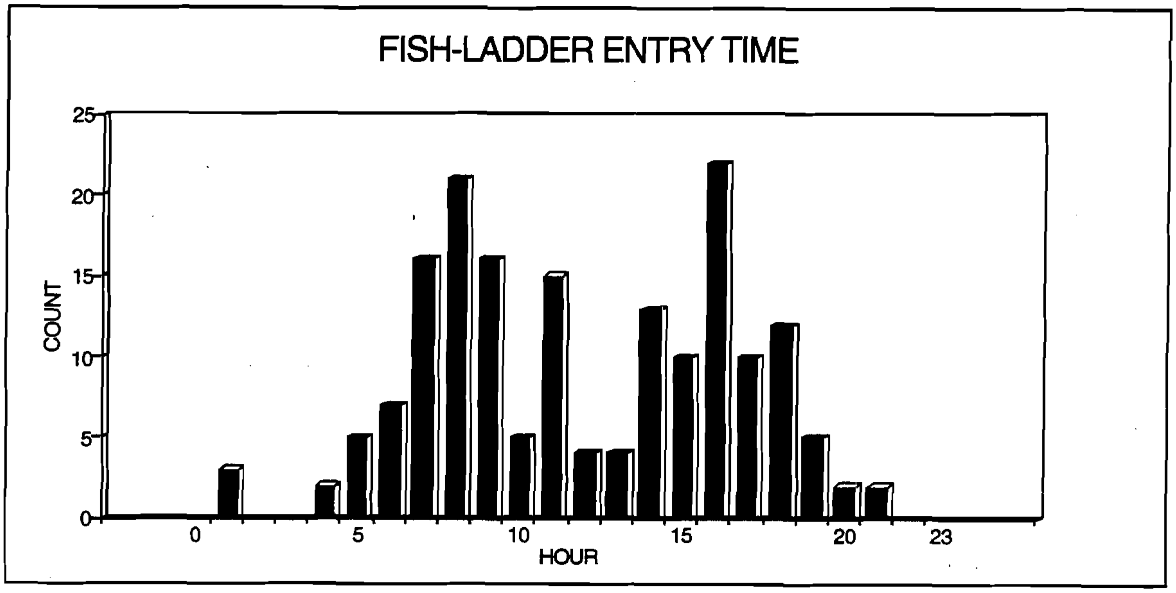


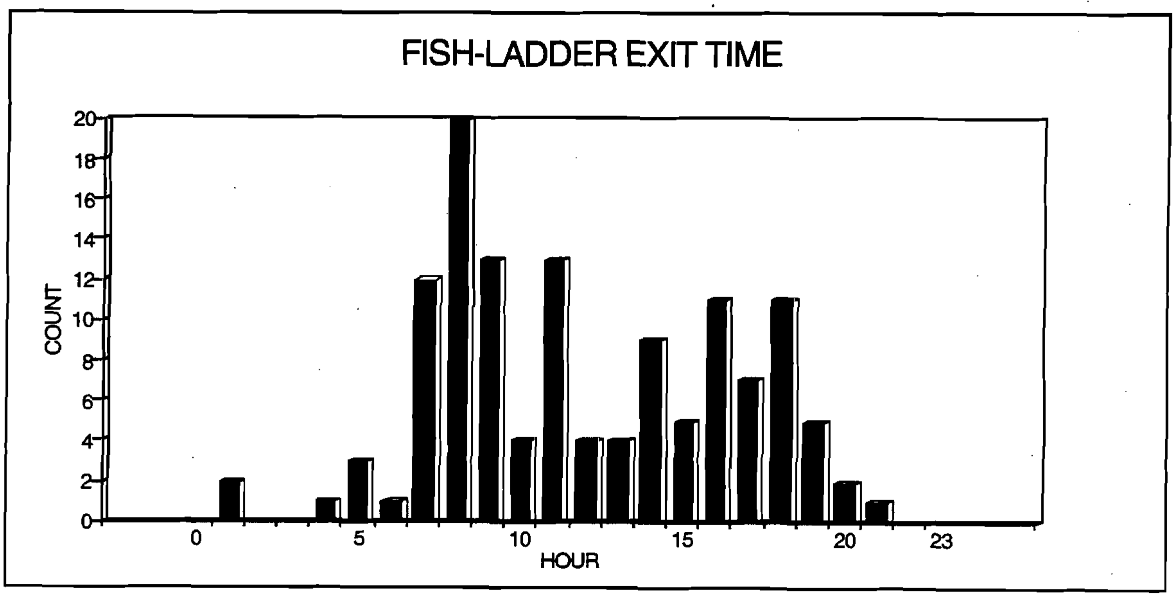
Appendix Figure B14.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Rocky Reach Dam, 7 May-3 July 1993.



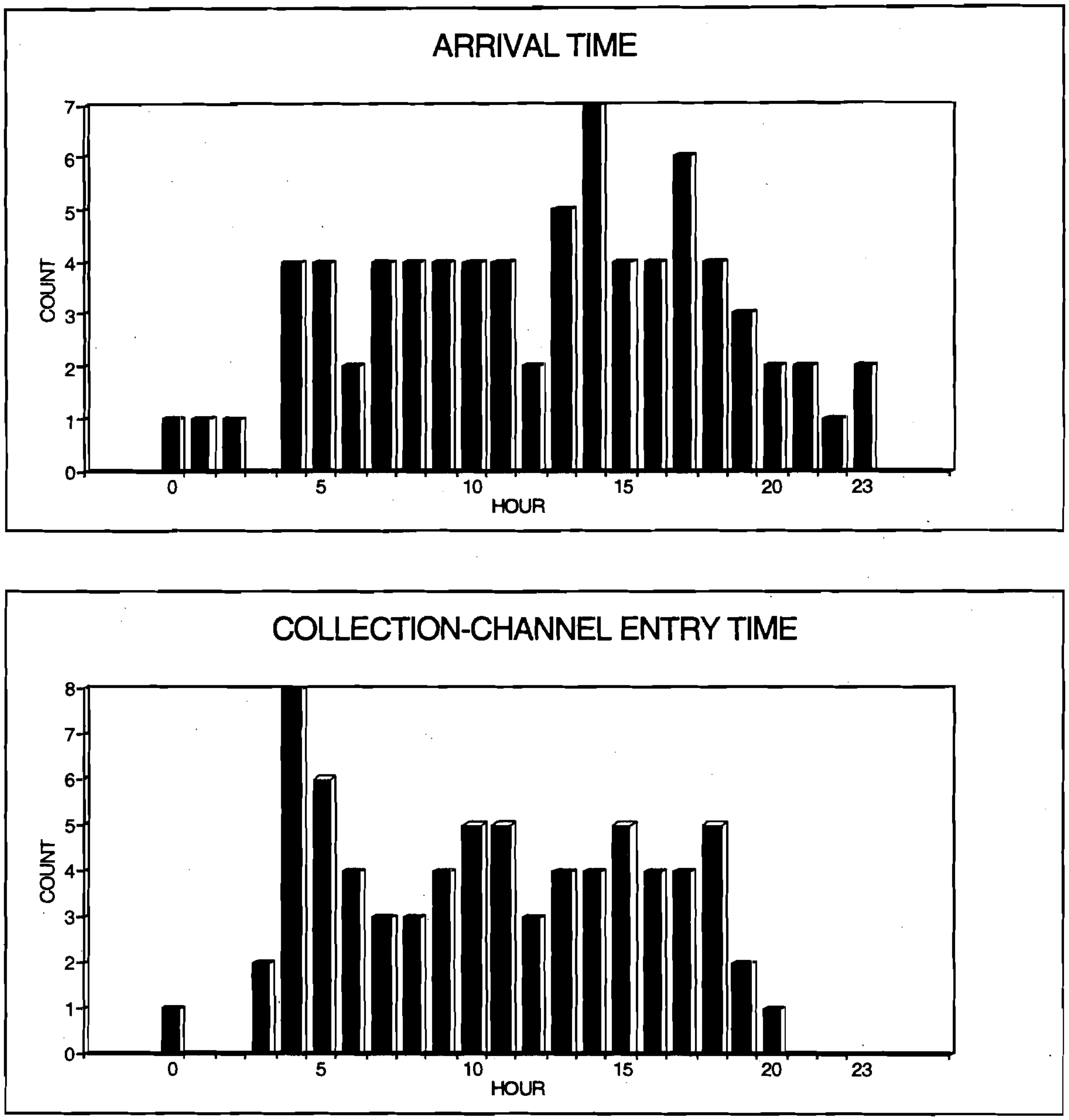


Appendix Figure B15.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Rocky Reach Dam, 18 June-8 October 1993.

