MAINSTEM CLEARWATER RIVER STUDY: ASSESSMENT FOR SALMONID SPAWNING, INCUBATING, AND REARING

Final Report

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The Nez Perce Tribe sub-contracted with EBASCO Environmental during this study to develop capabilities for predicting fish habitat conditions in the lower mainstem Clearwater River under a limited range of discharge regimes from Dworshak Dam. The Nez Perce Tribe used this information to analyze a range of discharges from Dworshak Dam for anadromous fish habitat requirements. The Tribe's analysis does not necessarily reflect views of EBASCO Environmental.

Flow analyses provided to the Bonneville Power Administration and/or U.S. Army Corps of Engineers within this report on the lower mainstem Clearwater River shall in no way limit or influence future water rights claims or flow recommendations made by the Nez Perce Tribe for any purposes. Flows analyzed in this report are independent of conditions for upstream or downstream anadromous fish migration and of any other purposes not specifically stated.

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EXECUTIVE SUMMARY

The purpose of this study was to assess salmonid spawning, incubation, and rearing in the lower 61 kilometers (km) of the lower mainstem Clearwater River (LMCR), Idaho. The Northwest Power Planning Council amended the 1987 Columbia Basin Fish and Wildlife Program to include this project under measure 703(c)(3). This third and final report presents information collected on the LMCR from 1988 to 1991. Flow proposals developed in this report are for anadromous fish holding, spawning, incubation, and rearing and do not address flows for upstream or downstream anadromous fish migration, flows for other fishes, or flows for any other purposes.

Hydroelectric development within the Columbia River Basin caused a major depletion of anadromous fish runs. This depletion can be attributed primarily to passage problems and habitat loss. Inadequate fish passage facilities at the Washington Water Power (WWP) Diversion Dam at LMCR km 5 decimated the chinook salmon populations. The removal of the WWP Dam and construction of Dworshak Dam on the North Fork Clearwater River in 1971 markedly affected the LMCR's potential for natural anadromous fish production. Although fish could pass freely after the WWP Dam was removed, the existence and operation of Dworshak Dam eliminated access to the North Fork spawning habitat and changed the temperature and flow regime of the LMCR.

As partial mitigation for anadromous fish losses in the North Fork, Dworshak National Fish Hatchery (DNFH) was constructed near the confluence of the North Fork Clearwater River and the LMCR at river km 65.4. DNFH has maintained the North Fork steelhead trout stock through smolt releases since 1970. Kooskia National Fish Hatchery (KNFH), located 48 km upriver from DNFH on the Middle Fork Clearwater River, began producing spring chinook salmon smolts in 1972. DNFH also began spring chinook salmon production in 1982. Combined spring chinook adult returns to KNFH and DNFH since 1984 have ranged from a low of 423 in 1984 to a high of 2,704 in 1987. Because smolts are imprinted to hatchery water and naturally producing spring chinook and steelhead generally prefer spawning habitat conditions in smaller tributaries, few adults utilize the LMCR for spawning. Also, limited restoration efforts in the Clearwater River Subbasin were concentrated in more pristine headwater tributaries and none were directed towards production in the mainstem river. However, fall chinook spawning has been documented on the LMCR in recent years.

We studied both summer and fall chinook salmon because these stocks are escaping to Idaho's spawning habitat in threateningly low numbers and can spawn in rivers the size of the LMCR. Also, during 1991 these stocks in Idaho were proposed for listing as threatened or endangered by the Federal Endangered Species Act of 1973.

Our objectives from 1988 to 1991 were to:

1) Quantify and qualify the existing anadromous salmonid spawning and rearing habitat in the LMCR and develop capabilities to predict habitat conditions under a number of Dworshak Dam discharge regimes:

2) Document the use of the LMCR by anadromous and non-anadromous fish;

3) Investigate the incubation, rearing, and outmigration timing of fall and summer chinook salmon:

4) Use the information generated by objectives 1 - 3 to identify potential outplanting stocks of fall and/or summer chinook salmon for restoration or supplementation efforts; and

5) Determine habitat conditions for selected anadromous fish stocks under existing flow and temperature releases from Dworshak Dam and evaluate flow and temperature release alternatives to restore chinook salmon stocks identified in this study.

The Instream Flow Incremental Methodology (IFIM) . hydraulic simulation model was used to define where velocities, depths, and substrate were adequate for chinook salmon spawning in the LMCR. The total area suitable for spawning was divided by 20.1 m^2, an area required for each spawning pair, to obtain 95,489 potential redds. Based on one pair of spawners per redd, the LMCR could potentially support 190,978 spawning chinook salmon. This is probably an overestimate since we did not consider downwelling hydraulics in the spawning substrate and all biological or behavioral aspects of production potential. A limiting factor for chinook salmon spawning on the LMCR may be armoring of substrate particles which typically occurs below dams. A possible spawning substrate enhancement strategy may be to mechanically loosen or break up the armor layering in key spawning areas.

We documented the quality of spawning habitat in the LMCR by collecting freeze-core substrate samples in two fall chinook spawning areas identified from aerial redd surveys. For comparison of the LMCR spawning substrate quality, we collected freeze-core samples in chinook salmon spawning areas on the lower Snake River, Idaho and the Wenatchee River, Washington. Other comparative freeze-core data on the South Fork Salmon River, Idaho was provided by the U.S. Forest Service. Spawning substrate quality on the LMCR was higher in the first stratum (10 cm deep) than all rivers sampled. The fredle index of substrate quality was higher in strata 2 and 3 (10-20 and 20-30 cm deep) than all rivers sampled. Percent fines (< 0.85 mm) were slightly higher in strata 2 and 3 on the LMCR compared to the Wenatchee and South Fork Salmon Rivers. The comparatively high spawning substrate quality in the LMCR should facilitate chinook salmon natural reproduction.

During fall chinook aerial redd surveys, we observed 21, 10, 4, and 4 redds from 1988 to 1991 on the LMCR. Surveys were conducted in mid-November and during the beginning of December. All redds were located in the lower 35 km of the study area where island sections and more favorable substrate particles predominate. Of the 39 redds observed during the past 4 years, 54% were associated with island areas which represented only a small percentage of the potential spawning area. Aerial redd surveys may not have detected deep water (> 3 m) redds in main channel spawning habitat. The low numbers and decline of fall chinook redds in the LMCR and Snake River in recent years exemplify the need for timely protective measures if we are prevent the extinction of this native salmon in Idaho.

Relative seasonal densities of fishes present in the LMCR during 1989 and 1990 were estimated by snorkeling and SCUBA diving. Juvenile salmonid densities were low compared to densities in Idaho streams with "excellent" classification for carrying capacity. Only 1 chinook salmon juvenile was observed in 1989; 54 were observed in 1990. Highest densities of rainbow/steelhead trout were observed during the summer in 1990 and numbered 14.5, 16.5, and 25.8/ha for wild fry (age 0+), wild juveniles (age 1+), and hatchery juveniles, respectively. Sampling primarily by snorkeling during 1990 may have overestimated densities for the entire LMCR. Salmonids were most abundant in the summer, declined considerably in the fall, and were not observed in the winter. Highest redside shiner densities (24,966/ha) were observed during the summer, 1990. Sucker (largescale and bridgelip) densities were highest during the summer in 1989 at 160/ha. Mountain whitefish densities were highest at 72.5/ha in the fall, 1990. Suckers and whitefish were the most numerous species observed during the winter, 1989 at 10.9 and 7.9/ha, respectively. Averaging densities during the summer and fall of 1989 and 1990, whitefish and sucker densities combined outnumbered juvenile salmonids approximately 10 to 1. The LMCR may better exemplify a migration corridor than an "excellent" rearing river. The LMCR lacks woody debris and boulder cover is limited. However, based on the productivity, the LMCR should be favorable for rearing salmonids.

We documented chinook salmon incubation timing in the LMCR by placing fertilized eggs in incubation boxes. Emergence (button-up) timing of Snake River fall chinook salmon (Lyon's Ferry Hatchery) on the LMCR was May 21 compared to approximately May 2 on the Snake River. Later emergence of fall chinook on LMCR could be attributed to colder November water temperatures as compared to the Snake River. South Fork Salmon River (SFSR) summer chinook salmon (McCall Hatchery) emerged November 30 on the LMCR. Warm September water temperatures in the LMCR accelerated SFSR summer chinook egg developmental rate. Upper Columbia River (UCR) summer chinook salmon (Wells Hatchery) emerged April 29 on the LMCR. Higher egg-to-smolt survival would be expected for the UCR summer chinook and the Snake River fall chinook salmon than for the SFSR summer chinook in the LMCR.

We attempted to relate survival to hatch of three chinook salmon stocks to intergravel dissolved oxygen and temperature, and sedimentation in artificial redds on the LMCR. Other than high September water temperatures (18.5 °C) possibly affecting the survival of SFSR summer chinook, intergravel temperatures and dissolved oxygen were favorable throughout incubation. The intrusion basket technique biased chinook salmon embryo survival and therefore impeded direct survival measurements. However, intrusion baskets appeared to provide an adequate measure of fine sediment accumulation into redds. With the relatively low percent fines (< 0.85 mm) that accumulated in baskets and high fredle index of substrate quality calculated for baskets after chinook salmon hatched, high survival to emergence would be expected on the LMCR.

The original goal of our smolt outmigration timing study was to document Snake River fall chinook (Lyon's Ferry Hatchery) outmigration timing through a summer release of PIT-tagged parr in the LMCR. Unfortunately, we were unable to obtain fall chinook and alternatively used DNFH spring chinook subyearlings. We PIT-tagged and panjet marked 3,956 spring chinook parr and another 3,990 non-tagged parr served as a control to assess effects of tagging on mortality and behavior. We held both groups at DNFH for two weeks and released them into a side channel at the LMCR Potlatch River site in October. PIT-tagging did not contribute to any short-term mortality. Emigration of parr out of the side channel was immediate as snorkeling resulted in only 106 parr observed one day following release. A total of 526 (13.3%) of our PIT-tagged parr were detected the following spring at Lower Granite, Little Goose, and McNary Dams. Peak migration was April 14, April 25, and May 4 at these dams, respectively. Based on an estimated fish guidance efficiency of 57.3% and turbine mortality was 11% at all Snake River dams, overwinter survival of PIT-tagged spring chinook parr in the LMCR and/or Snake River pools was conservatively estimated at 25%.

Although efforts have not been attempted to supplement chinook salmon production in the LMCR, we did document limited fall chinook spawning in recent years. Whether these fish are naturally spawning Clearwater or Snake River stocks, Lyon's Ferry Hatchery stock, or a combination of stocks has not been determined. The upper Columbia River summer chinook may be an excellent candidate for the LMCR based on incubation timing. The Snake River fall chinook may smolt and outmigrate during unfavorable low flow and temperature conditions. However, given alternative flow and temperature releases from Dworshak Dam, incubation and outmigrating conditions may be improved for fall chinook salmon in the LMCR. Additional research is needed on growth rates and outmigration timing of fall chinook salmon in the LMCR.

Because limited fall chinook salmon spawning has been documented in the LMCR in recent years and because declining numbers in Idaho has caused this stock to be proposed as threatened or endangered by the Federal Endangered Species Act of 1973, the Snake River fall chinook should be considered a prime candidate for natural reproduction development in the LMCR. We found the quantity and quality of LMCR physical habitat was more than adequate for facilitating chinook salmon natural reproduction. We recommend Lyon's Ferry Hatchery fish (Snake River stock) for experimental releases in the LMCR.

The Stream Network Temperature Model (SNTEMP) and Physical Habitat Simulation Model (PHABSIM) were used to model temperatures and habitat on the LMCR under a number of Dworshak Dam release alternatives. We simulated hydraulic and habitat characteristics of the LMCR to quantify and analyze relationships between anadromous fish holding, spawning and rearing habitat versus discharge. Results of temperature, hydraulic, and habitat modeling were used to evaluate effects of current Dworshak Dam operating conditions on anadromous fish habitat in the LMCR. We also used the results to explore alternative flow regimes which might benefit existing and potential anadromous fish stocks.

Proposed total river discharges for the LMCR are based on optimal flows that provide maximum habitat area values for all target species and their life stages. In consideration of Dworshak Dam and Dworshak National Fish Hatchery operations and unregulated inflow patterns from the upper mainstem Clearwater River, the following LMCR total steady-state discharges at the Spalding Gaging Station and Dworshak Reservoir temperature releases would provide optimal habitat for critical target species and their life stages in the LMCR:

1) 142 cms (5,000 cfs) from July 1 through August 31 for spring chinook salmon adult holding and juvenile rearing, fall chinook rearing, and rainbow/steelhead trout rearing;

2) A Dworshak Reservoir release of 10 °C (50 °F) water from July 1 through September 15 for rearing salmonids. A 7.2 °C (45 °C) release would be optimal provided a Dworshak Reservoir water supply is available to Dworshak National Fish Hatchery;

3) 142 cms (5,000 cfs) from September 1 through October 31 for rainbow/steelhead trout rearing and adult steelhead trout and fall chinook holding:

4) 142 cms (5,000 cfs) from November 1 through December 15 for fall chinook spawning and rainbow/steelhead trout rearing and adult steelhead trout holding;

5) A Dworshak Reservoir release of the warmest water possible from November 1 through December 31 for fall chinook salmon incubation;

6) flows from December 15 through April 31 be maintained at maximum sustained flows that existed during fall chinook spawning (November 1 through December 15) for fall chinook incubation: and

7) higher flows that naturally occur in the LMCR during May and June would be required for steelhead trout and spring chinook salmon smolt outmigration.

INTRODUCTION

We studied chinook salmon *Oncorhynchus tshawytscha* enhancement or restoration potential for the lower 65 km (40 miles) of the lower mainstem Clearwater River (LMCR), Idaho. The Nez Perce Tribe Department of Fisheries Management and EBASCO Environmental conducted the research using Bonneville Power Administration funding. Our 1988 and 1989 annual reports (Connor 1989; Connor et al. 1990) detail the history of this study.

We concentrated on the anadromous fish production potential of the LMCR's physical habitat components. The physical habitat components considered included water depth, velocity, temperature, and substrate. Our study also included a biological component composed of chinook salmon egg incubation timing, seasonal fish densities, and chinook salmon parr/smolt survival studies. We believe these components are key to the LMCR's ability to sustain natural populations of summer *or* fall chinook salmon.

Originally, we selected summer and fall chinook salmon for study because they are escaping to Idaho's spawning habitat in threateningly low numbers (Fish Passage Center 1989; Irving and Bjornn 1980; Horner and Bjornn 1981) and they can spawn in large mainstem rivers (Fulton 1968). Also, evidence suggests these chinook stocks were decimated by the construction of the Washington Water Power Diversion Dam on the LMCR at river km 5 in 1927 (Parkhurst 1950). On October 27, 1927, the Lewiston Tribune reported "salmon 2-4 feet and 20 or 30 at a time were attempting to leap the dam's spill gates, as water was of insufficient height to flow through the fish ladder. No salmon were observed successfully jumping the dam". During 1991, these stocks in Idaho were proposed for listing as threatened or endangered by the Federal Endangered Species Act of 1973. The proposed listing further emphasized the need to determine whether or not the LMCR would-be suitable as an outplanting location for chinook salmon restoration or enhancement efforts.

Our study objectives from 1988 to 1991 were to:

1) Quantify and qualify the existing anadromous salmonid spawning and rearing habitat in the LMCR and develop capabilities to predict habitat conditions under a number of Dworshak Dam discharge regimes;

2) Document the use of the LMCR by anadromous and non-anadromous fish:

3) Investigate the incubation, rearing, and outmigration timing of fall and summer chinook salmon;

4) Use the information generated by objectives 1 - 3 to identify potential outplanting stocks of fall and/or summer chinook salmon for restoration or supplementation efforts; and

5) Determine habitat conditions for selected anadromous fish stocks under existing flow and temperature releases from Dworshak Dam and evaluate flow and temperature release alternatives to restore chinook salmon stocks identified in this study.

We arranged this final report into self-contained chapters entitled:

1) Description of Project Area

2) Chinook Salmon Aerial Redd Surveys

3) Chinook Salmon Egg Incubation Timing

4) Spawning Substrate Quality

5) Chinook Salmon Survival to Hatch

6) Fish Density Estimates

7) Smolt Outmigration Timing and Survival

8) Hydraulic Model

9) Fish Suitability Curves

10) Habitat Simulation Modeling

11) Spawning Habitat Quantification

12) Temperature Analysis

13) Conclusions and Recommendations

Additional data generated through the accomplishment of our objectives and not provided in this report may be obtained from the Bonneville Power Administration.

CHAPTER 1

DESCRIPTION OF THE PROJECT AREA

The lower mainstem Clearwater River (LMCR) project area began at the Clearwater Memorial Bridge at Lewiston, Idaho and extended approximately 61 km (38 mi) upriver to the North Fork Clearwater River confluence (Figure 1.1). We stratified the LMCR into the Potlatch River, Bedrock Creek, and Big Canyon segments based on flow regime and geomorphologic features. For a detailed description on river stratification and hydraulic simulation, see our 1989 annual report (Connor et al. 1990). Originally, the Big Canyon segment was named the North Fork segment, however we collected more data at the Big Canyon study site and changed the name accordingly in this report.

The morphology of the LMCR's channel has been influenced by a number of geological events leading to a variety of rock and soil types. During the Precambrian era, most of Idaho, including the Clearwater basin, was covered by a shallow sea (Asherin and Orme 1978). Subsequential folding, faulting and uplifting gave rise to the mountain formations in the basin's headwater reaches. These mountain ranges were formed primarily of metamorphosed sedimentary rocks of the Belt series and granitic intrusions of the Idaho Batholith (USACE 1975). Volcanic activity filled the lower valleys of the Clearwater basin with basalt flows (Asherin and Orme 1978), and is probably responsible for the basalt and granite composition of the LMCR's channel.

Winters with little snow accumulation and summers that are hot and dry predominate in the lower portions of the Clearwater basin. Precipitation usually occurs in the late fall-winter and spring periods over much of the area. Average precipitation in the Clearwater basin varies from 36 cm (14 inches) at the mouth of the LMCR (Asherin and Orme 1978) to 178 cm (70 inches) near the summit of the Bitterroot Range (USACE 1986). Prevailing winds are westerly from the Pacific Ocean and can carry moist air masses over much of the area. Average annual temperature is 10 °C (50 °F) in the lower Clearwater basin (USACE 1975), however, winter polar air masses produce air temperatures as low as -34° C (-29° F) (USACE 1986). Historically, these cold winter periods commonly produced ice build-up in the LMCR (USACE 1986).

It is believed that the establishment of a permanent botanical community in the riparian zone of the LMCR was precluded by the scouring effect of these ice jams (Kronemann and Lawrence 1988). However, annual forbs, grasses, shrubs and vines are currently colonizing the

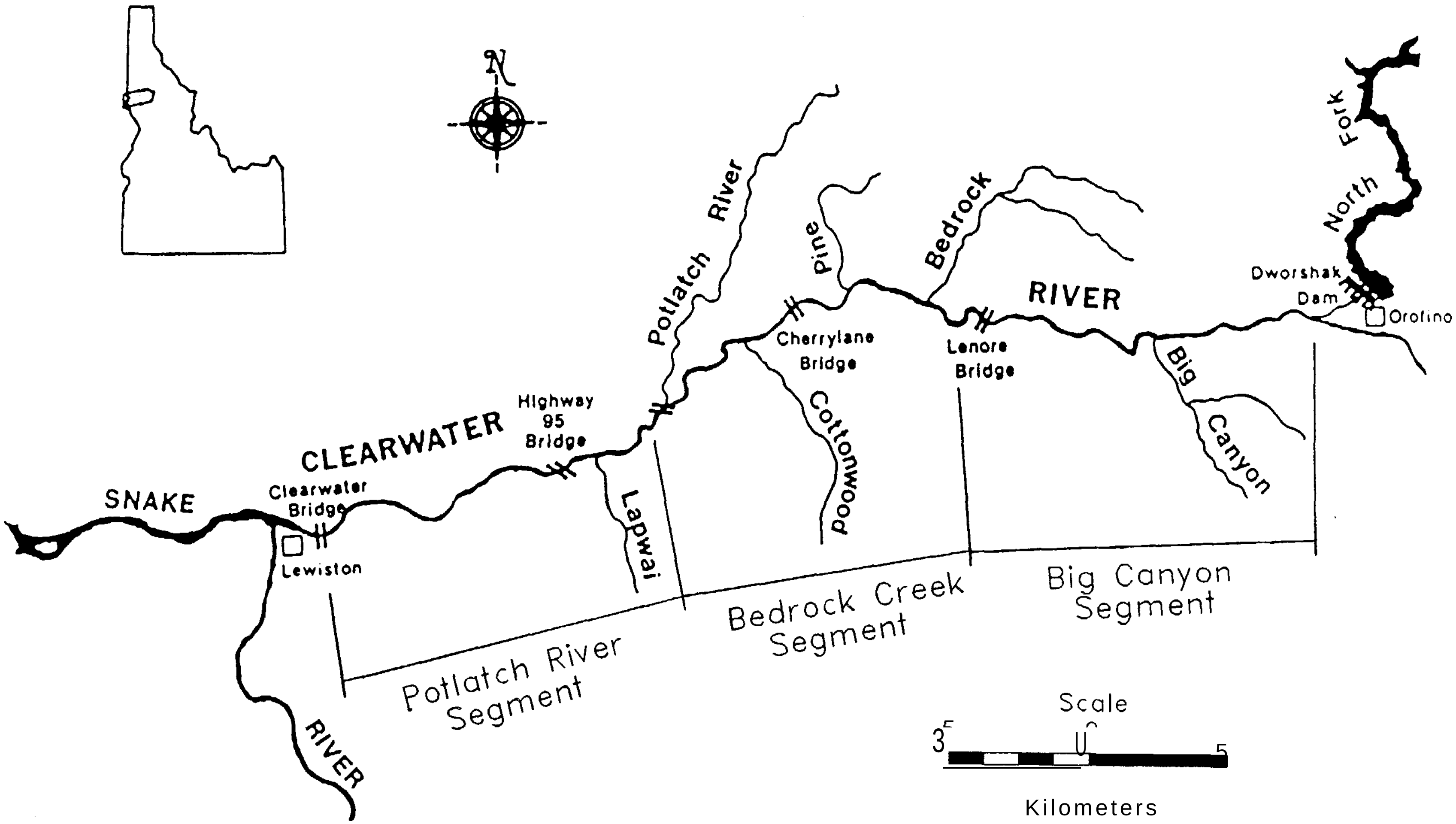


Figure 1.1. Lower mainstem Clearwater River (LMCR) project area divided into the Potlatch River Bedrock Creek, and Big Canyon Segments.

riparian zone as a direct result of hydrological changes in the LMCR (Kronemann and Lawrence 1988). Specifically, the LMCR's winter instream water temperatures have been warmed and its annual hydrograph extremes stabilized by the impoundment of its largest tributary, the North Fork Clearwater River (NFCR).

The U.S. Army Corps of Engineers impounded the NFCR by constructing Dworshak Dam in 1971-72. Dworshak Dam is located on the NFCR 3 km (1.9 mi) up from its confluence with the Clearwater River at river km 65.4 (mi 41). The dam controls water from a 6,319 km^2 (2,440 mi^2) drainage area for flood control, power generation, recreation, water quality, and fish and wildlife uses (USACE 1986).

Dworshak Dam is a straight concrete-gravity structure 218.5 m (717 ft) high with a crest length of 1001.9 m (3,287 ft) and a crest width of 13.4 m (44 ft) (USACE 1986). The dam's power intakes are equipped with multilevel selector gates which allow selection of suitable water temperatures for fish production at Dworshak National Fish Hatchery. Twenty-one temperature sensors located at different elevations along the upstream face of the dam measure water column temperatures (USACE 1986).

The NFCR discharge contributes 40.8% of the LMCR's average annual flow. Currently, Dworshak Dam stores NFCR spring run-off and redistributes it throughout historically low flow periods. Prior to Dworshak Dam construction, highest flows in the LMCR occurred during April, May, and June coinciding with peak snowmelt runoff (Figure 1.2). Median flows (50% exceedance) were greatest during May at 1,331 cms (47,000 cfs). Peak flows (10% exceedance) were also highest in May at 2,237 cms (79,000 cfs). Lowest flows prior to dam construction occurred during August, September, and October, with median flows ranging from 85 to 113 cms (3,000 to 4,000 cfs) during this period. During dry conditions (90% exceedance), flows during these months ranged from 51 to 59 cms (1,800 to 2,100 cfs) (Figure 1.2).

The annual flow release pattern of Dworshak Dam affects discharges in the LMCR in two fundamental ways: 1) high flows occurring from April through June were reduced, especially during May; and 2) flows were increased from July to March, especially during September and from December through January (Figure 1.2). Highest yearly flows (10% exceedance), which historically occurred in May, were shifted to June under Dworshak Dam influence. June has a post-dam 10% exceedance value of 1,643 cms (58,000 cfs). For dry periods (90% exceedance), flows increased from 57 to 85 cms (2,000 to 3,000 cfs) in August and from 51 to 91 cms (1,800 to 3,200 cfs) in October under Dworshak Dam

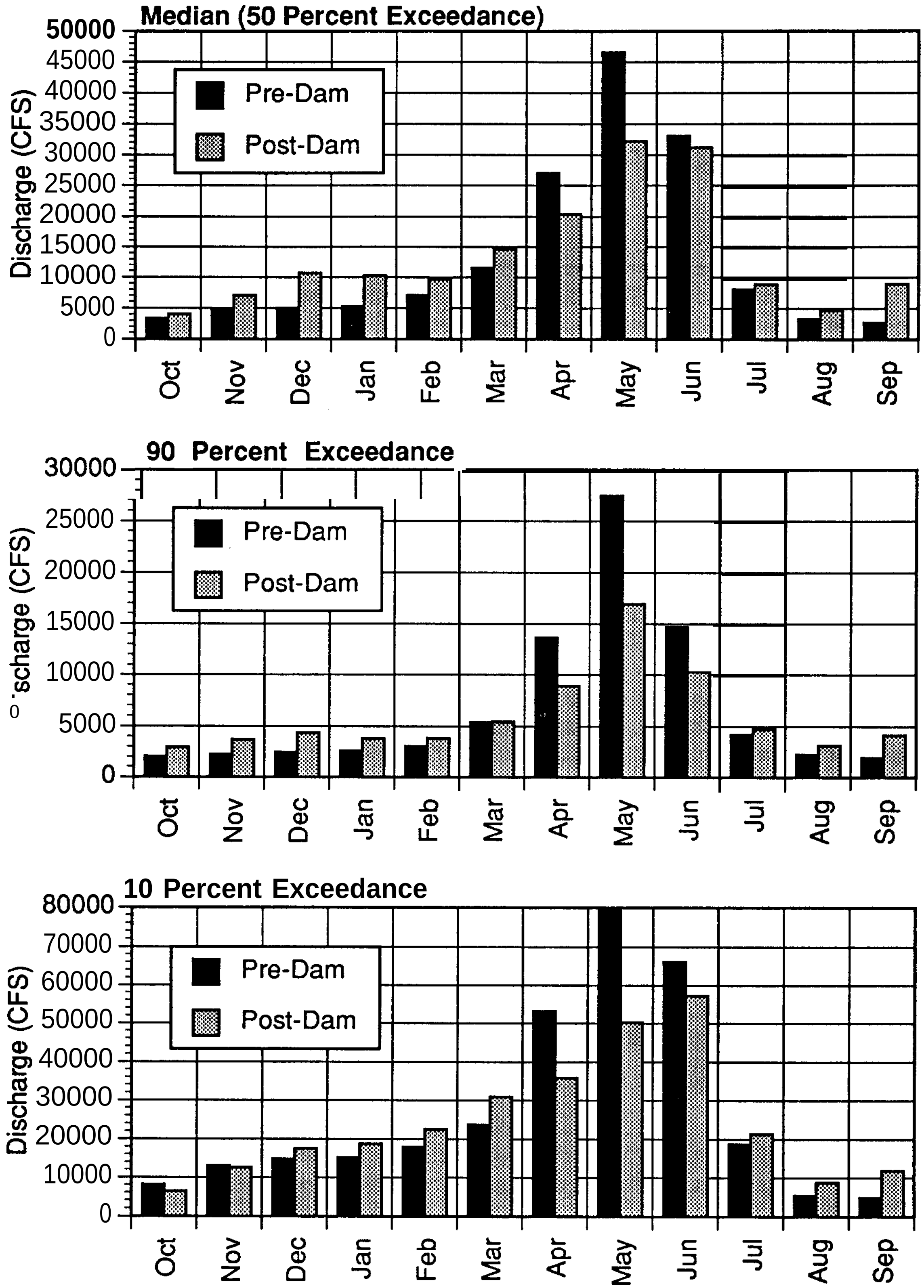


Figure 1.2. Daily discharge statistics by month for the lower mainstem Clearwater River showing pre-Dworshak (1925 to 1972) and post-dam (1973 to 1990) conditions (source: USGS Spalding gaging station records).

influence. The greatest flow increase occurred in September with median discharges increasing from 85 to 255 cms (3,000 to 9,000 cfs), and 90 percentile discharges increasing from 57 to 113 cms (2,000 to 3,000 cfs). Increased September discharges result from water evacuation (approximately 700,000 acre feet) from Dworshak Reservoir mainly for flood control purposes.

Median monthly flow releases from Dworshak Dam are highest during September and December with discharges of 204 and 201 cms (7,200 and 7,100 cfs), respectively (Figure 1.3). Median monthly flow releases are lowest during April, August, and October, when approximately 59 cms (2,100 cfs) is released. Peak (10% exceedance) flow releases are highest during March and June with discharges of 510 and 425 cms (18,000 and 15,000 cfs), respectively. During dry conditions (90% exceedance), lowest flows occur during May because of peak reservoir filling. Flows are as low as 17 cms (600 cfs) during dry conditions (Figure 1.3).

The upper mainstem Clearwater River (above the NFCR confluence) average monthly discharges resemble the LMCR discharges prior to Dworshak Dam operation. Highest flows occurred in April, May, and June, at median discharges (50% exceedance) of 396, 708, and 680 cms (14,000, 25,000, 24,000 cfs), respectively (Figure 1.4). Peak flows (10% exceedance) during these months are 793, 1,218, and 1,274 cms (28,000, 43,000, and 45,000 cfs), respectively. During dry conditions (90% exceedance), flows in the upper mainstem Clearwater River decline to 42 cms (1,500 cfs) in August and 28 cms (1,000 cfs) in September and October (Figure 1.4).

Water temperatures in the LMCR are strongly influenced by temperatures in the upper mainstem Clearwater River, and by temperatures released from Dworshak Reservoir into the NFCR. Temperature records obtained from thermographs during 1989 indicate that water temperatures were highest in the upper mainstem Clearwater River during July and August (Figure 1.5). During these months, average daily water temperatures were as high as 23 °C, while maximum daily water temperature were as high as 25 °C. Temperatures as high as 27 °C were observed in the upper mainstem Clearwater River during 1990 (Figure 1.6). Water temperatures dropped to nearly 0 °C during December 1989 in the upper mainstem Clearwater River (Figure 1.5). Water temperatures in the upper mainstem river were well below 5 °C from December to March (Figures 1.5 and 1.6).