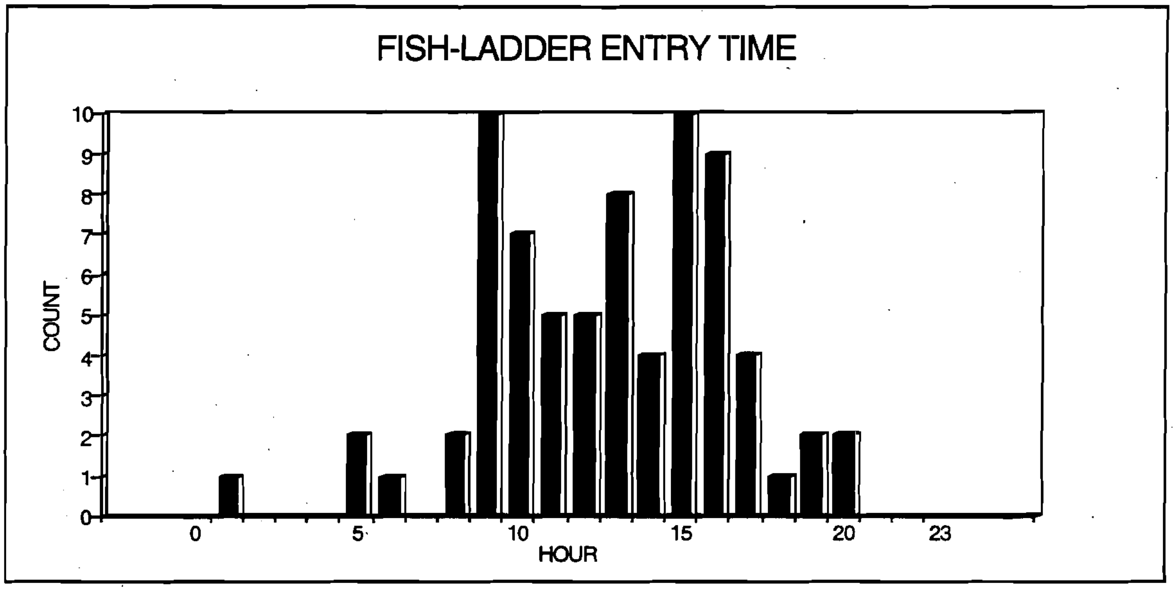


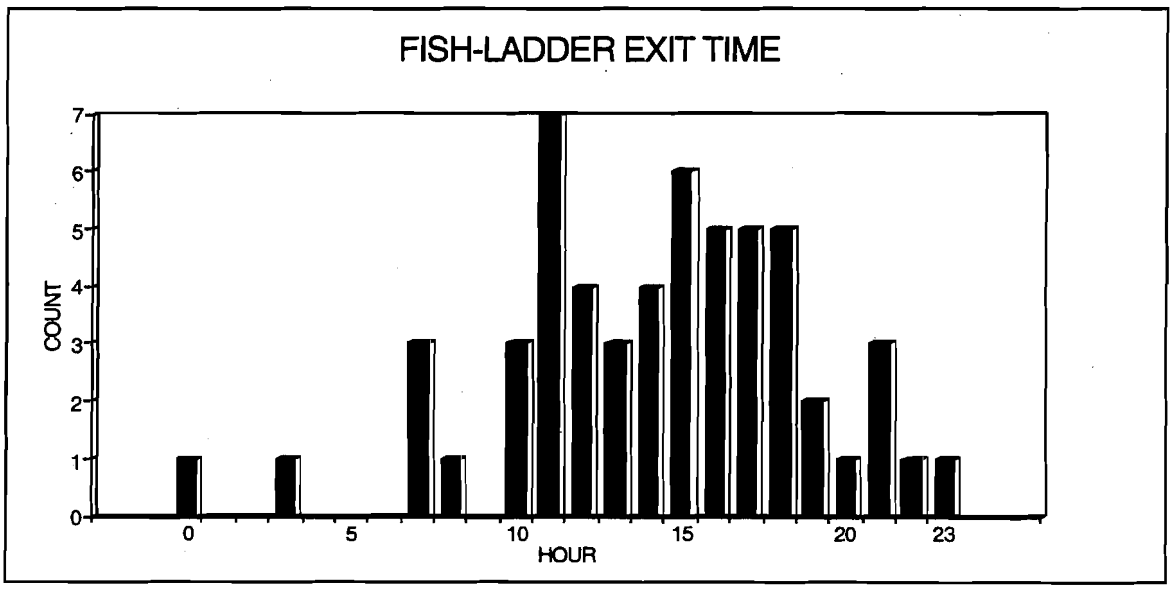


Appendix Figure B16.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Rocky Reach Dam, 18 June-8 October 1993.

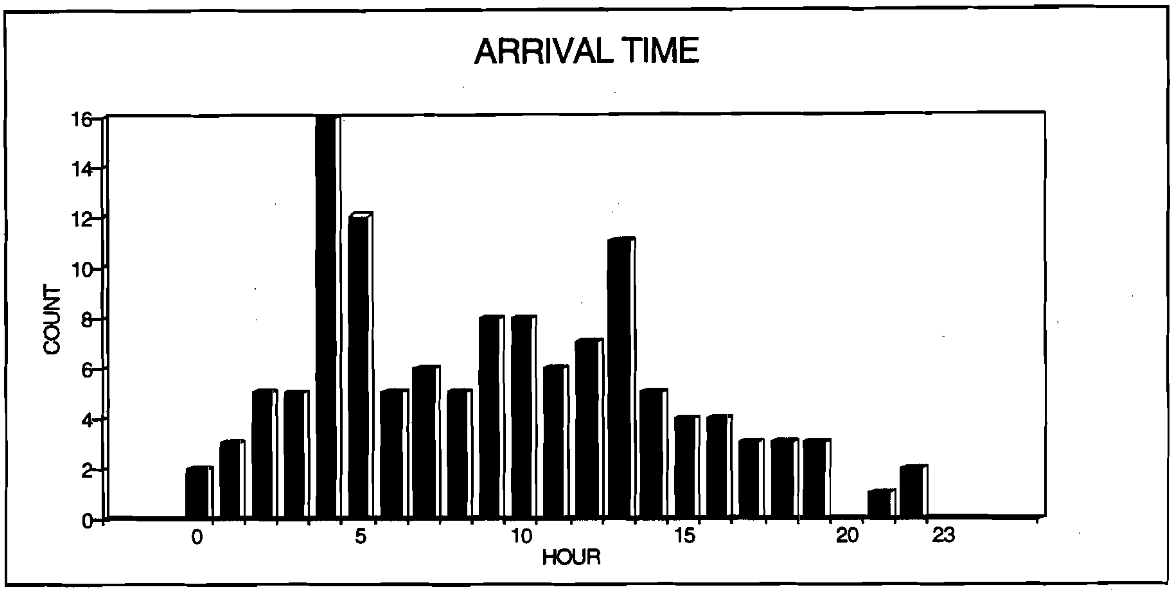


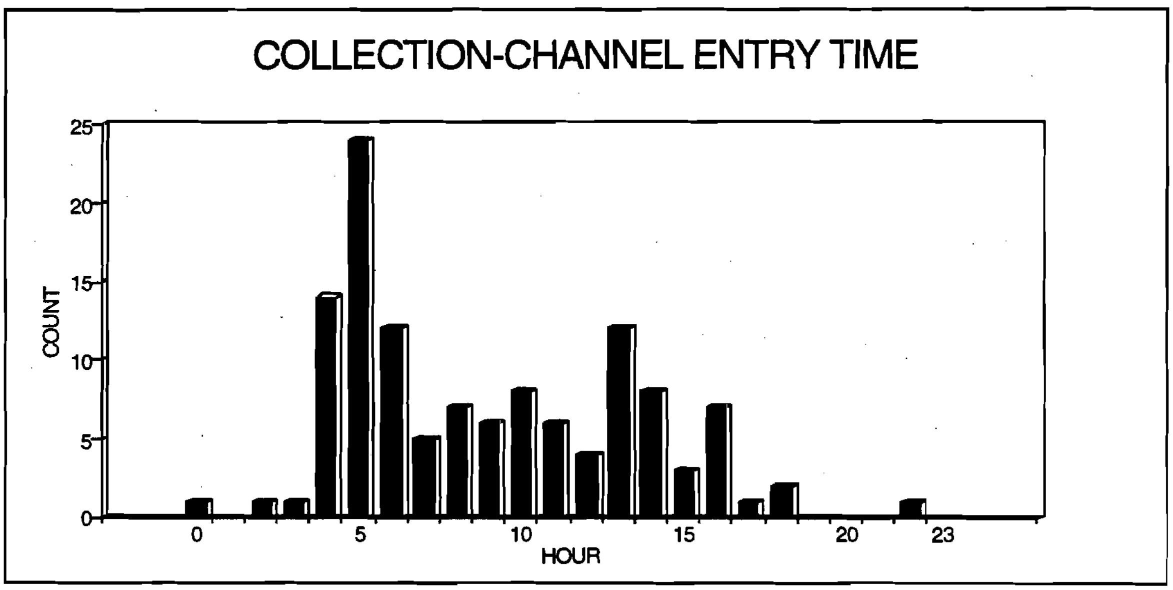
Appendix Figure B17.--Radio-tagged spring chinook salmon diel activity (dam arrival and collection channel first entry times) at Wells Dam, 16 May-15 July 1993.



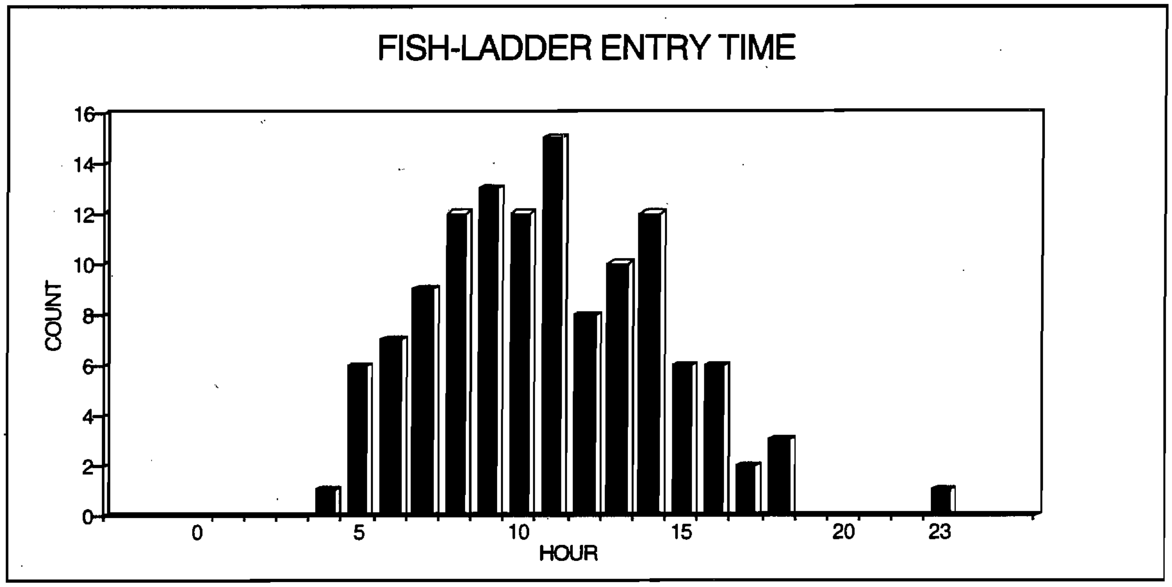


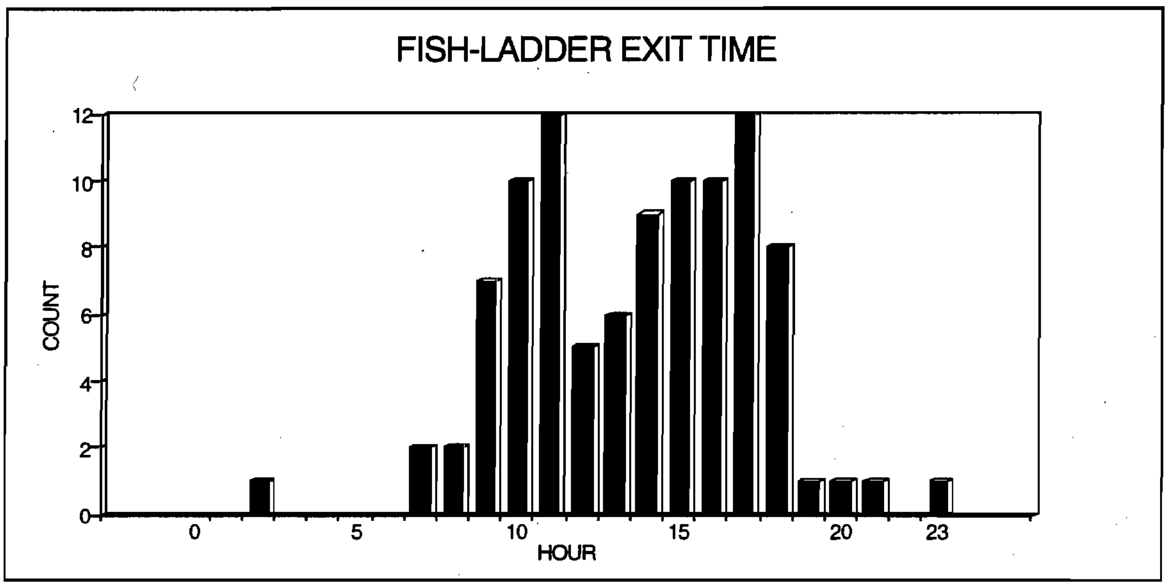
Appendix Figure B18.--Radio-tagged spring chinook salmon diel activity (fish-ladder entry and exit times) at Wells Dam, 16 May-15 July 1993.





Appendix Figure B19.--Radio-tagged summer chinook salmon diel activity (dam arrival and collection channel first entry times) at Wells Dam, 20 June-19 August 1993.

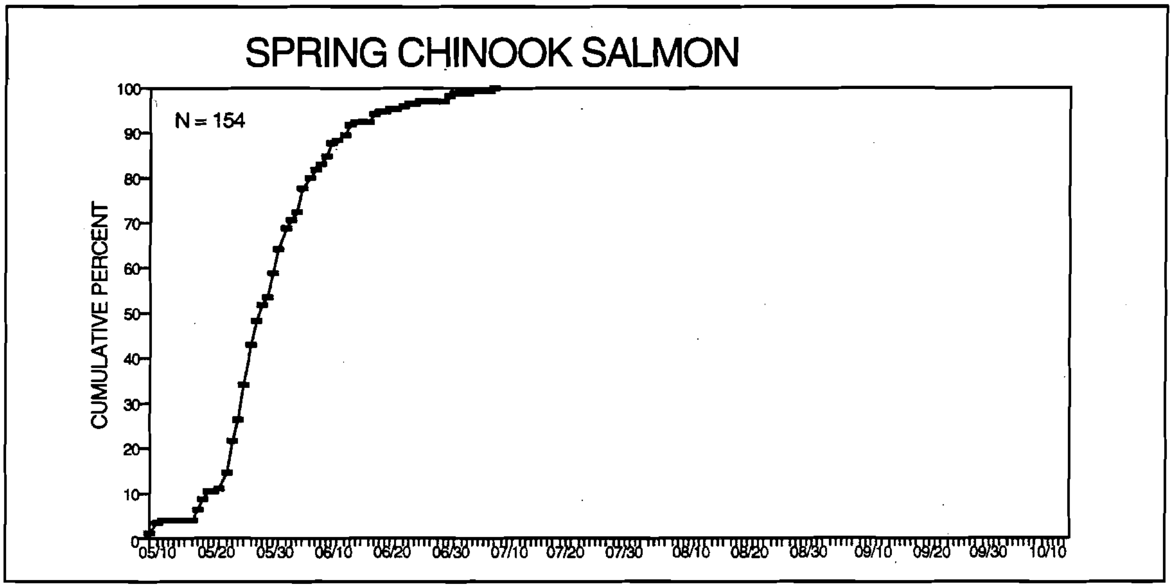


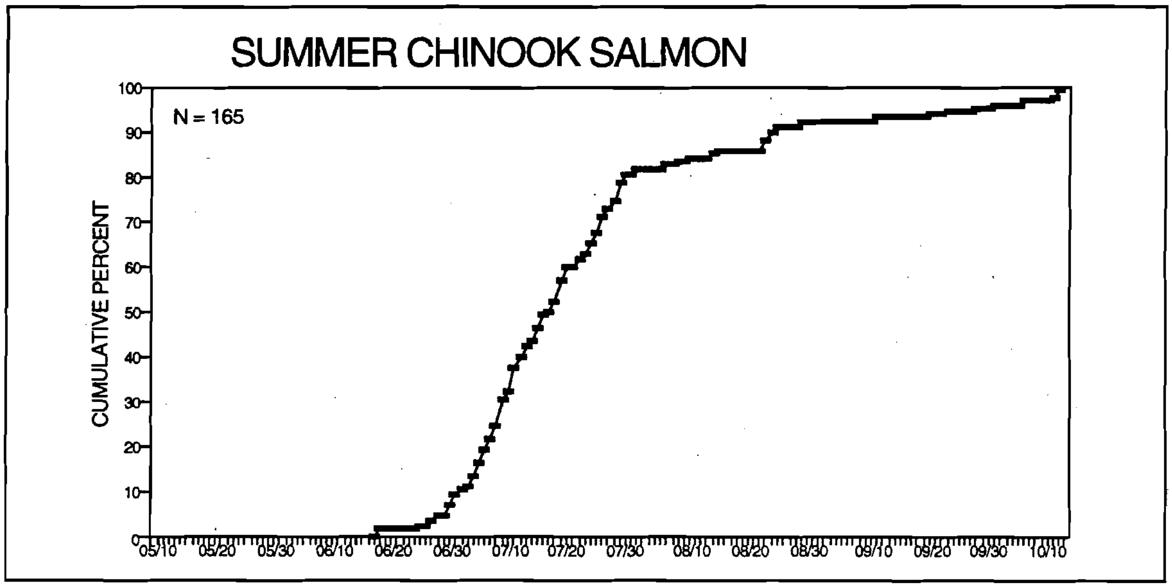


Appendix Figure B20.--Radio-tagged summer chinook salmon diel activity (fish-ladder entry and exit times) at Wells Dam, 20 June-19 August 1993.