Temperature releases from Dworshak Reservoir into the NFCR are much less variable than temperatures in the upper mainstem Clearwater River. Reservoir release temperatures are considerably lower during summer months and higher

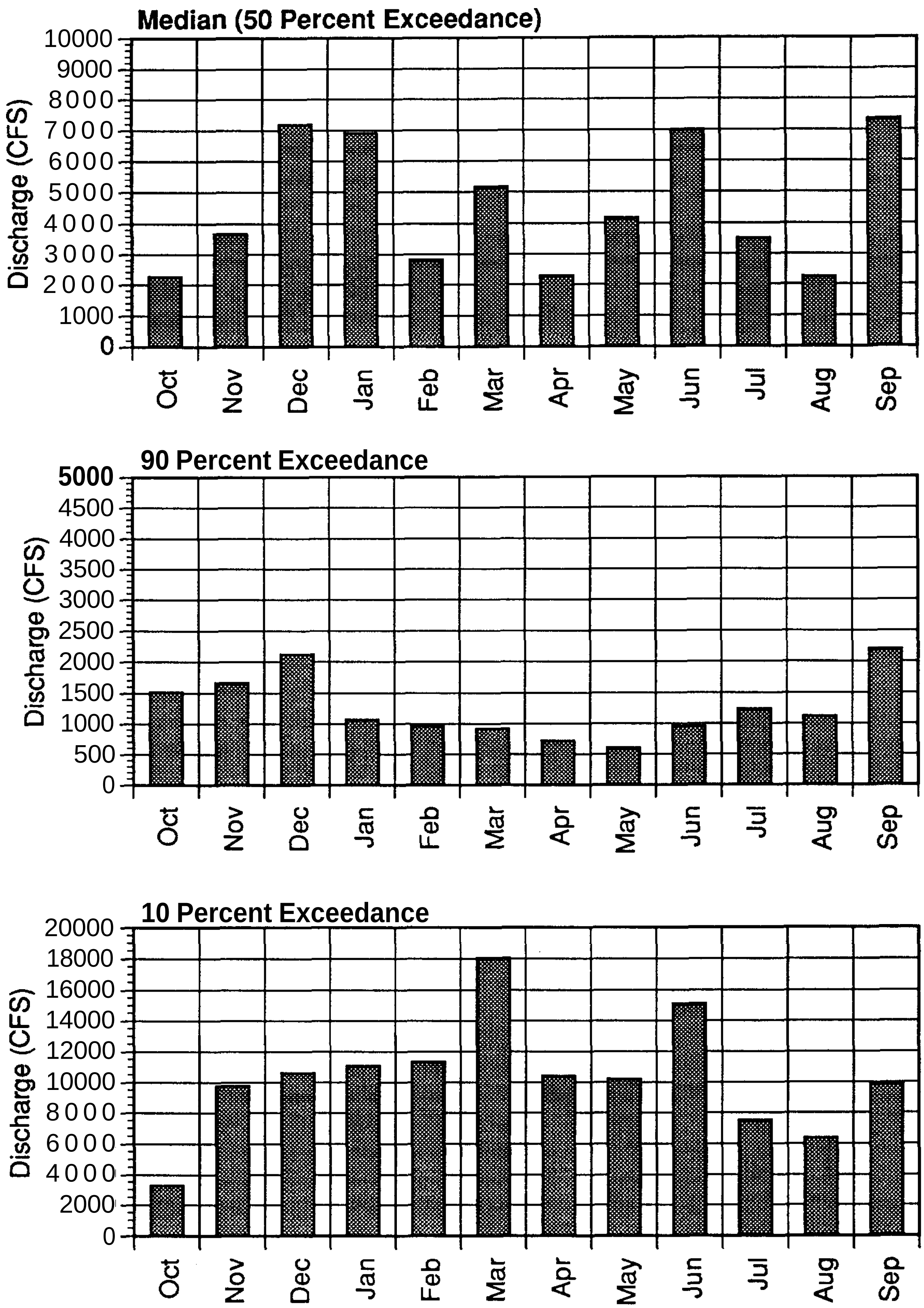


Figure 1.3. Daily discharge statistics by month for Dworshak Reservoir, 1973 to 1990 (source: USGS Orofino and Peck gaging station records).

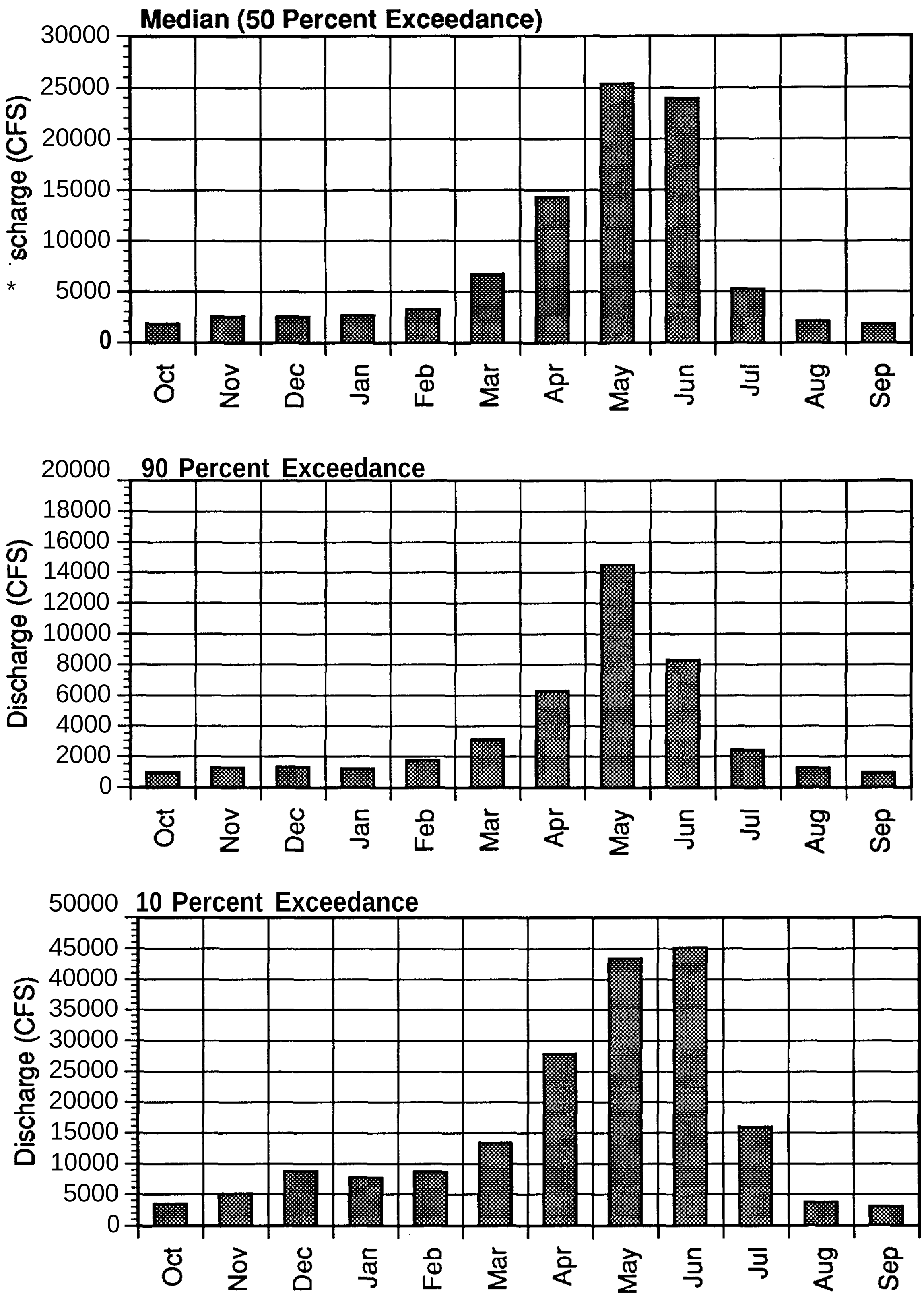


Figure 1.4. Daily discharge statistics by month for the upper mainstem Clearwater River, 1973 to 1990 (source: USGS Orofino gaging station records).

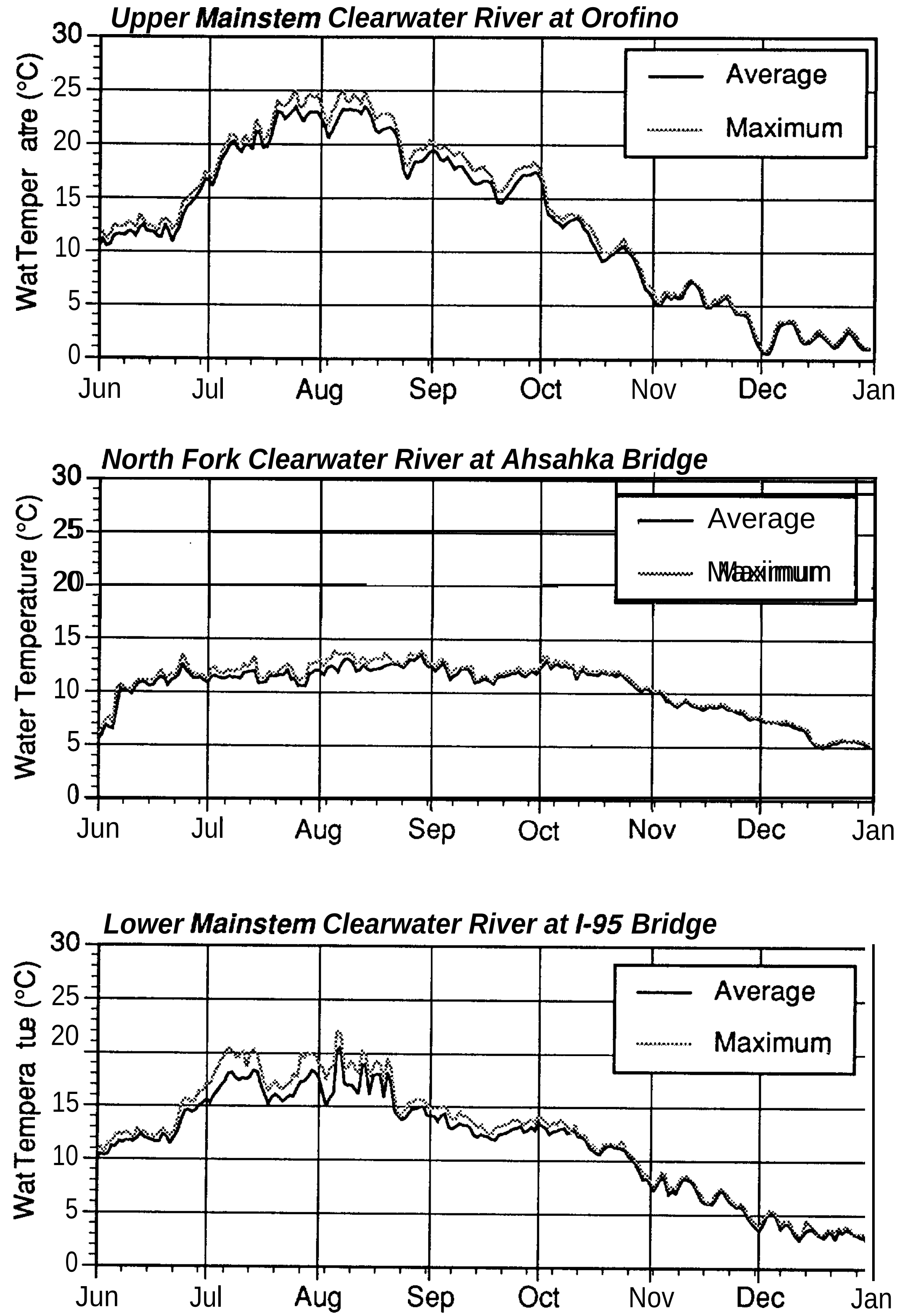


Figure 1.5. Average and maximum daily water temperatures of upper mainstem, North Fork, and lower mainstem Clearwater River from June 1 to December 31, 1989.

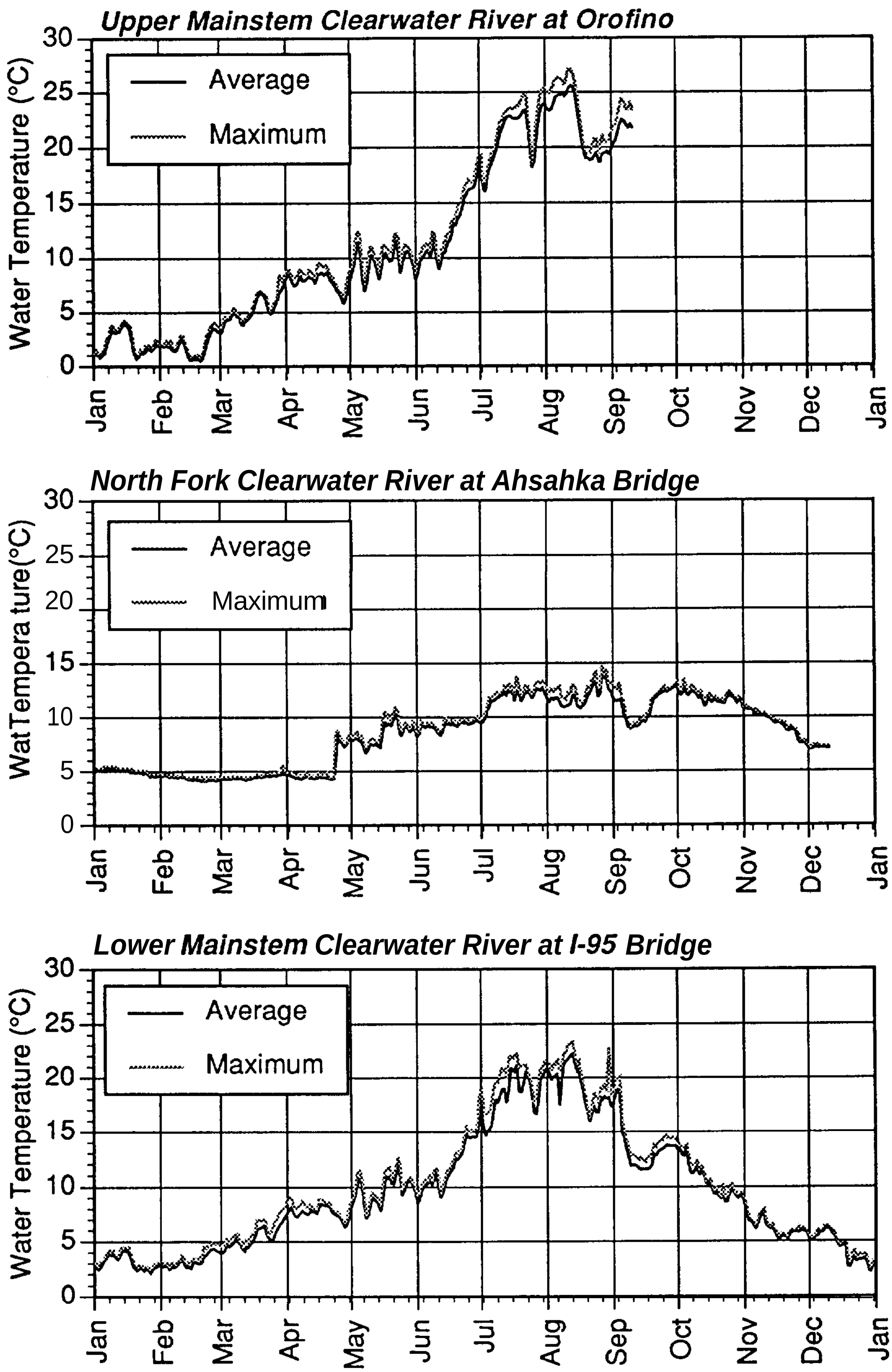


Figure 1.6. Average and maximum daily water temperatures of upper mainstem, North Fork, and lower mainstem Clearwater River from January 1 to December 31, 1990.

during winter months. Temperature records indicate that maximum temperatures are released in July and August (Figures 1.5 and 1.6). Maximum release temperatures of 13 and 14 °C were observed during August, 1989 and 1990, respectively. Minimum reservoir release temperatures of approximately 5 °C were observed from mid-December to mid-April.

Water released from Dworshak Reservoir into the NFCR moderates water temperatures in the LMCR throughout the entire year. Peak summer water temperatures in the LMCR are significantly less than those observed in the upper mainstem Clearwater River (Figures 1.5 and 1.6). In the LMCR, peak temperatures of 22 and 24 °C were observed in August, 1989 and 1990, respectively. Minimum water temperatures in the LMCR are several degrees warmer than those in the upper mainstem river. Minimum water temperatures in the LMCR were between 3 and 5 °C during December, 1989 to March, 1990 (Figures 1.5 and 1.6).

CHAPTER 2

CHINOOK SALMON AERIAL REDD SURVEYS

Abstract-We conducted fall chinook salmon *Oncorhynchus tshawytscha* aerial redd surveys on the lower 65 km of the mainstem Clearwater River (LMCR) from 1988-91. We observed 21, 10, 4, and 4 redds from 1988-91, respectively. Redds were located in the lower 35 km where island sections and more favorable substrate particles occur in greater proportions than in the upper 30 km of the study area. Low adult escapement and lack of spawning site competition may reflect fish spawning in these prime spawning areas. Of the 39 redds observed, 54% were associated with island areas which represented only a small percentage of the total potential spawning area. Aerial redd surveys may not have detected deep water (> 3 m) fall chinook redds in main channel spawning habitat. The low number and decline of fall chinook redds in the LMCR and Snake River in recent years exemplifies the need for timely measures if we are to protect these important fish.