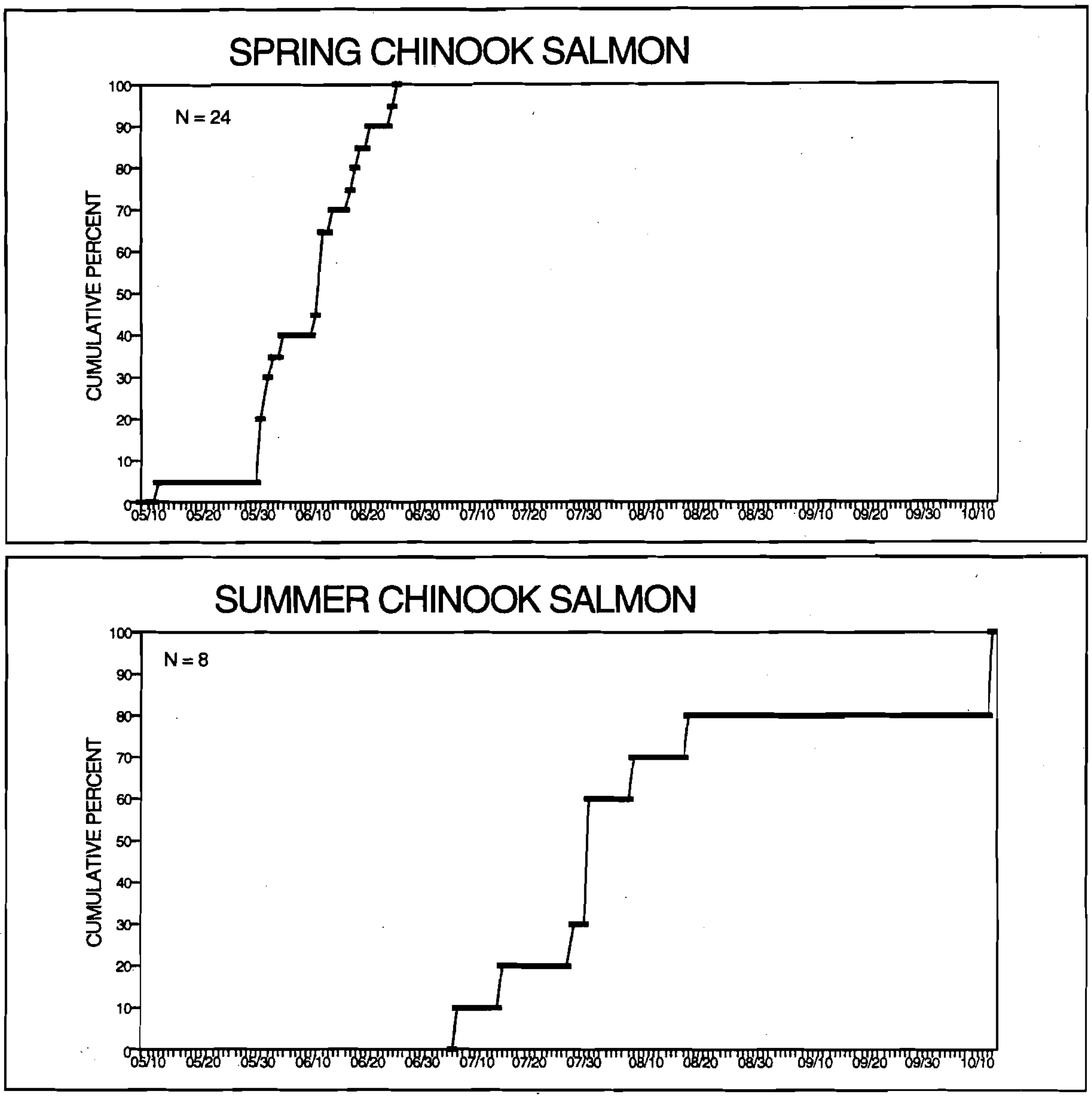
APPENDIX C

Tributary Entry Dates

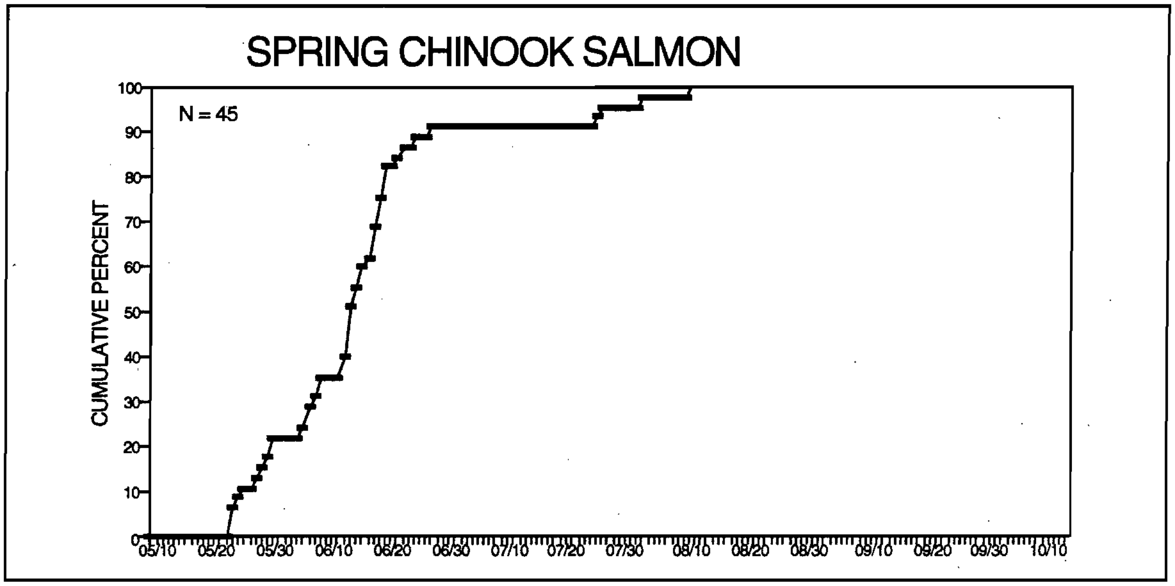


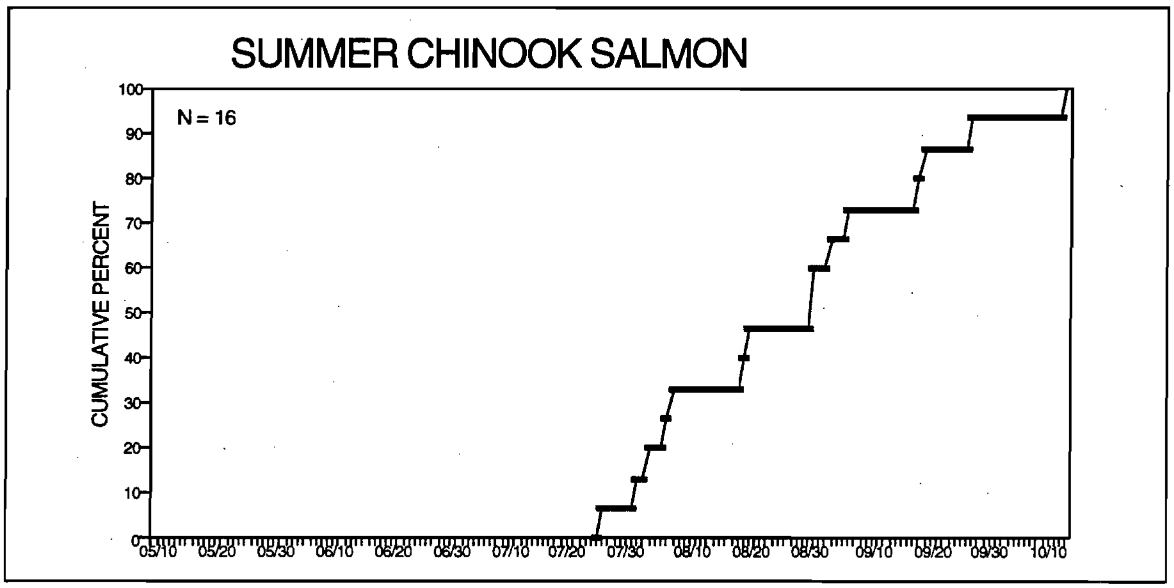


Appendix Figure C1.--Entry dates of radio-tagged chinook salmon into the Wenatchee River, 1993.

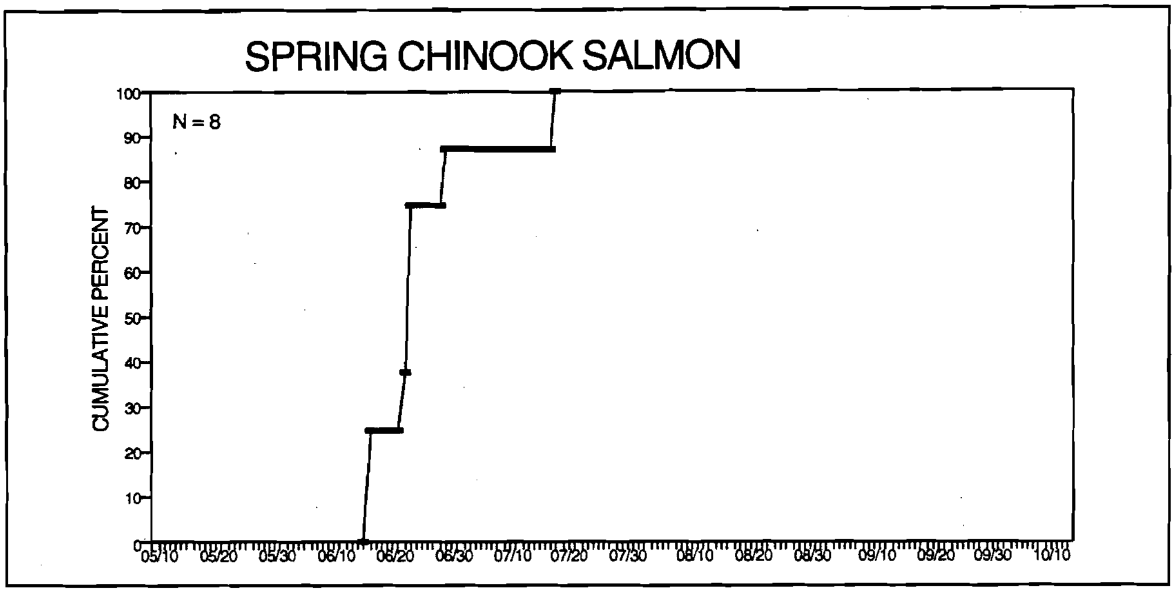


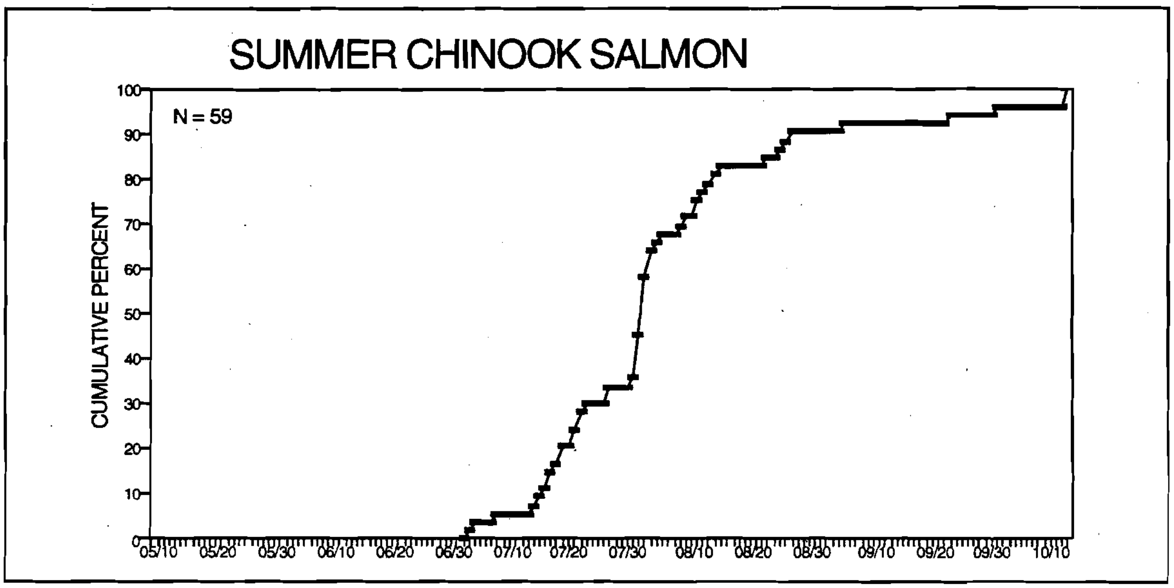
Appendix Figure C2.--Entry dates of radio-tagged chinook salmon into the Entiat River, 1993.





Appendix Figure C3.--Entry dates of radio-tagged chinook salmon into the Methow River, 1993.

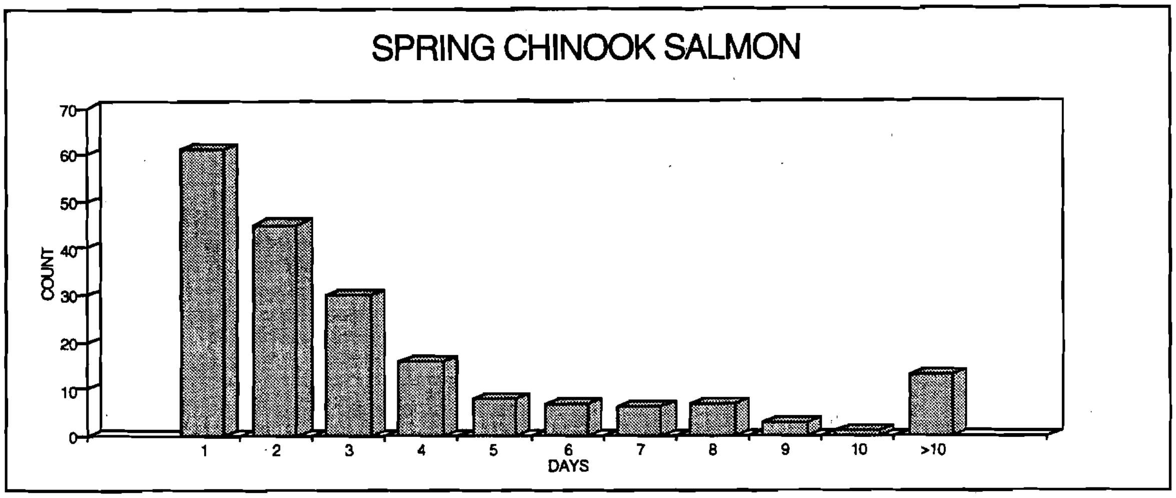


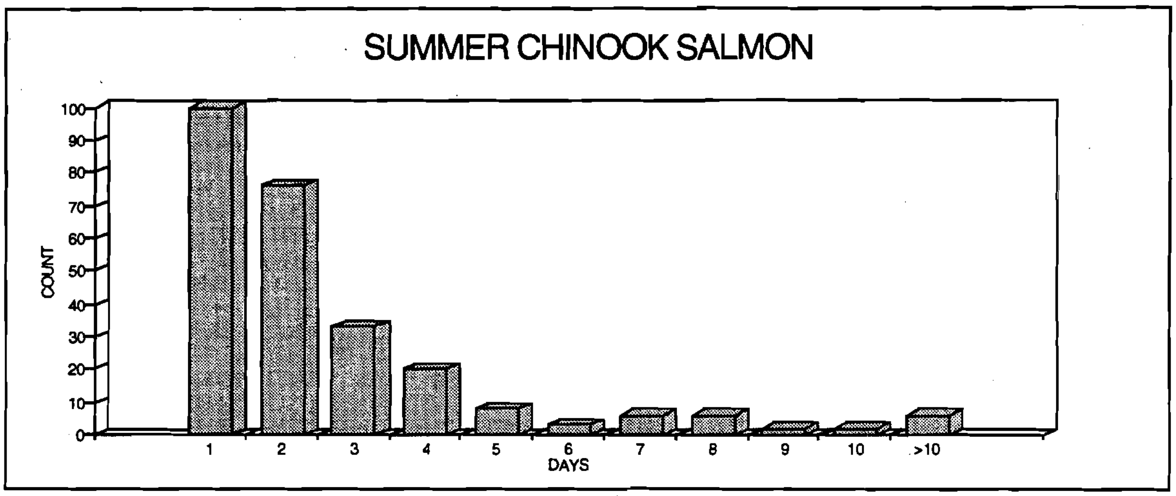


Appendix Figure C4.--Entry dates of radio-tagged chinook salmon into the Okanogan River, 1993.

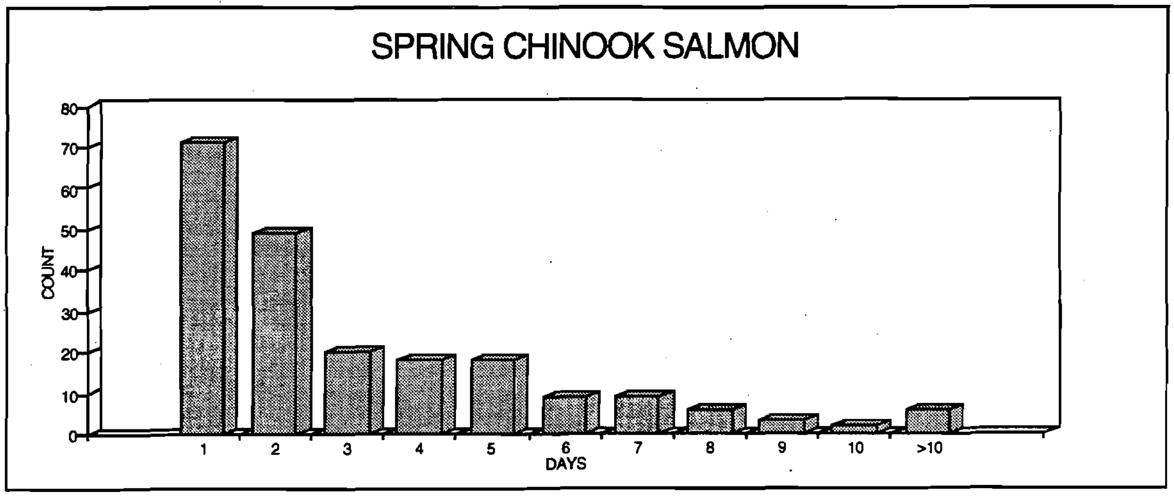
APPENDIX D

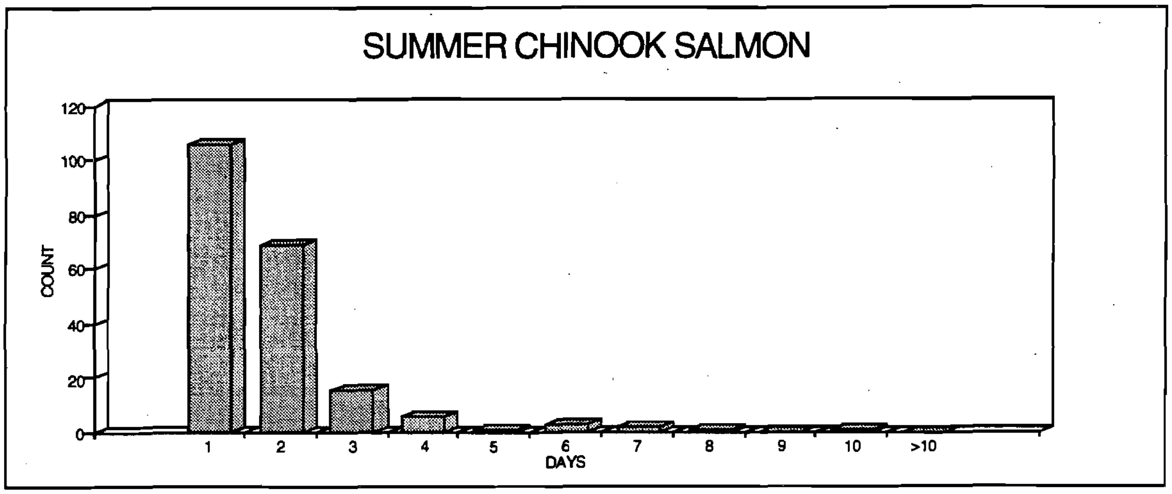
Dam Passage Time

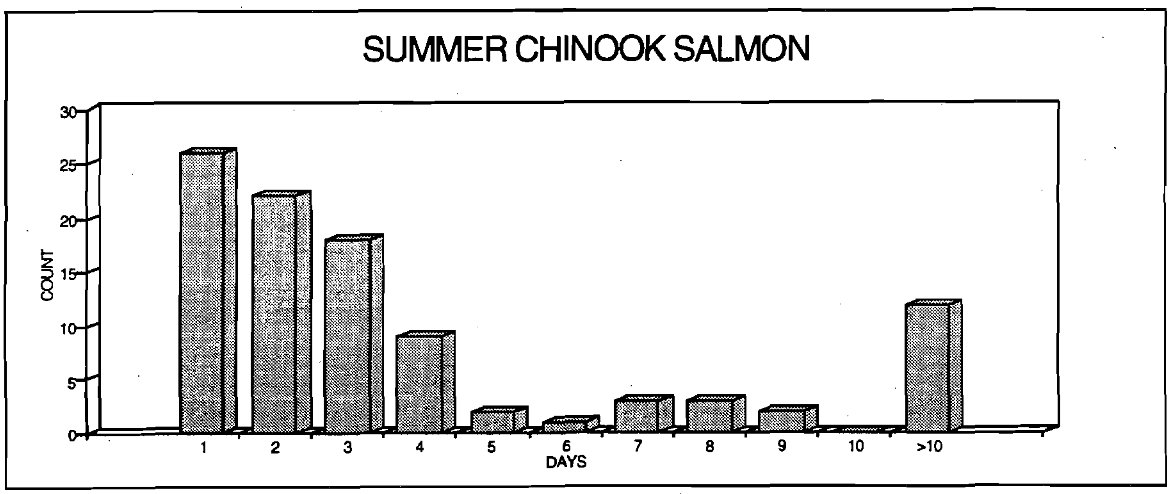




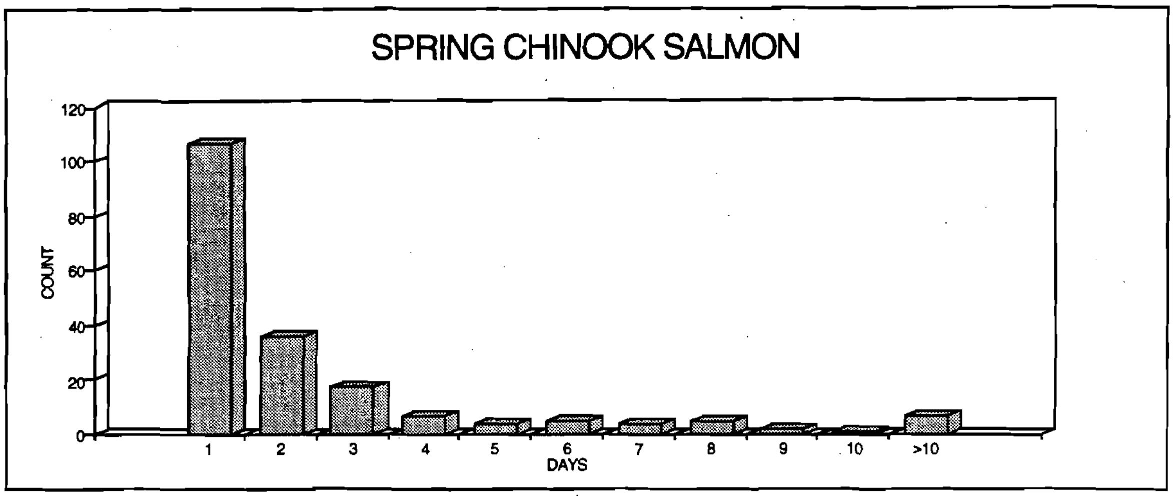
Appendix Figure D1.--Radio-tagged chinook salmon total passage times at Priest Rapids Dam, 1993.