Introduction

This study was the first attempt to monitor fall chinook salmon ***Oncorhynchus tshawytscha*** spawning in the lower mainstem Clearwater River (LMCR). Aerial redd surveys have proven to be reliable estimates of the spawning population (Platts et al. 1983). We chose to conduct helicopter surveys because of the large size of the LMCR (commonly > 100 m wide) and the occurrence of side channels in the lower river. Our objectives were to: 1) document fall chinook spawning areas and timing, 2) provide baseline data on fall chinook adult escapement, and 3) collect biological information from fall chinook carcasses.

Methods

We conducted fall chinook salmon aerial redd surveys on the LMCR by helicopter. We surveyed the LMCR once during 1988 on December 1. From 1989 to 1991, two surveys were made each year, one approximately mid-November and one after December 1. Surveys started at the mouth of the LMCR and continued upstream to the mouth of the North Fork Clearwater River (NFCR) (see Chapter 1, Figure 1.1). We flew the river during late morning to mid-day to take advantage of the best lighting conditions. We recorded weather conditions, water transparency (Secchi disk), and total LMCR discharge (USGS Spalding gaging station data) on most surveys. Fall chinook redds and carcasses seen from the air were mapped on aerial photographs, however, we show only general locations in this report. We mapped only obvious redds and ignored "test redds" and narrow, elongated jet-boat scours. Following each flight, ground crews collected and measured all recoverable carcasses.

Data on fall chinook salmon entering the ladder at Dworshak National Fish Hatchery (DNFH) from 1987-1991 are also presented. Most fall chinook were tabulated and measured by hatchery personnel and released back into the LMCR.

Results

Fall Chinook redd numbers declined from 21, 10, 4, and 4 from 1988 to 1991 (Table 2.1). Redds recorded on the second flight were cumulative and included all redds seen on the first flight during that year. Therefore, total redds counted in 1989, for example, was 10 (i.e. the count number for the second flight). Apparently, all fall chinook spawning did not cease by mid-November, as additional redds were observed during the second survey after December. All redds were located in the lower 35 km (below Pine Creek) of the LMCR (Figure 2.1).

Survey weather conditions were mostly clear and sunny (Table 2.1). Water transparencies varied from 2.0 to 4.3 m on surveys where data were recorded. LMCR discharges during surveys varied considerably and ranged from 4,137 to 13,540 cfs (117 to 383 cms). We did not see a correlation between redd numbers and discharge or water transparency.

Ground crews recovered 4 carcasses in 1988, 1 in 1989, and none in 1990 and 1991 (Table 2.2). All 5 fish recovered were females and mostly spent except the fish in 1989 which retained approximately 50% of her eggs.

Fall chinook entering the fish ladder at DNFH totaled 4 in 1988 and 1 in 1990 (Table 2.2). No fall chinook entered DNFH in 1989 or 1991. Fall chinook entering the hatchery are all strays since the hatchery does not raise fall chinook.

Discussion

No fall chinook salmon redds were observed in the upper 30 km of the LMCR study area (i.e. Pine Creek up to the confluence of the NFCR), however, adequate spawning habitat was previously mapped (Connor 1989). Low adult escapement in-the LMCR may explain this trend. With no competition for spawning sites, fish could select areas comprised of prime spawning substrate and hydraulic characteristics in the lower portion of the LMCR. Our substrate quality study (Chapter 4) indicated a higher percentage of gravel and

Table 2.1. Fall chinook salmon aerial redd survey dates, survey conditions, and number of redds and fish observed on the lower mainstem Clearwater River, Idaho, 1988-91.

Survey date	Weather conditions	Transparency (m)	Discharge (cfs)	No. redds observed	No. fish observed
12/1/88	clear, cold	----	4,920	21	3
11/19/89	clear, sunny	3.0	5,560	8	0
12/2/89	clear, sunny	3.0	6,550	10[a]	1
11/16/90	----------	2.0	-----	1	0
12/3/90	---------	4.3	13,540	4[a]	0
11/20/91	clear, sunny	3.0	10,520	1	1
12/17/91	clear, sunny	3.8	4,137	4[a]	0

[a] Includes redds observed on the first survey and represents the total number of redds observed for that year.

Table 2.2. Length, sex, and percent spawned data from fall chinook salmon collected on the lower mainstem Clearwater River, Idaho and live fish entering Dworshak National Fish Hatchery (DNFH), 1988-91.

Date	Location	Fork length (cm)	Mid-eye hypural length (cm)	Sex	Percent spawned
12/01/88	Cherry Lane Bridge	91.5	76.0	F	100
12/01/88	Cherry Lane Bridge	88.5	74.0	F	100
12/01/88	Lewiston Dam Site	76.0	66.0	F	100
12/14/88	Cherry Lane Bridge	98.0	80.0	F	90
11/15/88	DNFH	49	ND	M[a]	---
11/15/88	DNFH	49	ND	M[a]	---
11/15/88	DNFH	ND[b]	ND	F	Ripe
12/06/88	DNFH	90	ND	F	Ripe
12/04/89	Cherry Lane Island	79.3	73.1	F	50
11/07/90	DNFH[c]	ND	ND	F	Ripe

DNFH data provided by the Idaho Fishery Resource Office
ND = no data collected
[a] Jack
[b] No measurement; length estimated at 70-80 cm.
[c] Umatilla River stray, coded wire tag # 73914.

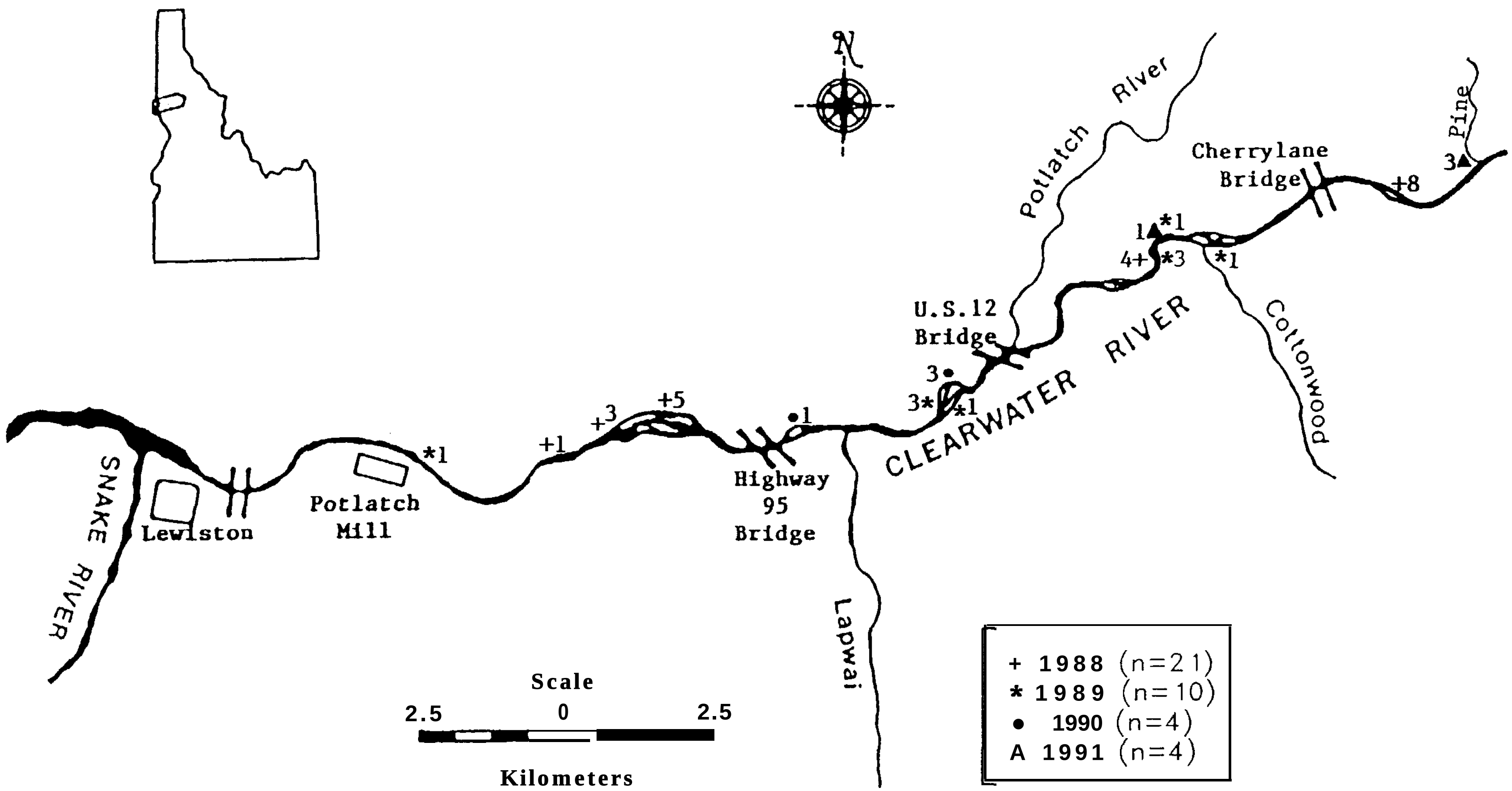


Figure 2.1. Loca:ion and number of fall chinook salmon redds from aerail redd surveys on the lower mainstem Clearwater River, Idaho, 1988-9 1.

small cobble associated with the islanded sections in the lower river. Islanded sections in the LMCR represent only a small percentage (< 10%) of the total potential spawning habitat, however 54% of all redds observed in the last 4 years were associated with islands. Only a few small islanded areas occur in the LMCR above the mouth of Pine Creek.

A possibility exists that all fall chinook redds in the LMCR are not visible from aerial redd surveys. Swan (1989) estimated only about 20% of fall chinook redds were visible from aerial surveys at the Hanford Reach on the Columbia River. Fall chinook redds deeper than 3 m could not be detected from the air, however divers documented a higher percentage of spawning occurred at greater depths (Swan 1989). U.S. Fish and Wildlife Service divers (Connor, unpublished data) observed multiple clusters of fall chinook redds in one spawning area that were not detected during 1991 aerial redd surveys on the lower Snake River. Although deep water spawning habitat exists in the LMCR, the extent of fall chinook spawning was not documented since we did not dive deep water sections.

Conclusions

The decline of fall chinook salmon redds in the LMCR paralleled that in the lower Snake River. Bugert (Washington Department of Fisheries letter to various agencies dated January 15, 1991) reported 66, 57, 58, and 37 fall chinook redds counted from aerial redd surveys in 1987 to 1990, respectively. Redd numbers declined to 32 on the Snake River in 1991 (Mendel, Washington Department of Fisheries letter to various agencies dated December 16, 1991). The low number and decline of fall chinook redds in both the lower Clearwater and Snake Rivers in recent years greatly exemplifies the need for timely protective measures if we are to prevent the extinction of this native salmon in Idaho.

CHAPTER 3

CHINOOK SALMON *EGG* INCUBATION TIMING

Abstract-We documented eye, hatch, and button-up (emergence) timing of Snake River fall chinook salmon ***Oncorhynchus tshawytscha*** (Lyon's Ferry Hatchery), South Fork Salmon River (SFSR) summer chinook (McCall Hatchery), and upper Columbia River (UCR) summer chinook (Wells Hatchery) using fertilized eggs in incubation boxes on the lower mainstem Clearwater River (LMCR). As a comparison to the LMCR, we also documented eye and hatch timing of fall chinook in the Snake River. Fall chinook emerged the third week in May, almost three weeks later compared to fall chinook in the Snake River. This could be attributed to colder November water temperatures in the LMCR, as compared to the Snake River. Warm September water temperatures in the LMCR accelerated SFSR summer chinook incubation with emergence starting November 30. The UCR summer chinook emerged by May 1. Average daily temperature units (°C) for emerging fry were 900, 952, and 968 for the UCR summer, SFSR summer, and Snake River fall chinook salmon, respectively. Average total fry length at button-up was 32.1, 36.5, and 38.9 mm for same stocks, respectively. Higher egg-to-smelt survival would be expected for the UCR summer and the Snake River fall chinook than for the SFSR summer chinook in the LMCR.

Introduction

The success of enhancing or restoring chinook salmon ***Oncorhynchus tshawytscha*** natural reproduction to the lower mainstem Clearwater River (LMCR) will depend largely upon the stocks' emergence timing. The objective of this study was to examine incubation timing parameters from fertilization to button-up (emergence) of potential chinook salmon outplanting stocks for the LMCR. We studied the Snake River fall chinook (age 0+ outmigrants), South Fork Salmon River (SFSR) summer chinook (age 1+ outmigrants), and the upper Columbia River (UCR) summer chinook (age 0+ outmigrants) as potential outplanting stocks.

Methods

During the fall 1989, we placed Snake River fall chinook salmon (Lyon's Ferry Hatchery) eggs in incubation boxes at the Potlatch River and Bedrock Creek study sites, and at Orofino upstream from the North Fork Clearwater River confluence (see Chapter 1, Figure 1.1). During the fall 1990, we placed South Fork Salmon River (SFSR) (McCall Hatchery) and upper Columbia River (UCR) (Wells Hatchery) summer chinook salmon eggs in incubation boxes at the

Potlatch River and Bedrock Creek study sites only. Also during the fall 1990, we compared incubation timing of Snake River fall chinook by placing eggs in incubation boxes in the Snake River above confluence of Billy Creek (river km 262). We did not use eggs from the Snake River fall chinook stock in incubation boxes on the LMCR during the fall 1990, however documented hatch timing using these eggs in intrusion baskets placed in artificial redds during our survival to hatch study (Chapter 5).

Eggs from each chinook salmon stock were from one female fertilized with one or two males. We transported green eggs in Zip-Lot bags, separate from oxygenated sperm, in iced coolers. Both eggs and sperm were kept off the ice by a burlap liner. Transportation time from egg take to placement in the LMCR ranged from 6 to 22 hrs. Eggs were fertilized on the LMCR at each study site, iodophored, water hardened, and placed into baskets immediately. Total time from fertilization to implantation was 4 hrs or less, except for the SFSR summer chinook eggs. The SFSR eggs were transported from the SFSR adult trap to the LMCR already fertilized, iodophor treated, and water hardened. We placed the SFSR eggs in the LMCR the following day within 18-22 hrs of fertilization.

We placed 25-100 chinook salmon eggs in gravel-filled nylon net bags (30 X 30 cm X 2 mm mesh) which were tied shut to prevent egg loss or fry escapement. Egg bags were then placed in incubation boxes cabled to the river bottom. Incubation boxes (65 X 90 X 30 cm high) were constructed of 1.9 cm plywood and screened with 6.4 mm mesh hardware cloth on the top, sides, and 45° slanted front section (Figure 3.1). Five boxes, cabled 3 m apart in series downstream, were used for each chinook salmon stock at each study site. We placed four 20 X 20 cm lengths of PVC pipe inside each box and filled the box with spawning gravel and cobble. Egg bags were then placed inside the PVC pipes which were extracted allowing the spawning substrate to enclosed around each bag.

Periodically, we pulled egg bag samples to check egg or alevin development. Immediately after hatching, we placed the sacfry from egg bags into 19 1 buckets to monitor button-up timing. Buckets were fitted with tight-sealing lids and perforated (2 mm holes) to allow for water circulation. At approximately 50% button-up, fry were euthanized for development measurements.