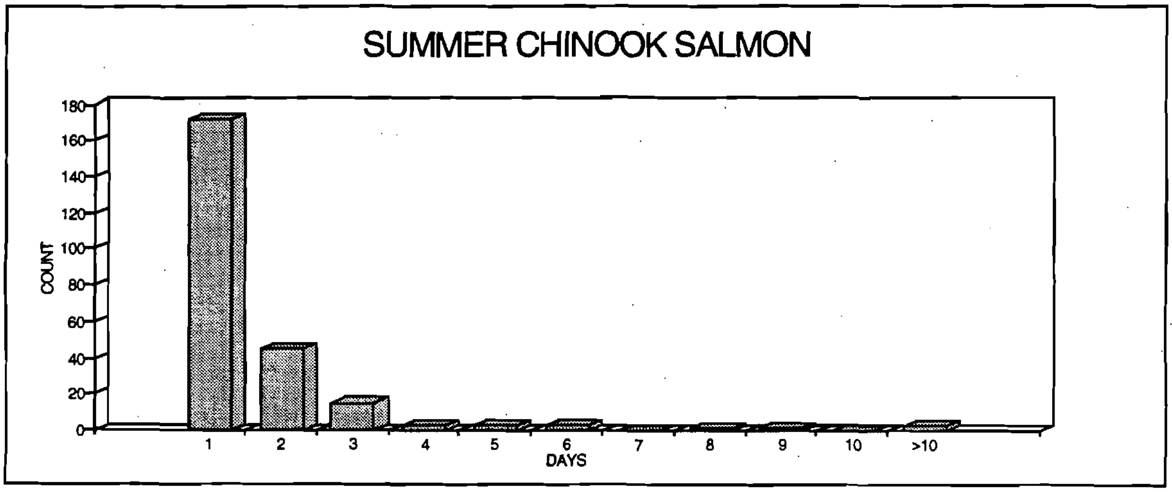


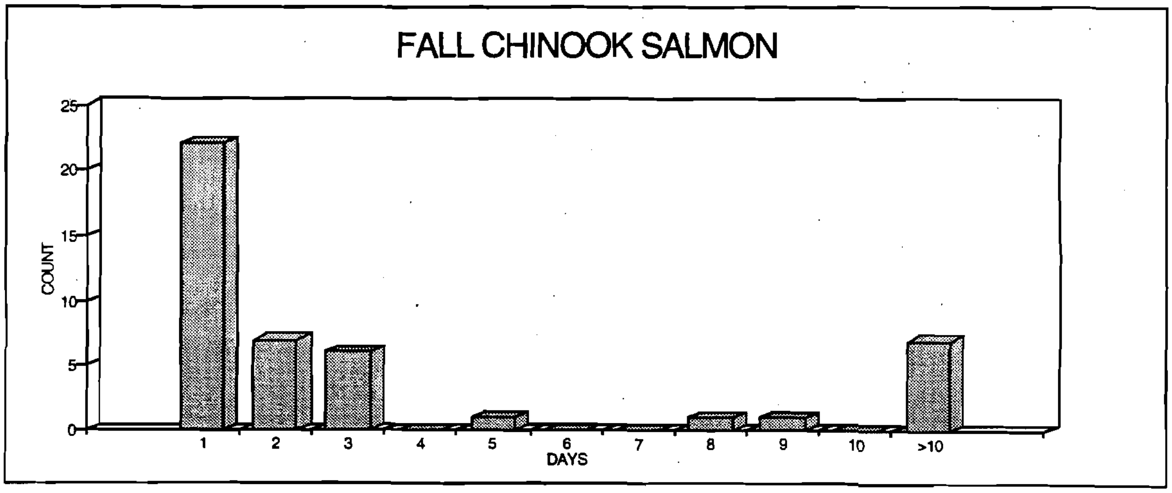




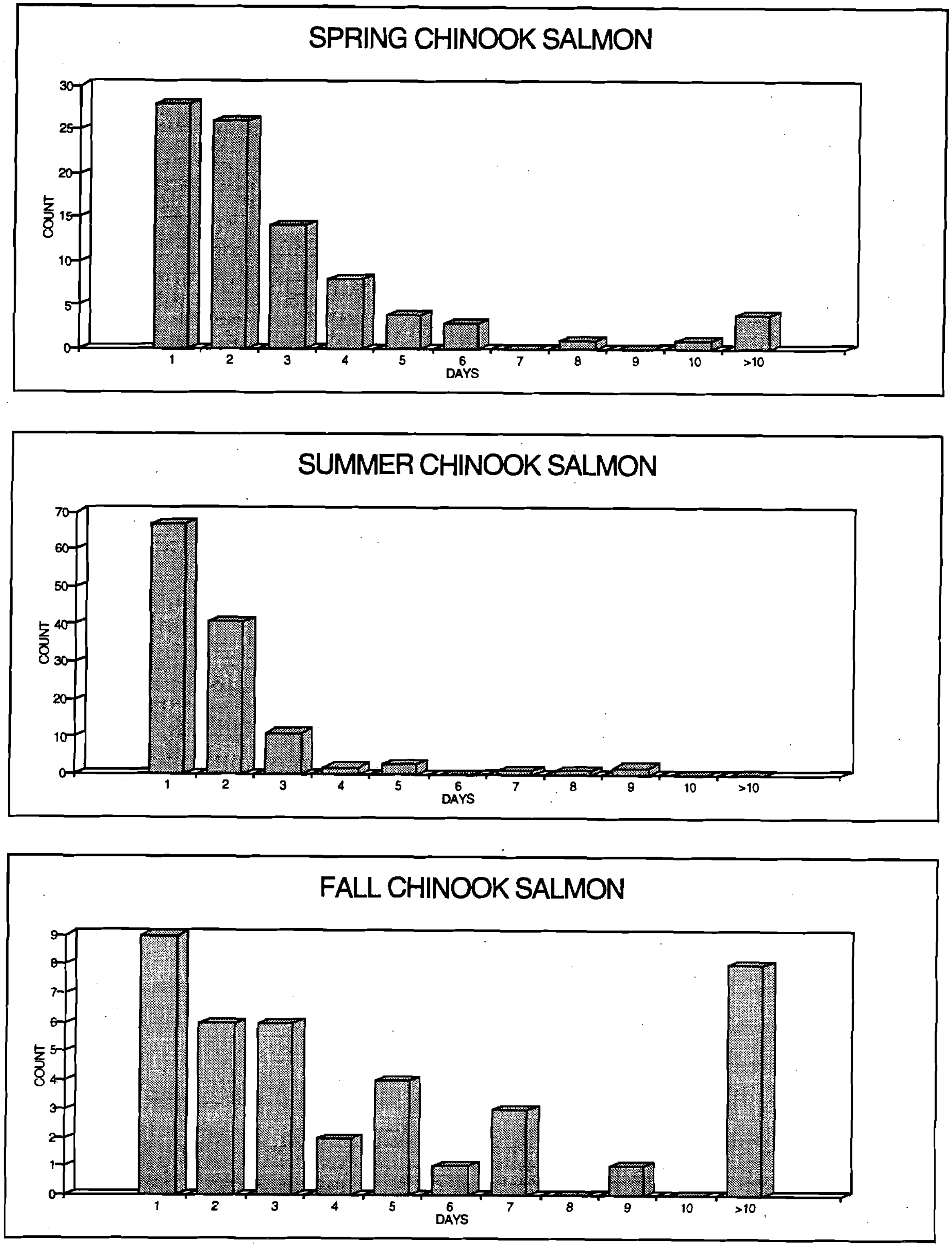
Appendix Figure D2.--Radio-tagged chinook salmon total passage times at Wanapum Dam, 1993.



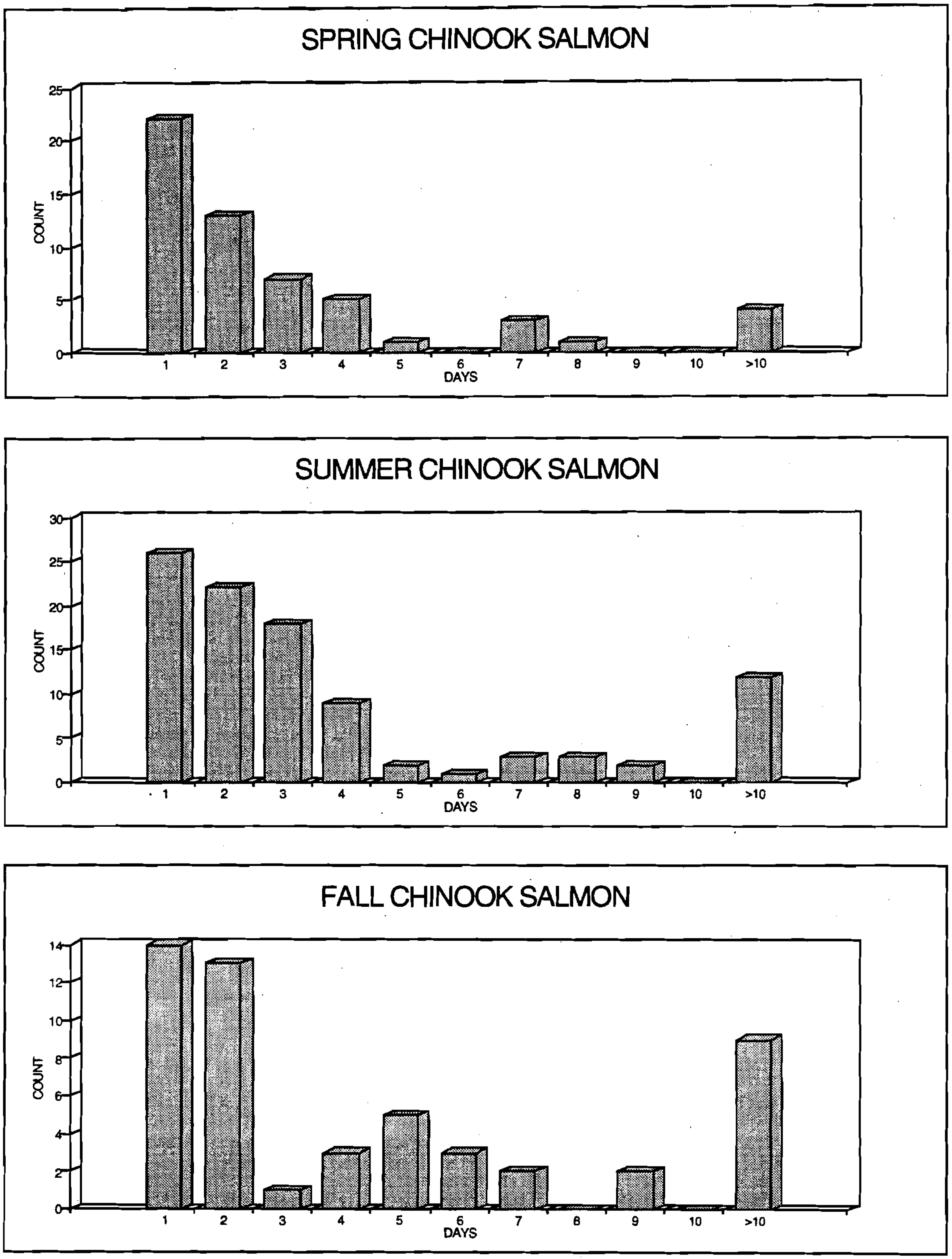




Appendix Figure D3.--Radio-tagged chinook salmon total passage times at Rock Island Dam, 1993.



Appendix Figure D4.--Radio-tagged chinook salmon total passage time at Rocky Reach Dam, 1993.



Appendix Figure D5.--Radio-tagged chinook salmon total passage times at Wells Dam, 1993.

STATE OF WASHINGTON
DEPARTMENT OF FISHERIES AND WILDLIFE
COLUMBIA RIVER PROGRAM

DECEMBER 8, 1994

MEMORANDUM

TO: **Chris Carlson, Senior Fisheries Biologist**
Grant County PUD

FROM: Rod Woodin RW

SUBJECT: Comments for draft report: MIGRATIONAL CHARACTERISTICS OF ADULT SPRING ,SUMMER,AND FALL CHINOOK SALMON PASSING THROUGH RESERVOIRS AND DAMS OF THE MID-COLUMBIA RIVER

GENERAL COMMENTS

The report is well organized and clearly written. It represents an excellent effort for summarization and presentation of a voluminous data base.

SPECIFIC COMMENTS

P.19. Results and Discussion. Since the time/location patterns of adult fish activity are the principal data being assessed, much more information should be presented on the timing of initial marking and the relationship of marking activity to "run at large". This should be done for each chinook race and marking site. If the John Day marking data is presented in another report, the appropriate portions of the report could be included as an appendix. In general the Median, Maximum and Minimum statistics presented are useful descriptive data for the population at large. I realize that the data base for this report is awkward and difficult to work with, however more detail on the fish which had passage times greater than the Median may be useful in identifying problem areas. The Maximums **far** exceed the Medians in most of the passage categories. Any common behavior patterns for fish at or near the maximums may be more illustrative of facility problems than medians.

P.24. Travel Time. It should be specified that Median data is being presented.

P. 25 Table 3. This comment applies to all travel time tables. It is physically impossible for any time intervals between two points to be **zero**. Either data is being included for fish which were not detected at one of the two points of the interval of interest or the time was less than the minimum measurement which appears to be 0.1 hours. This should be cleared up and corrected! There should not be zero values in the travel time tables. Also in several of these tables there are greater values for channel exit than for total passage time. These values are in the max. column. This is probably due to fish which entered the collection channel but did not pass the dam. If so a footnote should be included to clarify this issue.

P.37. Figure 8. This is a helpful illustration. It would be more useful if it were enlarged.

P.38. Table 8. This is the first specific indication that the fish marked at Priest Rapids and Rocky Reach are being utilized in the data base. The segregation of these fish as done here seems appropriate. These fish should probably also be segregated in the Travel Time tables (if they were included). If the authors have a convincing rationale for not segregating the fish marked at Priest Rapids and Rocky Reach it should be presented in the methods discussion. Also, was there a cross check done to verify that no fish detected or tagged in the Mid-Columbia entered the Snake River? That appears to be the case from table 8.

P. 73. Fate of Radio-Tagged Fish. The fall chinook discussion should include the fallbacks at Priest Rapids. from the fallback description it appears that about 10% of the fall chinook had a final "fate" of mainstem below Priest Rapids.

P. 73. para.3. What is the threshold for significance in passage delay? I did not see this defined! Median values for passage do look reasonable in most cases. Some of the greater than median values in and around the collection channels could be a concern! More information on these timing distributions could be useful.

P. 74. para.1. The statement regarding selection of left-bank ladders can not apply at Rocky Reach. It only has one ladder which is on the right bank. Statement should be modified.

P. 75. Recommendations.
1) This recommendation appears out of place! There is no rationale or data summary presented to justify such a radical recommendation! Also if such recommendations are to be made they must be specific to each dam and specify a mechanism for accomplishment of the recommended operating strategy. My review of the report leads me to the conclusion that substantial positive passage occurs via entrances other than those nearest the base of the ladder(s) at Priest Rapids, Wanapum and Rocky Reach.

2) This recommendation is interesting, but, are the logistics of such flow modifications within the realm of practicability? The diffuser flow systems are literally cast in concrete.

3) The concept of more accurate data is desirable. However, unless there is high annual variability in fallback, the existing data base should be a highly reliable **index** of escapement.

P. 107. Appendix C. The inclusion of sample size for each of these figures would be helpful.

Thank you for the opportunity to provide comment on this draft report. If you have question regarding this response please call at (206) 586-4345.

FISH PASSAGE CENTER
2501 S.W. FIRST AVE. • SUITE 230 • PORTLAND, OR 97201-4752
PHONE (503) 230-4099 • FAX (503) 230-7559

MEMORANDUM

DATE: January 9, 1995

TO: Chris Carlson, Sr. Fisheries Biologist
Grant Co. PUD

FROM: Larry Basham, FPC

RE: Comments on 1993 Radio Telemetry Study Conducted by NMFS at the Mid-Columbia Dams and Tributaries Entitled: MIGRATIONAL CHARACTERISTICS OF ADULT SPRING, SUMMER, AND FALL CHINOOK SALMON PASSING THROUGH RESERVOIRS AND DAMS OF THE MID-COLUMBIA RIVER.

I'm sure that the data base provided a tremendous amount of information to sift through in order to confine the report to the objectives listed, and the authors summarized the data in a fairly well-organized manner. My comments will be directed mainly to the Recommendation Section, but general or specific comments will be listed as well. Editorial changes are made on the draft report and attached to this memo. I received a copy of Rod Woodin's comments regarding the report and basically agree with the changes he recommended, but will expand ideas I have on the recommendations which the authors proposed.

COMMENTS

In general, nomenclature of main fishway entrance and orifice gates should be consistent with the design drawings. There were some differences in this report, which made it somewhat confusing to follow where and what the authors were referring to at the various fishways. The author should recheck to confirm labelings.

Also, it might be beneficial to give a brief description of the adult fishways at each project, e.g., see project descriptions of adult fishways in the 1994 Draft DFOP for the mid-Columbia dams.

p. 4 & 8. - It would be helpful if the authors included a Figure that illustrated size of the radio tag and tagging procedure.

p. 7 & 9. - Label Figures 3 & 4 (Plan View, Sectional, etc.) similar to Figure 2.

p. 46, 48, 54, & 59. - Figures 12, 14, 19, and 23 need clarification in their labeling. Does the author mean that 100% of the fish at the Rock Island Dam's Center and Left Powerhouse ladders fell out of the channel before ascending the fish ladder; I doubt it.

p. 55, 57, 58, & 59. - Figures 20, 21, 22, and 23 should change OPE labels on OPE4, OPE5, and OPE6 to OPE16, OPE18, and OPE20 to coincide with the actual openings at the project.

p. 50. - Figure 15 lists LEW (Left Entrance Weir); it does not exist at Wanapum Dam. Mislabel.

p. 49. - The text does not even list the left bank fishway or the center fishway. To help clarify the right bank fishway entrances, I suggest that the author consider renaming the RPE to RBLPE, as this entrance is on the right bank and actually is located at the left end of the powerhouse.

p. 16. - The terms listed on page 16 are keys to understanding what the author is trying to portray and should be noted by bullets, underlining, or bold print.

p. 19. - Under the heading **Fallback**, the authors assigned a route to below the project for each fallback; however, no record of which avenue of fallback is listed in a table or in the text. No mention was given of spill Q during daytime hours. This may or may not be a factor but should be given consideration since mortality of a fish over a spillbay would certainly be less than through a turbine unit.

p. 20. - The authors listed that the run timing of spring and summer chinook at the Wenatchee River, Priest Rapids, Wanapum, and Rock Island dams was considerably more advanced than run timing for fish that passed Rocky Reach and Wells dams. Does this mean there was a problem in passage at the lower dams or was the difference due to tagging (Fig. 7), or is this insignificant?

p. 26. - A handling associated delay was suggested by the authors. Part of the delay could be due to the time of day and specifically when the tagged individual was released at the Priest Rapids trapping site. I suspect that part of any delay is due to time of release of an individual fish which has been anesthetized and is recovering from that stress. Did fish released late in the afternoon take 10-12 h longer to make it to Wanapum Dam than fish released during the morning hours? Additional detail should be added to the report.

p. 30. - It should be noted that the ladders at Rock Island Dam are about half the height of the other dams, and one would expect salmon to pass this project more quickly than at the higher head dams.

p. 35. - After the first paragraph, a new heading should be placed to denote a general summary of the passage through the projects and reservoirs.

p. 56. - The authors should break out the passage between the two LPEs at Rocky Reach Dam. It is also unclear in the text whether the fish entering the LPEs and moving to the junction pool area turn around and drop back out the LPEs or through the OGs along the powerhouse channel. This should be clarified.

p. 65 & 68. - Combine Table 13 with Table 11.

p. 64-71. - It appears that fallback was a problem at some dams: Priest Rapids & Wanapum during the spring passage season (apparently most fallbacks were from Ringold Hatchery), Wells Dam during the summer, and four of the five projects during the fall season had fallback rates of near 11% and up to 21%. The authors should determine route of fallback during these time frames. The other question that will face fish passage specialists, is whether or not this fallback can be reduced at the various dams and whether a safer fallback route is available for fish which overshoot a tributary or hatchery located below the dam. This information should alert managers that fallbacks and overcounts are occurring at individual projects.

p. 73. - The authors indicated that there was no significant delay associated with various routes of passage. Based on the tables, some of the fish spend considerable time attempting to pass through a collection channel. Delay should be qualified and defined by the authors since there are fish that take considerable time to pass the projects.