We compared incubation timing parameters between chinook salmon stocks studied on the LMCR along with a range of natural spawning and emergence dates in their native river. The outermost ranges of natural spawning and

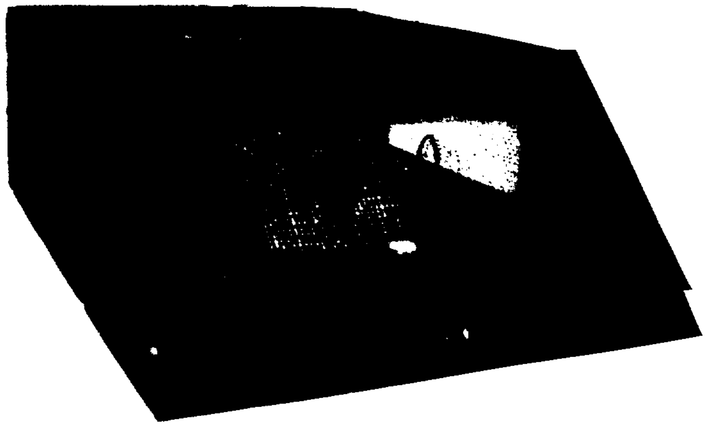


Figure 3.1. Egg incubation box used on the lower mainstem Clearwater and Snake Rivers, Idaho, 1989-91.

emergence were obtained by consulting fisheries biologists familiar with the chinook salmon stock in their natural habitats. We calculated actual daily temperature units (DTU's) from thermograph data at each site for each incubation timing parameter (Piper et al. 1989). We compared DTU's for incubation timing dates among chinook salmon stocks studied on the LMCR. SFSR chinook salmon incubation timing and length at emergence on the LMCR were also compared to study results conducted by the U.S. Forest Service on the SFSR.

Results

During the 1989-90 incubation period, Snake River fall chinook hatched by the end of March and were button-up fry by May 21 (Table 3.1, Figure 3.2). High water levels at Orofino prevented monitoring eggs at critical incubation times. Based on accrued DTU's calculated from thermograph data, fall chinook at Orofino would have emerged approximately two weeks later than in the lower river (Table 3.1). This was a result of colder winter water temperatures in the upper mainstem Clearwater River above the influence of warm water releases from Dworshak Dam.

During the 1990-91 incubation period, Snake River fall chinook hatched over three weeks later in the LMCR compared to fall chinook in the Snake River (Table 3.1). Due to high flows in the Snake River, we could not document emergence timing, but would approximate it at May 2 based on thermograph data and DTU calculations. Fertilization of

Table 3.1. Observed fall and summer chinook salmon incubation timing dates (except those noted as calculated), daily temperature unit accrual (°C) to that date, and total fry length at button-up on the lower mainstem Clearwater (LMCR) and Snake Rivers, Idaho.

Date placed	Chinook stock	River/ site	No. eggs	Eyed date	Hatch date	Button-up date	Length (mm)
11/15/89	Snake River falls	LMCR/ Potlatch River	1200	2/21 (355)	3/28 (526)	5/21 (970)	39.5
		LMCR/ Bedrock Creek	1200	2/21 (360)	3/28 (526)	5/22 (966)	38.3
		LMCR/ Orofino	1200	3/25[a] (358)	4/16[a] (525)	6/4[a] (963)	----
8/29/90	SFSR summers	LMCR/ Potlatch River	900	10/1 (454)	10/10 (564)	11/30 (953)	32.1
		LMCR/ Bedrock Creek	900	10/1 (441)	10/11[a] (561)	12/3[a] (952)	----
10/25/90	Upper Columbia River summers	LMCR/ Potlatch River	520	12/5 (269)	2/26 (529)	4/29 (902)	36.5
		LMCR/ Bedrock Creek	1795	12/5 (267)	2/26 (530)	5/1 (899)	36.5
11/9/90	Snake River falls	LMCR/ Potlatch	1500	1/8[a] (283)	3/21[b] (508)	5/22[a] (963)	----
		Snake/ Billy Creek	1575	12/14 (282)	2/25 (481)	5/2[a] (968)	----

[a] Date calculated from accrued daily temperature units.
[b] Hatch timing was documented using eggs in intrusion baskets placed in artificial redds.

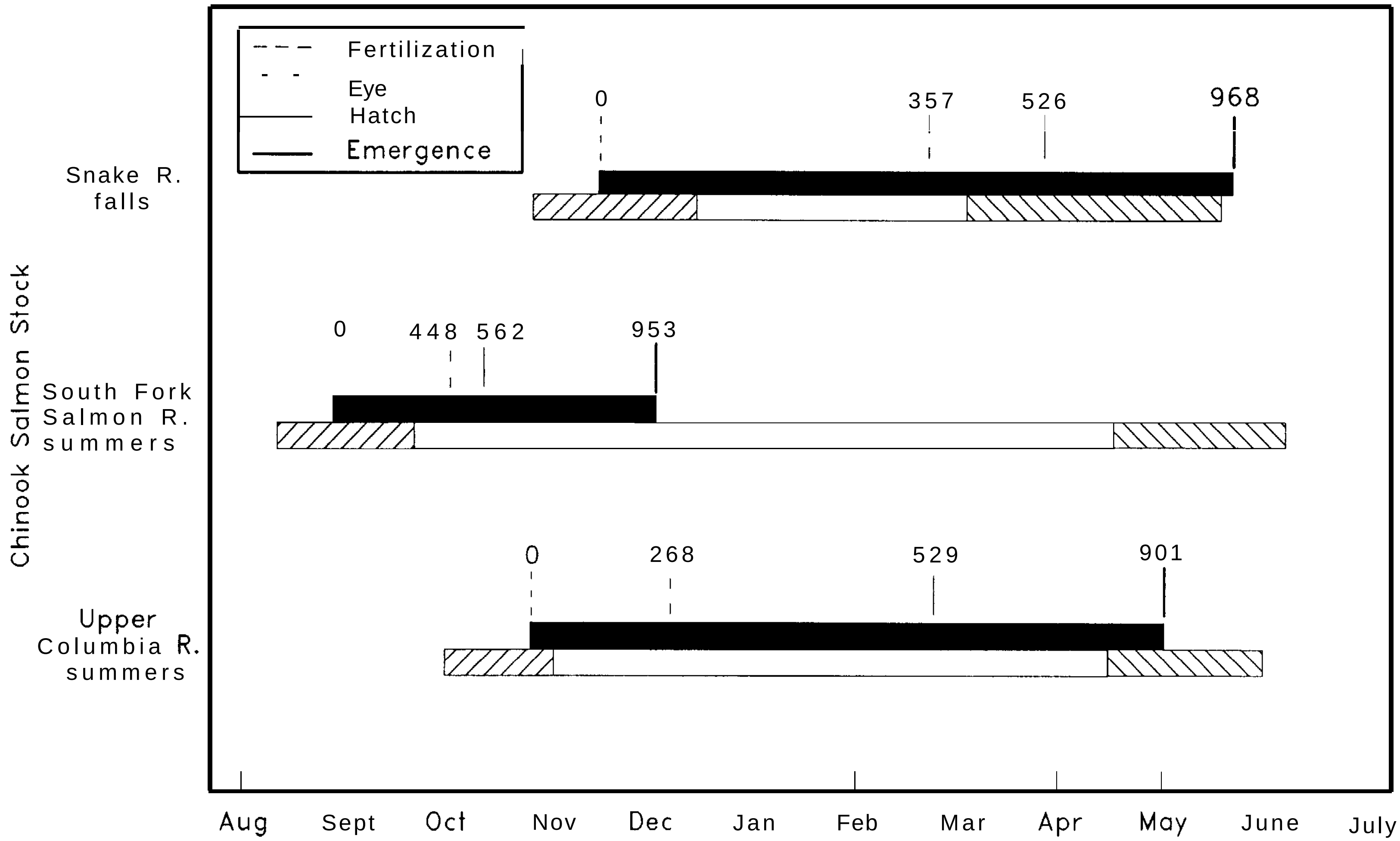


Figure 3.2. Observed ▬ fall and summer chinook salmon incubation timing dates by stock on the lower mainstem Clearwater River, average daily temperature units (°C) accrued to that timing, and range of natural spawning ▨ and emergence ▧ of each stock in its native river.

Snake River fall chinook on the LMCR was within the range of their natural spawning, however, emergence was slightly later than in their native river (Figure 3.2). Recent research by the U.S. Fish and Wildlife Service on the Snake River suggest the outermost ranges of fall chinook spawning occurs from late October until mid-December and emergence occurs from March through mid-May (Connor, unpublished data).

The SFSR summer chinook eggs placed in the LMCR at the end of August hatched by October 10 and were button-up fry by the end of November (Table 3.1, Figure 3.2). Emergence of SFSR summer chinook in the LMCR was over 5 months earlier than in their native river (Figure 3.2). Thurow and King's (unpublished data) work on the.SFSR resulted in mid-May emergence for summer chinook eggs placed in intrusion baskets on August 28, 1990, a day prior to egg placement in the LMCR. The outermost ranges of natural SFSR summer chinook spawning occurs from the second week in August through the third week in September and emergence occurs from mid-April through the first week in June (Don Anderson and Robert Hill, Idaho Department of Fish and Game, and Russ Thurow, U.S. Forest Service, personal communication).

The UCR summer chinook eggs placed in the LMCR on October 25 hatched by the end of February and were button-up fry by the end of April (Table 3.1, Figure 3.2). Emergence timing of the UCR summers on the LMCR paralleled emergence timing in their native river (Figure 3.2). The UCR summer chinook, in the Wenatchee River, WA, naturally spawn throughout October and emerge from mid-April to approximately the end of May (Bill Zook, Washington Department of Fisheries, personal communication).

DTU's for button-up fry averaged 900, 952, and 968 for the UCR summer, SFSR summer, and Snake River fall chinook salmon, respectively (Table 3.1). Average total fry length at button-up was 36.5, 32.1, and 38.9 mm for the same stocks, respectively (Table 3.1).

Discussion

We believe that water temperatures were responsible for the late fall chinook emergence time on the LMCR. We recorded temperatures as much as 4 °C colder in the LMCR than in the Snake during November. During early winter, Dworshak Reservoir water releases are as warm as possible to accommodate fish production at DNFH. However, in years where discharges and temperatures could be increased over 1989-90 conditions, emergence timing of fall chinook in the LMCR may be accelerated by a week or more. For example, a temperature release of 10.0 °C at a constant reservoir release of 113 cms (4,000 cfs) from mid-November through December (Chapter 12) and would accelerate emergence of fall chinook by approximately 9 days over 1989-90 observed emergence time. Fall chinook that would spawn naturally in the LMCR on November 15 would be expected to emerge by May 12 instead of May 21. It is probably not possible for Dworshak Dam to release water at 10.0 °C during most years in December, however selecting the warmest temperature at discharges specified (Chapter 13) may advance fall chinook incubation somewhat.

Under the 1989-90 temperature regime, fall chinook emerged in late May and would probably be dispersed downstream into Lower Granite Reservoir. Bennett et al. (1991) suggested the existence of this migration scenario for naturally produced Snake River fall chinook in the Snake River. Fall chinook outmigration timing is discussed in Chapter 7.

Warm water temperatures in the LMCR during late August and early September (see Chapter 5, Table 5.2) accelerated SFSR summer chinook salmon egg development. When we fertilized SFSR summer chinook eggs, the LMCR was 8.5 °C warmer than the South Fork Salmon River. Consequently, SFSR summer chinook on the LMCR may emerge in early winter under environmental conditions for which they did not evolve.

Emergence timing of the UCR summer chinook in the LMCR followed the pattern of their native river. UCR summer chinook emerged three weeks earlier than the Snake River fall chinook. Earlier emerging fry would reach smolt size sooner so they would likely avoid warm summer water temperatures and low Snake River outmigrating flow conditions. We discuss this in more detail in Chapter 7.

Temperature unit requirements for SFSR summer chinook emergence were more similar to Snake River fall chinook than UCR summer chinook. Piper et al. (1989) reports DTU's vary even within a species and are affected by fluctuating temperatures. DTU's observed for all chinook stocks studied on the LMCR were somewhat higher than values of 250, 417, and 889 for eye, hatch, and emergence given in Piper et al. (1989). Fluctuating temperatures on the LMCR may have prolonged the incubation period somewhat in all chinook stocks studied.

The extremely high water temperatures on the LMCR during the beginning of the SFSR summer chinook incubation may have also affected their length at emergence. Thurow and King (1990 unpublished data) reported a range of 33-35 mm for emerging summer chinook salmon from capped redds on the SFSR. We found emerging SFSR chinook fry length averaged slightly less on the LMCR. Heming (1982) reported chinook salmon incubated at temperatures as high as 12 °C were generally smaller than fish incubated at lower temperatures. The UCR summer chinook emerged 4.5 mm longer than the SFSR summer chinook, however they were 3 mm shorter than the Snake River fall chinook. Natural variation in length at emergence may also occur between chinook salmon stocks.

Conclusions

The success of enhancing or restoring naturally reproducing chinook salmon in the LMCR will depend largely upon egg-to-smolt survival. Of the three chinook stocks studied on the LMCR, we believe that SFSR summer chinook salmon survival would be limited, since the water temperature regime in which these fish evolved is drastically different from the LMCR. On the other hand, UCR summer and Snake River fall chinook salmon incubation timing was similar to that of their native rivers. The UCR summer chinook showed the advantage of earlier emergence, while the Snake River fall chinook delayed developmental rate may subject fry and smolts to less favorable temperature and flow conditions during outmigration. Fall chinook emergence may be advanced somewhat by selecting the warmest temperature releases possible from Dworshak Dam during the incubation period.

CHAPTER 4

SPAWNING SUBSTRATE QUALITY

Abstract-As a measure of chinook salmon ***Oncorhynchus*** tshawytscha spawning substrate quality on the lower mainstem Clearwater River (LMCR), we collected freeze-core samples in two documented fall chinook spawning areas. As a comparison to the LMCR spawning substrate quality, we also collected freeze-core samples in chinook salmon spawning areas on the lower Snake River, Idaho and the Wenatchee River, Washington. Other comparative freeze-core data from the South Fork Salmon River, Idaho was provided by the U.S. Forest Service. We modified the CO_2 tri-tube sampler (Everest et al. 1980) to sample larger rivers. Core samples were thawed over a subsampler to obtain vertical stratification of substrate particles in three equal 10.16 cm strata. Substrate particles were wet-sieved and the dry weight for each sieve obtained using a correction factor. Spawning substrate particle size distributions for most freeze-core sites approximated a lognormal distribution. The LMCR Potlatch River site had a higher percentage of gravels (2.36 to 25 mm) compared to the LMCR Bedrock Creek site which contained more cobbles > 50 mm and fines < 0.85 mm. The geometric mean diameter (d_g) of substrate particles on the LMCR compared favorably to other rivers, however, percent fines on the LMCR were slightly higher in strata 2 and 3 (middle and deep strata). Fredle index values for the LMCR Potlatch River site, Wenatchee River, and Snake River Billy Creek site in all three strata were not significantly ($P < 0.05$) different. Fredle numbers for the LMCR Bedrock Creek site were significantly higher in stratum 3 than all other sites. The comparatively high spawning substrate quality in the LMCR should facilitate chinook salmon natural reproduction.

Introduction

We conducted an Instream Flow Incremental Methodology (IFIM) study on the lower mainstem Clearwater River (LMCR) (Connor et al. 1990) in part to quantify chinook salmon ***Oncorhynchus tshawytscha*** spawning habitat (Chapter 11). However, a shortcoming of our IFIM modeling approach was the absence of data on vertical stratification and measured particle size of spawning substrate. To fill this data gap and provide a measure of egg to emergence survival, we collected freeze-core substrate samples on the LMCR. Our objective was to assess and compare the LMCR spawning substrate quality with freeze-core data taken on the Snake, Wenatchee, and South Fork Salmon Rivers (SFSR). Also, we evaluated chinook salmon survival to emergence in the LMCR by comparing literature sources relating substrate quality indices with survival.

Methods

We collected freeze-core samples in the LMCR at two fall chinook spawning areas documented from our aerial redd surveys (Chapter 2). Core samples were extracted in July prior to the fall spawning period. We selected this time to coincide with low flows and felt substrate conditions would not change prior to spawning. Stowell et al. (1983) suggested that survival to emergence predictions may be based on substrate samples taken prior to spawning. This implies that cleaned redds will revert back to post-spawning conditions over incubation (Young et al. 1989).