RECOMMENDATION SECTION

p. 75. - In the first recommendation by NMFS, closure of all collection channel openings, with the exception of the main openings closest to the base of the fish ladders, was recommended for improving adult fish passage. Does this include closing gates LEW-2 at Priest Rapids, SE-3 at Wanapum, the left powerhouse entrance and the downstream entrance at the right bank fishway at Rock Island, the spillway and the right powerhouse entrance at Rocky Reach Dam? Not only would this be debatable, but would likely be detrimental to adult fish passage. Without a test to assess a radical change in operation, the proposed closure could result in a total block of fish passing a facility, e.g., if powerhouse units, particularly Unit 10 at Priest Rapids, were operated at an overload condition, passage through the LEW-4 gate could be completely blocked with no other gates open to pass fish. The 1993 study did not test turbine unit operation and as such I question whether a blanket recommendation could ever be accepted without further testing to validate a change such as recommended.

I believe that any reduction in flow from the orifice gates should be followed by adding flow to the main fishway entrances. Even then, this premise needs careful consideration since flows added into a particular area (junction pool) may cause fish to reject or refuse passage through an area.

I also do not agree that main entrances such as LEW-2 should be closed. For an example, during the past year or two, there were times when LEW-4 was closed (repairs required), and adult passage appeared satisfactory when using the far entrance and orifice gates to attract fish to the channel and up past the counting station. Although this does not prove that passage was improved without operating LEW-4 (closest to main fish ladder), it did show that fish passed through the channel at a "satisfactory" rate while the LEW-4 was out of service.

I am certainly open to closure of some orifice gates at each project, but don't believe the study would indicate closure of all orifices.

Recommendation 2 from NMFS, which was to modify flows between the openings and the base of the fish ladders and moving the diffuser flows upstream and closer to the base of the fish ladder, would require lots of dollars, logistical concerns, hydraulic concerns and possibly constraints; I am assuming that potentially wall diffusers would replace floor diffusers. Whether this would be the panacea to improve passage through the junction pools and into the fish ladders must be evaluated. At present, there are wall diffusers at Rock Island Right Bank Fishway and both fishways at Wells Dam. The authors should pursue this issue further. Adding several thousand cfs of water to a small localized area will not promote a smooth laminar flow.

Recommendation 3 from the report related to fallback of fish at the project and resulting over counts of fish passing a project. This report was the first real data to show that fallback exists at each of the mid-Columbia dams. As earlier stated, I believe that managers will now be more aware that fallback occurs and counts at a project may be inflated. If fish were available for additional radio telemetry studies, fallback could be indexed over a range of flows and spill throughout a series of years; however I must be dreaming to think that a study or better yet, that sufficient salmon would be available to even have fish available to mark for a test.

Some items not noted in the report:

- effects of turbine unit operation on fish passage at each project.
  flow levels through the powerhouse, spillway, and combinations thereof that affect fish behavior, i.e., passage into a particular entrance of a fishway.
- I believe that at Wells Dam only one of the two gates at the east and west bank fishways is required to improve fish passage. It appears that opening the end gates to a maximum of 8.0 feet open would supply more attraction flow and hopefully less fallout from the entrance channel than using the side gate as well. It may be that the inside gates (also open 8.0 feet) would be the best to use during non spill periods. Again, this should be brought up in the proper forum for discussion and hopefully tested if and when another radio telemetry study is proposed.
- Based on visual observation only, I believe that removing Orifice Gate 20 at the right end of the Rocky Reach powerhouse would provide much better passage and attraction conditions for adult fish than continued operation of both RPEs. The flow from the open slot would project into the tailrace at a better angle than flow from the RPEs. This should be tested in future telemetry studies.
- Related to the second item above, daytime spill and its effect on passage, fallback level, and overall fish passage should be covered in this report or another short report.
- Also, in-season data transmission was not covered in the report. It would be very helpful in future studies to improve data collection and transmission (table form) throughout the fish passage season if possible.

The Fish Passage Center appreciated the opportunity to comment on the Draft NMFS Radio Telemetry Study conducted in the Mid-Columbia River during the 1993 adult fish passage season. Please feel free to call me if there are questions regarding these comments. My phone number is (503) 230-4287.

SUBJECT: Response to comments on draft report: MIGRATIONAL CHARACTERISTICS OF ADULT SPRING, SUMMER, AND FALL CHINOOK SALMON PASSING THROUGH RESERVOIRS AND DAMS OF THE MID-COLUMBIA RIVER.

Rod Woodin's comments (December 8, 1994)

P.19. Results and Discussion. Text was added to pages 20 and 24 to explain differences between the number of spring chinook salmon passing John Day Dam and the number of fish tagged throughout the run.

Appendix D was added to show the distribution of total passage times for each race at each dam. Given that the median passage times at the mid-Columbia River dams were within the range observed at other mainstem Columbia River dams, detailed analysis of individual passage problems was not completed.

P.24. Travel Time. The word median was added to the text as appropriate.

P.25. Table 3. Zero values were changed to <0.1 in the travel time tables. Very short (seconds) transitions between at dam sites were previously reported as 0 hours of time.

An asterisk was added to each travel time table for maximum individual passage times that were greater than the maximum total dam passage time.

P.37. Figure 8. Figure 8 was enlarged.

P.38.Table 8. Text was added to page 17 to explain why fish marked at Priest Rapids and Rocky Reach Dams were not separated in the travel time tables.

Fish with fates in the Snake River were included in the last location tables.

P.73. Fate of Radio-tagged Fish. Text on pages 72 and 73 addresses fallback of fall chinook salmon at Priest Rapids Dam. No changes were made.

P. 73 para.3. There is no information on when total passage time at a dam becomes significant. The medians passage times in this report are within the range of those observed at other Columbia River dams. No changes were made in response to this comment. The word delay was removed from the report. It was replaced with an appropriate travel time estimate.

P.74. para.1. The text on page 72 was changed to qualify the right bank ladder at Rocky Reach Dam.

P.75. Recommendations. 1) The rationale for the first recommendation follows the recommendation. In addition, nearly every evaluation of adult collection channels has recommended closure of openings to the long powerhouse channels. Despite those recommendations, very little has been done.

This study was designed to identify areas where there may be concerns about adult passage at the mid-Columbia River dams. The area with the greatest potential for reducing total passage time at the dam is between the junction pool and the base of the fish ladders. Each dam has different physical structure and flows in that area. The engineering of structure and flows is beyond the scope of this research project and was not addressed.

At dams with long adult collection channels across the face of the powerhouse, there is substantial net positive entrances occurring at the distal end of the channels. Our analysis indicates that this activity may be at great expense to total passage time at the dams.

Recommendation. 2) No changes were made based on this concern. The engineering of structure and flows is beyond the scope of this research project.

Recommendation. 3) No changes were made based on this concern. The fallback estimates obtained in 1993 may be good for the conditions that existed. However, changes in daytime spill rate, total river discharge, and the success of the Ringold Hatchery program will cause major deviations from the 1993 estimates.

P.107. Appendix C. Sample size (N) was added to each figure in Appendix C.

Larry Basham's comments (January 9,1995)

COMMENTS The nomenclature of the main fishway entrances and orifice gates were changed based on the recommendations given.

No changes were made to the description of the adult fishways. Drawings of the facility at each dam are presented in Appendix A.

p. 4 & 8. Information on the tag size and weight were already given in the text (page 4) and tagging procedure was described on page 8. No figures were added to supplement this information.

p. 7 & 9. The labels for Figures 3 and 4 were changed.

p. 46, 48, 54, & 59. The titles for the base-of-the-fish-ladder figures were changed to reflect the formula (2) in the Methods section.

p. 55, 57, 58, & 59. Nomenclature changes were made in the text and figures.

p. 50. The error in the title for Figure 15 was corrected.

p. 49. Text was added to the report to address the information at the center and left fish ladders.

p. 16. Bullets and bold print were added to the definitions of dam passage terms.

p. 19. Determination of fallback location was not possible due to long periods between fish ladder exits and the next record downstream from the dams. Fallback location was removed from the Methods section of the report.

p. 20. Two areas come to mind when addressing run timing of individual stocks. The first is which stocks are being harvested in limited seasons. The second is the selection of brood stock at the dams that have adult collection facilities.

p. 26. Fish tagged at Priest Rapids Dam had significantly longer travel times to Wanapum Dam than fish tagged at John Day Dam whether released in the morning or afternoon. No changes were made.

p. 30. Ladder passage time at the Snake and Columbia River dams is the same regardless of ladder height or length. Counting stations likely affect passage time much more than ladder height or length. No changes were made.

p.35. The general summary information was moved to the Summary section of the report.

p. 56. Net passage rates at the two LPEs at Rocky Reach Dam were separated and new figures created.

p. 65 & 68. Tables 11 and 13 have been combined.

p. 64-71. Because fallback routes could not be determined, no changes were made.

p. 73. "Delay" was removed from the report and the appropriate passage time estimates were inserted.

p. 75. Virtually every study on adult collection channels has recommended closure of orifices. Given the fish behavior observed in this study, we believe our first recommendation should be evaluated as a means of reducing the passage time associated with multiple entries and wandering in the adult collection channels.

Items not noted in the report:

First bullet - Based on total passage times and an interest in timely completion of the report, we did not attempt to correlate fish behavior with dam operating conditions.

Fourth bullet - Due to the long period between ladder exit and verification of a fallback below the dams, fallback times and locations could not be determined. In addition, cause and effect cannot be determined from uncontrolled tests of fish behavior during 1 year's spill conditions. Studies with test and control observations over a wide range of flows are needed before observations will become meaningful.

Fifth bullet - We are somewhat unsure about the meaning of "data transmission" in this bullet. We added a sentence to the end of the radio-tracking section (page 10) to indicate how the data were moved to the Pasco, WA data center. If the intent was to have raw data available outside of the research group, the nature of radio-telemetry raw data (RF noise) precludes this turn-key approach. Preliminary summaries are highly unreliable, take immense amounts of time, and lead to premature conclusions that may not be supported in a final report.

We appreciate the comments of the reviewers. The quality of this and future telemetry studies will benefit from their comments.