On the LMCR, we collected freeze-core samples along hydraulic cross-sections BDR-3 (Bedrock Creek study site), PL-4 and PL-5 (Potlatch River study site) established during our IFIM study to model known fall chinook spawning areas (Connor et al. 1990). We froze the first core on each cross-section at a point representative of the spawning area and accessible over the range of flows encountered during sampling. Once the location for the first core was selected, we systematically sampled beside it by taking two additional cores along the cross-section at 3 m intervals. Next, we measured 3 m upriver from each of the first three cores and froze a second series of samples. We took a total of 12 and 6 samples at the Potlatch River and Bedrock Creek study sites, respectively. Six McNeil samples (McNeil and Ahnell 1964) were taken at the Bedrock Creek site to test for freeze-coring biases towards small or large particles.

A tri-tube freeze-core sampler, fueled by liquid CO_2 (Everest et al. 1980), was modified to sample medium size cobbles (75-150 mm) commonly found in spawning areas of large mainstem rivers. The stainless steel cryogenic probes were lengthened from 1.2 to 1.7 m for sampling water depths up to 1.3 m. Templates separating the probes were modified from 7.6 cm centers to 15.2 cm for extracting a substrate sample approximately 26.0 cm in diameter and 30.5 cm deep. A throttle valve and pressure gage, adjusted between 65 and 70 psig, enhanced CO_2 control and cooling efficiency during delivery (Platts and Penton 1980). A 22.7 kg CO_2 cylinder froze the sample within 25 to 60 min (mean = 44 min). We also modified the McNeil sampler to the dimensions of 30.5 X 30.5 cm for freeze-core bias testing.

We placed a diamond-shaped galvanized deflector (0.5 X 0.9 X 1.4 m high) around the freeze-core sampler to shunt water flow, increase freezing efficiency, and prevent loss of substrate particles during extraction. Reinforced plastic tarps placed around the deflector's bottom edge and secured with large cobbles prevented upwelling around the probes. We used a digital thermometer (Omega model HH-72T) to monitor the last probe in series receiving CO,. We injected CO, until a temperature of -40 to -45 C was reached in the last probe and dry ice escaped from the relief valve. The system was then quickly turned off, delivery hose disconnected, and the core extracted using an adjustable aluminum tripod and 2-ton come-a-long.

We thawed extracted core samples using a blow torch over a subsampler which stratified the core into three 10.16 cm strata (Everest et al. 1980). Sediments were wet-sieved in the field using U.S. Standard sieves with mesh sizes of 152, 75, 50, 25, 2.36, 0.85, 0.425, and 0.212 mm. The volume of well-drained substrate particles retained on each sieve was determined by water displacement (McNeil and Ahnell 1964). Volumetric data was converted to dry weight using a correction factor (Shirazi and Seim 1979). We used dry weight values from each sieve to calculate mean particle size distributions for each site.

The first step in data analysis was to compare freeze-core and McNeil samples to detect particle size biases using analysis of variance (ANOVA) (Ott 1984). Since vertical stratification is not practical with McNeil samples, the three strata of our freeze-core samples were combined for comparative purposes. The weight of particles passing each sieve size were in percentages, therefore data were normalized by arcsin transformation for ANOVA (Ott 1984). Next, we examined mean particle size distributions at each freeze-core site by plotting substrate data on a semi-logrithmic scale., Researchers have suggested that spawning substrate samples have particle size distributions close to lognormal (Shirazi and Seim 1979; Tappel and Bjornn 1983). Particle size distributions were plotted on a log scale by taking the percentage of particles by weight of the total core sample that passed each sieve size used. We then connected sieve size values to obtain a smooth line on the graph.

Percent fines (< 0.85 mm) data were calculated from sieve data for each stratum at all sampling sites. Percent fines were calculated by taking the percentage by weight of the total core sample that passed the 0.85 mm sieve.

Geometric mean diameter values (d,) (Platts et al. 1983) were calculated for each strata at all sampling sites. Geometric mean is calculated by the following method:

$$d_g = (d_1^{w_1} \times d_2^{w_2} \times \ldots . d_n^{w_n})$$

where: d_n = midpoint diameter of particles retained on the nth sieve: and

w_n = decimal fraction by weight of particles on the nth sieve

We choose the fredle index of substrate quality (Lotspeich and Everest 1981) to statistically compare ($P \geq 0.05$) vertical stratification within and between each site using ANOVA. The fredle index (f) is calculated by:

$$f = \frac{d_g}{S_o}$$

where: d_g = geometric mean diameter

$$S_o = \frac{d_{75}}{d_{25}} = \text{sorting coefficient}$$

d_{75} and d_{25} = particle size diameters at which 75 or 25 percent of the sample is finer on a weight basis.

Fredle index numbers were log transformed (Ott 1984) for statistical comparison using the transformation equation:

$$f_T = \sqrt{f + 0.375}$$

We obtained comparative data by collecting freeze-core samples in documented chinook salmon spawning areas of the Wenatchee River, Washington and lower Snake River, Idaho. Eight cores were extracted from the Wenatchee River in August before summer chinook spawning began. We sampled the Wenatchee River systematically adjacent to one of our IFIM hydraulic cross-sections in a known chinook salmon spawning area. Six McNeil samples were also taken on the Wenatchee River to test for freeze-coring biases towards small or large particles.

Since hydraulic measurements were not taken on the Snake River, we collected freeze-core samples in two documented fall chinook spawning areas from aerial redd surveys; at river km 245 and immediately below the mouth of Billy Creek (river km 262). We first attempted to sample the Snake River in August. Four cores were sampled successfully at this time from the Billy Creek site.

However, warm summer water temperatures often thawed the core faster than we could extract it. We re-scheduled Snake River sampling during December towards the end of fall chinook spawning to avoid warm water temperatures. Five cores were extracted at Km 245 site adjacent to active fall chinook redds in undisturbed substrate. We noticed no adverse effects of our presence on the behavior of spawning pairs.

The U.S. Forest Service collected freeze-core samples in summer chinook salmon spawning substrate on the SFSR at Poverty Flat during 1990 (Thurow and King, unpublished data) and provided us additional comparative data. The SFSR was sampled during June in undisturbed substrate before spawning began. Of the 15 freeze-cores taken on the SFSR, 9 were comparable and the remaining samples were discarded from analysis because of inadequate sampling of stratum 3.

The potential for chinook salmon survival to emergence was evaluated by comparing the particle diameter composition, d,, percent fines, and the fredle index values calculated for the LMCR to data reported in the literature.

Results

There was no significant difference ($P < 0.05$) in substrate composition comparing freeze-core to McNeil samples taken on the Wenatchee River and LMCR Bedrock Creek study sites. Therefore, we concluded that our freeze core data contained no apparent biases toward large or small substrate particles.

Spawning substrate particle size distribution differences were observed between the six freeze-core sampling sites (Table 4.1, Figure 4.1). With the exception of the Snake River Km 245 site and the LMCR Bedrock Creek site, particle size distributions for freeze-core samples approximated a lognormal distribution. The Snake River Km 245 site contained the largest percentage of smaller substrate particles, approximately double the other sites, except the SFSR, in percentage of particles passing the 2.36 mm sieve. The LMCR Bedrock Creek was almost void of gravel (2.36 to 25 mm) substrate particles.

Comparing the two LMCR sites, Potlatch River site had a higher percentage of gravels (2.36 to 25 mm) than Bedrock Creek site (Table 4.1, Figure 4.1). The Bedrock Creek site contained a higher percentage of particles > 50 mm and fines < 0.85 mm than the Potlatch River site. A higher percentage of fines at the Bedrock Creek site may be a consequence of more interstitial voids created between the larger cobbles.

Table 4.1. Substrate particle size distribution of freeze-core samples from the lower mainstem Clearwater, Wenatchee, Snake, and South Fork Salmon Rivers, 1990.

River (Site)	n	Percentage of particles passing sleve of designated size (mm)																					
		152	128	75	64	50	32	25	16	9.5	8	6.4	4	2.36	2.0	1.0	0.85	0.5	0.425	0.25	0.212	0.125	0.063
Clearwater (Potlatch R.)	12	100		80		52		26						9.2			6.4		1.5		0.01		
Clearwater (Bedrock Cr.)	6	100		70		31		10						9.7			8.5		1.7		0.02		
Wenatchee (W-4)	8	100		52		39		26						8.3			3.8		1.5		0.04		
Snake (Billy Creek)	4	100		67		43		25						10.7			7.2		1.7		0.03		
Snake (Km 245)	5	100		88		77		54						19.2			15.6		7.7		0.06		
SFSR[a] (Poverty Flat)	9		100		73		48		31	24	22	20	16		11	7.2	6.2	3.9	1.5	1.4		0.49	0.22

[a] (Thurow and King, unpublished data)

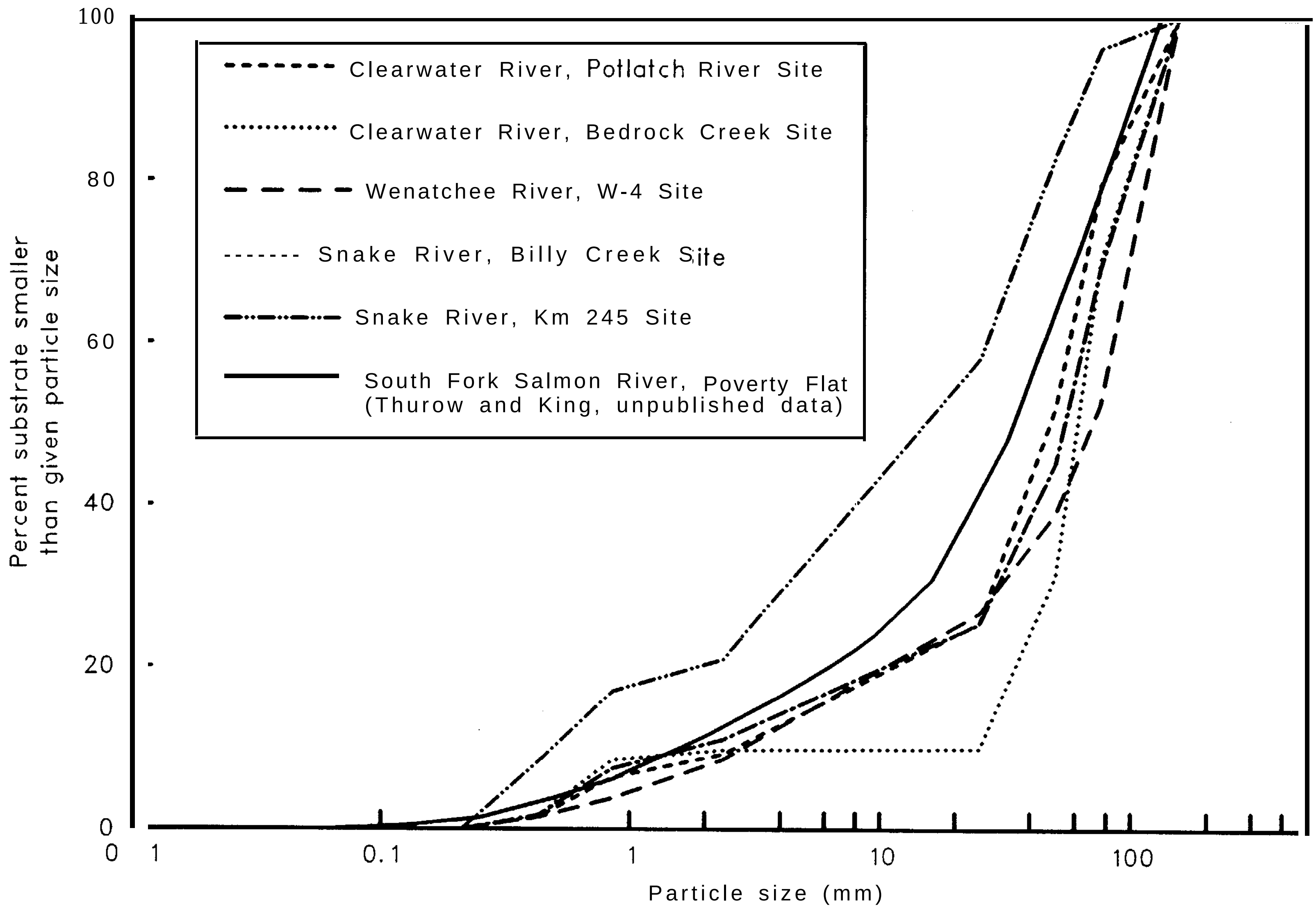


Figure 4. 1. Substrate particle size distributions of chinook salmon spawning areas from freeze-core samples, 1990.

The LMCR Potlatch River site, Wenatchee River, and Snake River Billy Creek site had similar particle size distributions (Table 4.1). The Wenatchee River site contained a somewhat higher percentage of substrate > 50 mm and a lower percentage of fines < 0.85 mm. Although containing slightly higher percentages of intermediate size gravels, the SFSR particle size distribution was most similar to the LMCR Potlatch River site.

Percent fines (< 0.85 mm) in stratum 1 were lowest at the LMCR sites (Table 4.2). Percent fines substantially increased with depth (strata 2 and 3) at both LMCR sites. Percent fines at the LMCR sites were most similar to those calculated for the Snake River Billy Creek site. The Snake River Km 245 site had substantially higher percent fines in all strata. With the exception of the Km 245 site, percent fines were relatively low and ranged from 1.4% in stratum 1 at the LMCR Potlatch River site to 10% in stratum 3 at the LMCR Bedrock Creek site. Unlike the other sites, percent fines on the SFSR were lower in stratum 3 than in strata 1 or 2. This may have resulted from samples inadequately frozen at the freeze probe ends (Russ Thurow, U.S. Forest Service personal communication). Mean dry weight of substrate particles was 1.5 kg for stratum 3 on the SFSR, which was approximately half that of strata 1 and 2 (2.9 and 3.1 kg, respectively). In comparison, our freeze-cores were slightly lower in weight in stratum 1 which averaged 3.0 kg compared to 4.1 and 4.3 kg for strata 1 to 3, respectively.

The geometric mean diameter (d_g) of substrate particles in stratum 1 were similar at both sites on the LMCR, however strata 2 and 3 were considerably higher at the Bedrock Creek site (Table 4.2). The LMCR Bedrock Creek and the Wenatchee River sites had similar d_g values in all three strata. The LMCR Potlatch River site had d_g values that paralleled closely to values calculated for the Snake River Billy Creek site. Overall, the Snake River Km 245 site had the lowest d_g values followed by the SFSR.

Mean fredle index numbers for both sites on the LMCR were relatively high and ranged from 14.0 for stratum 3 at Potlatch River site to 38.8 for stratum 1 at Bedrock Creek site (Table 4.2: Figure 4.2). Mean fredle numbers were significantly higher in stratum 1 than strata 2 or 3 at the Potlatch River site (Table 4.3). Mean fredle numbers for strata 2 and 3 were not significantly different at the Potlatch River site. There was no significant difference in fredle numbers among the three strata at the LMCR Bedrock Creek site. Fredle numbers for stratum 3 at the Bedrock Creek site were significantly higher than stratum 3 at all other sites. Overall, the fredle index tended to decline with depth at most study sites (Figure 4.2).

Table 4.2. **Chinook salmon spawning habitat quality indices based on freeze-core samples from the lower mainstem Clearwater, Wenatchee, Snake, and South Fork Salmon Rivers, 1990.**

River (site)	n	Percent fines (< 0.85 mm) stratum 1	Percent fines (< 0.85 mm) stratum 2	Percent fines (< 0.85 mm) stratum 3	Geometric mean dia. (mm) stratum 1	Geometric mean dia. (mm) stratum 2	Geometric mean dia. (mm) stratum 3	Fredle index stratum 1	Fredle index stratum 2	Fredle index stratum 3
Clearwater (Potlatch River)	12	1.4	7.2	8.7	50.0	30.9	26.6	33.2	16.5	14.0
Clearwater (Bedrock Creek)	6	2.1	9.6	10.0	51.3	40.5	43.6	38.8	27.9	31.5
Wenatchee W-4	8	2.8	4.0	4.9	51.7	42.8	35.4	32.7	21.4	17.4
Snake (Billy Creek)	4	4.3	8.6	9.4	46.8	29.6	28.4	25.5	14.6	17.1
Snake (Km 245)	5	14.3	19.5	15.1	17.4	11.1	12.1	6.6	3.4	4.6
SF Salmon[a] (Poverty Flat)	9	6.1	6.9	5.6	22.1	19.9	29.0	10.6	7.5	18.0

[a] (Thurow and King, unpublished data)

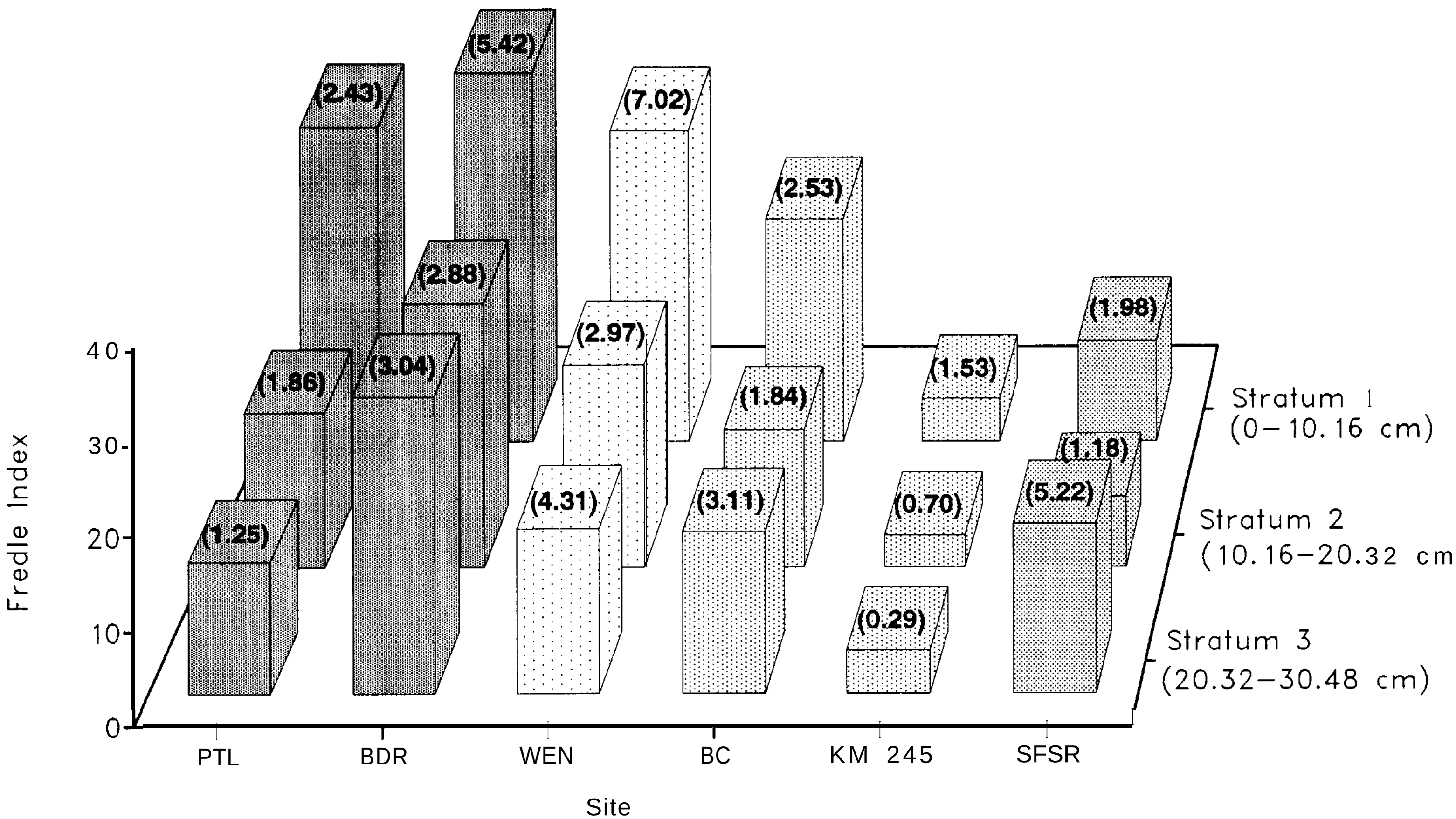


Figure 4.2 Comparison of mean fredle index numbers (standard error) from 1990 freeze-core data on the lower mainstem Clearwater River, Potlatch River (PTL) and Bedrock Creek sites (BDR); Wenatchee River (WEN); Snake River, Billy Creek (BC) and Km 245 sites; and South Fork Salmon River (SFSR) at Poverty Flat (Thurow and King, unpublished data).

Table 4.3. Comparison of mean log transformed fredle index numbers from 1990 freeze-core samples with a common line indicating no significant difference among strata within each site, and a common letter indicating no significant difference within the same stratum between sites, by ANOVA ($P < 0.05$).

River (site)	Sample size	Fredle Index stratum 1	Fredle Index stratum 2	Fredle Index stratum 3
Clearwater (Potlatch River)	12	5.75^{a}	4.03^{c}	3.76^{f}
Clearwater (Bedrock Creek)	6	6.19'	5.29^{d}	5.61
Wenatchee (W-4)	8	5.53^{a}	4.60^{cd}	4.02^{f}
Snake (Billy Creek)	4	5.07^{a}	3.85'	4.03^{f}
Snake (Km 245)	5	2.59^{b}	1.91	2.22^{g}
South Fork Salmon' (Poverty Flat)	9	3.19^{b}	2.73	3.92^{fg}

[1] (Thurow and King, unpublished data).

There was no significant difference in mean fredle index numbers between the three strata at the LMCR Potlatch River site, Wenatchee River site, and Snake River Billy Creek sites (Table 4.3). The Snake River Km 245 site had the lowest fredle numbers in all strata, although not significantly lower than the SFSR in strata 1 and 2. Fredle numbers did not differ significantly among the three strata within the same site at Snake River Km 245 and SFSR (Table 4.3).

Discussion

Despite the low numbers of chinook salmon spawning in the LMCR, overall spawning substrate quality indices were as good or better than all rivers studied, especially in stratum 1. Chapman (1988) reported that yearly spawners typically maintain a spawning area in a coarser and better condition than the surrounding gravels that remain unused. Therefore, the Wenatchee and SFSR sites should be in better condition than the LMCR because chinook salmon have been spawning there for many years. If adult escapement to the LMCR spawning areas would increase through supplementation, spawning substrate quality in strata 2 and 3 may be improved even more and be maintained by the spawners themselves. This is important, because the range of fall chinook egg pocket depths at Vernita Bar on the Columbia River as reported by Chapman et al. (1986) would be from stratum 2 to slightly below stratum 3 on the LMCR. Chapman et al. (1986) reported 4.3 to 5.8% fines (CO.85 mm) should not reduce survival of incubating fall chinook at Vernita Bar on the Columbia River. However, substrate samples at Vernita Bar were taken with the McNeil sampler, so vertical distribution of fines was not determined. Comparing our McNeil data on the LMCR, percent fines were only slightly higher than at Vernita Bar.

The decrease in substrate quality indices with depth as we documented on the LMCR has been noted elsewhere. Adams and Beschta (1980), Everest et al. (1982), and Young et al. 1989) also reported that spawning substrate quality decreased substantially with depth. However, natural variability within spawning substrate and even egg pockets have been documented (Platts et al. 1979; Adams and Beschta 1980; and Everest et al. 1987). The high amounts of fines in all strata at the Snake River Km 245 site may have been the result on a natural phenomena. Although a well documented fall chinook spawning location, the Km 245 site contained angular basalt chips and flakes not typical of smooth oval particles observed at other spawning sites. Meehan and Swanston (1977) reported that more fine sediment accumulated in angular verses round gravel mixtures at higher velocities in artificial stream channels. Higher percentage of fines and low fredle numbers at the Snake River Km 245 site may be attributable to substrate shape.

Shirazi and Seim (1979) showed a strong relationship between geometric mean diameter (d_g) of spawning substrate and survival to emergence using salmonid survival data from laboratory and field experiments. Salmonid species in these studies included coho salmon 0. *kisutch*, sockeye salmon 0. *nerka*, cutthroat trout *Salmo clarki*, and steelhead trout 0. *mykiss*. Predicted survival to emergence was 70-80% at a d_g

of 15 and no negative effect on survival occurred at a d_g of 20 and above. The lowest d_g values on the LMCR were much higher than the highest value tested by Shirazi and Seim. Therefore, if Shirazi and Seim's d_g values can be applied to chinook salmon in the LMCR, survival to emergence prediction would be greater than 90%.

Lotspeich and Everest (1981) used data by Phillips et al. (1975) to calculate fredle numbers in homogeneous gravel mixtures and related survival to "swim-up" for emerging coho salmon and rainbow trout 0. *mykiss* fry. Calculated fredle numbers of 2, 4, and 8 related to 30, 60, and 88% survival to emergence for coho and 45, 75, and 99% for rainbow trout (Lotspeich and Everest 1981). Under laboratory conditions, small increases in the fredle index related to marked increases in survival. However, Everest et al. (1982) stated these results may be misleading when applied to field conditions because homogeneous mixtures of particles are rarely found in natural spawning substrate. Also, the largest diameter of test particles used was only 32 mm which represents only about half the particles found in our freeze-core work.

Everest et al. (1982) compared freeze-core samples taken in fall chinook salmon and steelhead trout spawning substrate on four streams in the Rogue River Basin, Oregon. All streams supported either large populations of chinook or steelhead, however, Evans and Sams Creeks carried a much higher load of fine sediment during freshets than Slate and Foots Creeks. Comparing Evans and Foots Creeks, both streams were similar and classified "good" by visual inspection, however, substantial differences were observed with substrate depth. Fredle numbers calculated for Evans Creek were 8.0, 1.3, and 0.4 for strata 1, 2, and 3, respectively, compared to 8.4, 3.0, and 3.6 for Foots Creek. Survival to emergence was not measured, but predicted low in Evans Creek for fry trying to emerge through the 20-30 cm stratum with a 0.4 fredle index and 41.5% fines (< 1.0 mm). Greater than 50% survival was predicted on Foots Creek with a 3.6 fredle index and 11.5% fines (Everest et al. 1982). By comparison, greater survival would be predicted on the LMCR with considerably higher fredle numbers and lower percent fines.

Chapman (1988) related fredle numbers of laboratory mixtures of spawning substrate to steelhead and chinook salmon fry survival using data from Tappel and Bjornn (1983). Chapman's regressions between surviyal to emergence and fredle numbers were highly correlated ($r^2 = 0.85$ and 0.95 for chinook and steelhead, respectively). Survival to emergence exceeded 90% for a fredle index of 5.0 and above. Survival did not increase with higher fredle numbers as in the work of Lotspeich and Everest (1981) with coho salmon. Tappel and Bjornn (1983) noted the substrate mixtures tested had more 12.7-25.4 mm particles than natural gravels and no particles exceeded 51 mm. Chapman (1988) concluded that the exclusion of larger particles normally found in the egg pocket centrum of large salmonids may distant the test environment from natural redd conditions.

Conclusions

The relationships of egg-to-fry chinook salmon survival to substrate particle size distribution, percent fines, d,, and the fredle index have been studied in the laboratory and in the field and are complex. In general, low percentages of fines relate to high survival provided that some interstitial fines are present to anchor eggs within the egg pocket. High fredle numbers equate to high substrate quality since the magnitude of the index increases with pore size and permeability (Lotspeich and Everest 1981). Regression values in the literature show that a positive relationship exists between the fredle index value and survival to emergence for salmonids. High survival begins at a relatively low fredle index value on these regression lines. The application of published salmonid survival percentages versus particle size, percent fines, d,, or fredle indices to quantify survival in the LMCR would yield tenuous results at best. It is clear, however, that the comparatively high spawning gravel quality found in the LMCR should facilitate chinook salmon natural reproduction.

CHAPTER 5

CHINOOK SALMON SURVIVAL TO HATCH

Abstract-We used intrusion baskets in artificial redds on the lower mainstem Clearwater River (LMCR) as an attempt to relate over-incubation dissolved oxygen levels, water temperature, and sedimentation to chinook salmon ***Oncorhynchus tshawytscha*** survival to hatch. Chinook stocks included the Snake River falls (Lyon's Ferry Hatchery), South Fork Salmon River (SFSR) summers (McCall Hatchery), and Upper Columbia River (UCR) summers (Wells Hatchery). Fine sediment accumulation in baskets at Bedrock Creek (upriver) site was significantly lower than at Potlatch River (downriver) site. Embryo survival within 24 hrs after fertilization was significantly lower in intrusion baskets compared to control buckets. There was a significant higher percent fines (< 0.85 mm) in baskets compared to freeze-core samples at Potlatch River site using the SFSR stock, however, percent fines were significantly lower at Bedrock Creek site. Fredle index numbers were significantly lower in intrusion baskets compared to freeze-coring at Potlatch River site using the SFSR summer and Snake River fall chinook eggs. Other than high September water temperatures (18.5 °C) possibly affecting the survival of SFSR summer chinook, intergravel temperatures and dissolved oxygen were favorable throughout incubation. The intrusion basket technique biased chinook salmon embryo survival and therefore impeded direct measurements of survival. Intrusion baskets appeared to provide an adequate measure of fine sediment accumulation into redds. With the relatively low percent fines that accumulated in intrusion baskets and high fredle index numbers calculated for baskets after chinook salmon hatched, high survival to emergence would be expected on the LMCR.

Introduction

Our freeze-core data (Chapter 4) allowed an assessment of salmonid egg-to-fry survival based on calculated substrate quality indices. These indices, although well founded, were not verified with survival data collected in the lower mainstem Clearwater River (LMCR). Therefore, we attempted to relate survival to hatch of three chinook salmon ***Oncorhynchus tshawytscha*** stocks to over-incubation dissolved oxygen levels, water temperature, and sedimentation in artificial redds. Intrusion baskets (Burton et al. 1990) were fabricated, supplied with fertilized eggs, and implanted into artificial redds constructed on the LMCR near the peak of natural spawning for each stock. Chinook salmon stocks were from the same egg take as in our egg incubation timing study (Chapter 3) and included the Snake River falls (Lyon's Ferry Hatchery), South Fork Salmon River (SFSR) summers (McCall Hatchery), and upper Columbia River (UCR) summers (Wells Hatchery).

Methods

We constructed artificial redds in spawning substrate along hydraulic cross-sections BDR-3 (Bedrock Creek study site) and PL-5 (Potlatch River study site) established during our IFIM study for modeling known fall chinook spawning areas (Connor et al. 1990). The SFSR summer chinook stock was tested in artificial redds at both sites. Due to time constraints, the Snake River fall and UCR summer chinook stocks were tested in artificial redds constructed at the Potlatch River site only.

We constructed the first redd on each cross-section at a point representative of the spawning area and within the spawning habitat suitability criteria for velocity (< 1 m/sec). Once the location for the first redd was selected, we systematically constructed redds beside it at 3 m intervals. Redds measuring approximately 5 m^2 were constructed in a long oval shape as described by Burner (1951). We loosened and lifted the spawning substrate by hand and shovel to create a depression approximately 30 cm deep with a tailspill to mimic a natural redd. Disturbed substrate particles from the tailspill were used to fill three intrusion baskets per redd, with two or three larger cobbles placed at a depth of 20-25 cm in each basket to form the egg pocket centrum (Burton et al. 1990).

We constructed the cylindrical intrusion baskets (25.4 cm dia X 30.5 cm high) using an inner layer of extruded PVC netting (3.2 mm mesh) reinforced by an outer layer of hardware cloth (6.4 mm mesh) (Figure 5.1). Seams were sewn together with 27 kg test monofilament fishing line. The top lids of each basket were initially sewn half way to facilitate spawning substrate and egg placement. Eggs (100/basket) were distribution at an egg pocket depth of 20 to 25 cm. Our egg handling procedures were the same as in our egg incubation timing study (Chapter 3). We filled baskets with spawning substrate and sewed the lids shut prior to redd placement. We found that a length of PVC pipe placed centrally in the basket before substrate filling expedited egg placement. Eggs were funnelled into the pipe as it was gently raised to distribute the eggs vertically (Burton et al. 1990).

A canvas gravel collection bag with three ropes attached to a top ring was collapsed under each basket to facilitate extraction and prevent loss of fine sediment to the stream during extraction (Figure 5.1) (Burton et al.

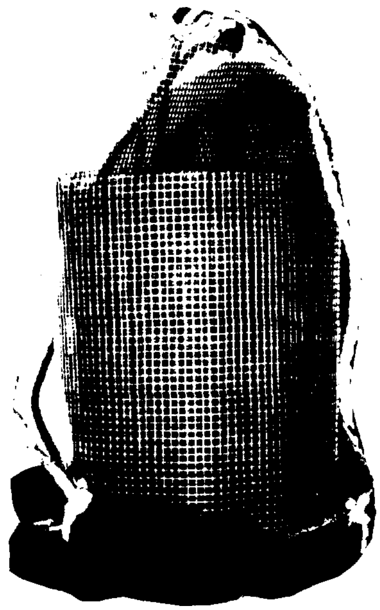


Figure 5.1. Intrusion basket and gravel collection bag used in artificial redds on the lower mainstem Clearwater River, Idaho.

1990). We placed baskets in a triangle approximately 10 cm apart inside the redd and covered them with substrate disturbed immediately upstream. Before covering, an intergravel monitoring probe (Burton et al. 1990) was placed horizontally and parallel to the flow beside the upstream basket at the egg pocket centrum depth of 20 cm.

We constructed intergravel monitoring probes (3.2 cm dia X 30.5 cm) using 0.025 mm continuous coil slot well screen as described by Burton et al. (1990). A length of aquarium tubing (95 mm dia) perforated with 16 mm holes in three locations was placed centrally in each probe and held in place by PVC caps on each end. A hole was drilled in one cap and an L-fitting (6 mm outside dia) attached to the inner tubing. A length of flexible tubing (1 m longer than the redd depth) was attached to the L-fitting which protruded through the substrate to the surface. We monitored intergravel oxygen and temperature periodically throughout incubation. A peristaltic pump was used to clear water from the flexible tubing, which was discarded, and an additional 500 mls extracted from the probe into a beaker. We immediately measured temperature and dissolved oxygen with a standard YSI oxygen meter. We also measured water column temperature and nose velocity (10 cm above baskets) at each redd.

We placed eggs from the Snake and UCR stocks into three 19 liter buckets (100 eggs/bucket) for controls to determine mortality from handling and intrusion basket placement. Control buckets were perforated (2 mm holes) and cabled in the river. A sample of three intrusion baskets were extracted from a randomly selected redd after 24 hours of incubation and mortality compared to control buckets.

We extracted intrusion baskets at hatch timing, as determined by daily temperature unit calculations and data from our incubation timing study (Chapter 3). We calculated survival to hatch for each basket. All basket substrate particles and fines in the gravel collection bags were sieved and measured as described in our freeze-core work (Chapter 4).

The first step in data analysis was to test for significant embryo survival differences ($P \geq 0.05$) between intrusion baskets and control buckets using analysis of variance (ANOVA) (Ott 1984). Next, we tested for potential basket placement biases within a redd and between redds of the same chinook salmon stock by testing for significant differences in percent fines (< 0.85 mm) and fredle index numbers. For a description of the fredle index see Chapter 4. Third, we tested for significant differences in percent fines and fredle index numbers between intrusion baskets in redds between the different chinook salmon stocks. Percentage data for fines were normalized by arcsin transformation for ANOVA (Ott 1984). Finally, as a comparison of pre- and post-spawning substrate quality, we compared percent fines and fredle index numbers in intrusion baskets to our freeze-core results (Chapter 4). Fredle index numbers were log transformed for statistical analysis (Ott 1984).

Results

After 24 hrs of incubation, intrusion baskets resulted in significantly higher egg mortality than the control buckets. Control buckets resulted in 1 and 1.8% mortality for the UCR summer and the Snake River fall chinook eggs, respectively, compared to 32.7 and 13.3% for the same stocks in intrusion baskets. In all likelihood, delayed mortality attributable to handling was a continuing factor to hatch, therefore we disregarded the survival results of this study.

There was no significant difference in percent fines or fredle numbers between intrusion baskets at different locations within a redd, therefore we conclude there was no bias caused by basket placement within the redd. We also found no significant differences in percent fines or fredle numbers between redds at each site using the same chinook salmon stock, therefore we conclude there was no bias caused by redd placement at each site.

Percent fines were significantly higher in intrusion baskets at the Potlatch River (downriver) site compared to the Bedrock Creek (upriver) site for the SFSR summer chinook redds (Table 5.1). At the Potlatch River site, percent fines were significantly higher in baskets within the SFSR summer chinook redds as compared to the Snake River fall chinook redds, but were not significantly higher than in the UCR summer chinook redds. Percent fines were not significantly different in baskets within the UCR summer and the Snake River fall chinook redds. Although baskets within the SFSR summer chinook redds were in the substrate only 77 days, percent fines were significantly higher than in baskets within the Snake River fall chinook redds which were in the substrate 132 days (Table 5.1).

Percent fines were significantly lower in intrusion baskets at Bedrock Creek site compared to freeze-core samples (Figure 5.1). Percent fines were significantly higher in baskets compared to freeze-core samples at the Potlatch River site, except for baskets within the Snake River fall chinook redds which were not significantly different.

Fredle index numbers were significantly higher in intrusion baskets at Bedrock Creek site compared to the Potlatch River site (Table 5.1). No significant difference in fredle numbers was noted for intrusion baskets within redds of various stocks at the Potlatch River site.

Fredle index numbers were not significantly different comparing baskets and freeze-core samples at Bedrock Creek site (Table 5.1). Fredle numbers for baskets were significantly lower than freeze-core samples at the Potlatch River site, except for baskets within the UCR summer chinook redds, which were not significantly different.

Intergravel water temperatures were as high as 18.5 °C on August 30 at the Potlatch River site within the SFSR summer chinook redds (Table 5.2). Intergravel water temperatures were favorable for all other chinook stocks throughout incubation. Intergravel water temperatures were slightly higher than water column temperatures. Dissolved oxygen levels were near saturation and favorable for all stocks throughout incubation (Table 5.2). Dissolved oxygen levels were slightly lower in the substrate compared to the water column.

Table 5.1. Comparison of percent fines (< 0.85 mm) and fredle index numbers in intrusion baskets (IB) and freeze-core (FC) samples on the lower mainstem Clearwater River (LMCR), with a common line indicating no significant difference between baskets and freeze-core samples and a common letter indicating no significant difference between baskets using different chinook salmon stocks, by ANOVA ($P \leq 0.05$).

Chinook salmon stock used	LMCR study site	No. of baskets tested	Date placed	Date pulled	No. days in substrate	Percent fines (IB)	Percent fines (FC)	Fredle index (IB)	Fredle index (FC)
South Fork Salmon River summers	Bedrock Creek	6	8/29/90	11/14/90	77	2.2	8.5	39.4	32.7
South Fork Salmon River summers	Potlatch River	6	8/29/90	11/14/90	77	13.4[a]	6.4	14.9[c]	21.2
Upper Columbia River summers	Potlatch River	9	10/25/90	2/26/91	124	9.4[ab]	6.4	17.6’	21.2
Snake River falls	Potlatch River	12	11/9/90	3/21/91	132	7.5[b]	6.4	13.1[c]	21.2

Table 5.2. Artificial redd substrate and water column temperature, dissolved oxygen (DO), and nose velocity (10 cm over redd) data for the lower mainstem Clearwafer River (LMCR), Idaho.

Chinook salmon stock used	LMCR study site	Date	Substrate temperature (°C)	Water column temperature (°C)	Substrate DO (mg/l)	Water column DO (mg/l)	Nose Velocity (cm/sec)
South Fork Salmon River summers	Bedrock Creek	8/30/90	16.8	16.2	8.8	9.6	55
		10/1/90	12.6	12.6			50
		10/8/90	10.0	9.8	10.3	10.8	70
		10/29/90	7.9	7.7	11.1	11.5	70
		11/14/90	4.7	4.4	12.0	12.4	60
South Fork Salmon River summers	Pottatch River	8/30/90	18.5	18.0	9.0	9.6	90
		10/1/90	12.1	12.0			88
		10/8/90	9.1	9.1	10.1	10.7	140
		10/29/90	7.8	7.5	11.1	11.7	126
		11/14/90	5.3	5.0	12.0	12.5	90
Upper Columbia River summers	Potlatch River	10/26/90	8.5	8.2	10.6	10.9	120
		10/29/90	8.0	7.6	11.2	11.7	96
		11/10/90	7.0	6.0	11.2	11.0	98
		11/14/90	5.3	5.0	12.1	12.5	89
		2/26/91	2.8	1.8	12.0	12.8	90
Snake River falls	Potlatch River	11/10/90	7.0	6.0	11.0	11.2	98
		11/14/90	5.8	5.0	12.2	12.5	49
		2/26/91	2.8	1.9	12.4	12.8	90
		3/21/91	5.0	4.2	12.8	13.4	84

Discussion

Survival of chinook salmon eggs in intrusion baskets was biased because of excessive handling mortality and mechanical shock during placement of baskets into artificial redds. Freshly fertilized eggs placed in intrusion baskets were subject for a short time to high water column velocities. Consequently, we observed eggs pinned and dying (turning white) on the downstream side of baskets as we were covering them with substrate. Also, covering baskets with spawning substrate may have contributed to mechanical shock. Perhaps a shield placed over the basket until redd placement and substrate covering would improve the intrusion basket technique to assess survival in large rivers. Although biases in the intrusion basket technique did not allow a direct measurement of over-incubation survival, baskets appeared to provide a good index of fine sediment accumulation into redds.

The significantly higher percent fines in baskets within SFSR summer chinook redds at the Potlatch River site, as compared to Bedrock Creek, may have resulted from a storm runoff event during mid-September. Murphy (1986) reported that LMCR tributaries transport large sediment loads during runoff events. High amounts of sediment transported via Potlatch River, located approximately 9 km upstream from the site, could have accelerated sedimentation into redds and baskets. Potlatch River traverses mostly agriculture land and is a larger tributary than Bedrock Creek. In contrast, Bedrock Creek descends through rocky canyon and has lower sediment loads.

Intergravel water temperatures in the LMCR during the end of August may have been too warm for chinook salmon survival. Olson and Foster (1989) reported chinook salmon eggs incubated at 16.1 °C did not experience significant loss. However, Heming (1982) reported reduced survival of chinook eggs incubated at 12 °C. Johnson and Brice (1953) found that chinook salmon eggs experienced excessive mortality when the initial incubation temperature was above 15.6 °C, even though temperatures were below 12.8 °C within a month. Intergravel water temperatures were favorable for chinook salmon incubation on the LMCR during the winter. Combs (1965) reported chinook salmon eggs that had developed to the 128-cell stage (12 days of incubation at 5.8 °C) could tolerate water at 1.7 °C for the remainder of the incubation period. After the 128-cell stage for chinook stocks studied on the LMCR, the lowest intergravel water temperature recorded was 2.8 °C.

Dissolved oxygen levels in artificial redds were near saturation throughout incubation. A minimum dissolved oxygen level of 5 mg/l during incubation seems to be the consensus for salmonids (Everest et al. 1987). Dissolved oxygen levels in the LMCR remained high during incubation at all sites and time periods measured.

Although intergravel temperature and oxygen were favorable throughout incubation, we measured slightly lower dissolved oxygen and higher water temperatures in the substrate compared to the water column. Burton et al. (1990) also reported slightly lower substrate dissolved oxygen concentrations in artificial redds using intergravel monitoring probes. Thurow and King (1991) reported temperatures in natural and artificial redds on the SFSR were generally within 1 °C of water column temperatures. However, Thurow and King (1991) reported that dissolved oxygen concentrations were depressed from decaying eggs in natural egg pockets but not in artificial redds. Placement of the intergravel monitoring probe outside of egg pockets in artificial redds may have inaccurately measured oxygen conditions in the immediate vicinity of the eggs (Thurow and King 1991). Had it been possible to place the intergravel monitoring probes inside the intrusion baskets next to the eggs, we may have measured slightly lower dissolved oxygen levels in the substrate on the LMCR.

Conclusions

We were unable to obtain direct measurements of chinook salmon egg to hatch survival due to excessive handling mortality that occurred during egg handling and intrusion basket placement. Physical data collected within artificial redds indicated that a fall storm runoff event may carry high sediment loads that could infiltrate redds of early spawning summer chinook salmon. Redds constructed later in the fall had a longer incubation period from egg to hatch, but showed little difference between pre- and post-spawning substrate conditions. Summer chinook spawning in August and September presents a risk of egg incubation in unfavorably warm water. October and November spawners would experience more favorable incubating temperatures. Overall, the relatively low percentage of fines that accumulated in intrusion baskets and the high fredle index numbers calculated after chinook salmon hatched, suggest favorable conditions for egg to emergence survival for chinook salmon on the LMCR.

CHAPTER 6

FISH DENSITY ESTIMATES

Abstract-We determined the relative seasonal densities of fishes present in the lower mainstem Clearwater River (LMCR) during 1989 and 1990. Direct observation lanes (snorkeling and SCUBA) were assigned into habitat types using a proportional sampling strategy. Fish densities were calculated based on the number of fish observed by area covered (#/ha). Fish densities in observation lanes were combined and averaged to reflect upriver and downriver densities. Only 1 chinook salmon Oncorhynchus *tshawytscha* juvenile (age 1+) was observed during 1989 compared to 56 in 1990. During 1990, chinook juvenile densities declined from 19.0 to 1.8/ha at the upriver sites and 4.9 to 1.3/ha at the lower river sites in the summer and fall, respectively. Wild rainbow/steelhead trout 0. *mykiss* fry (age 0+), juveniles (age 1+), and hatchery juveniles were also more abundant in 1990 than 1989. Highest 1990 summer densities were 14.5, 16.5, and 25.8 fish/ha for wild rainbow/steelhead fry, wild juveniles, and hatchery juveniles, respectively. Salmonid densities declined in the fall during both years and were not observed during the winter. The redside shiner *Richardsonius balteatus* was the most abundant species with densities as high as 24,966/ha during the summer, 1990. Shiner densities were highest in the summer, declined considerably in the fall, and shiners were rarely observed in the winter. Mountain whitefish *Prosopium williamsoni* and sucker (largescale *Catostomus macrocheilus* and bridgelip C. *columbianus)* densities were highest in 1989 at 72.5 and 160/ha, respectively. Sucker densities were highest in the summer and progressively declined in the fall and winter. Whitefish densities were highest in the fall in 1989 and in the summer in 1990. Whitefish were the most numerous species observed during the winter. Averaging densities during 1989 and 1990, whitefish and suckers outnumbered all juvenile salmonids approximately 10 to 1.

Introduction

This study was the first attempt to calculate fish densities in the lower mainstem Clearwater River (LMCR). We used direct observation (snorkeling and SCUBA diving) because the LMCR is large and deep, has good visibility, and its low conductivity is not conducive to electrofishing. Petrosky and Holubetz (1987) demonstrated that direct observation is an excellent method for censusing chinook, salmon *Oncorhynchus tshawytscha* and steelhead 0. *Mykiss* parr in typical Idaho streams. Our objective during 1989 and 1990 was to calculate relative seasonal densities of anadromous and resident fishes in the LMCR.

Methods

Direct Observation Lane Assisnment

Direct observation lanes were established within the LMCR study sites using a modification of the proportional sampling approach (Bain et al. 1982 cited in Bovee 1986). Proportional sampling requires the division of each study site into finely delineated habitat types (Appendix A, Table A.l). We used a modification of Bain's approach because of the large size of the LMCR. Pool and run habitat types located on bends were further divided into inside and outside units to provide for habitat differences caused by the triangular shape of the channel (Appendix A, Table A.2). We classified runs deeper than 4 m as deep runs.

We determined which habitat types to sample based on area. The most abundant habitats at each site were sampled. If a habitat type contributed less than 10% of the total site area it was not sampled except when this habitat was of special interest (i.e. intermittent side channel capable of stranding fish). We used a planimeter on aerial photographs taken at a flow approximately equal to LMCR's average annual discharge of 397 cms (14,000 cfs) to measure habitat area within each site.

The lane lengths varied to achieve sampling intensity proportional to habitat type area. The single most abundant habitat at all sites was represented with an arbitrarily established distance of 366 m (Appendix A, Table A.3). Lane lengths at all remaining sites were determined by dividing the area of their respective habitat by the area of the most abundant habitat. We then multiplied 366 m by this fraction to determine the length of the lane. This also insured that sampling effort at each site was proportional to site area. Larger sites received more sampling effort (in terms of lane length) than small sites.

During our 1990 sampling, we corrected an error made in the proportional sampling strategy in 1989. An additional study lane at Potlatch River site and two additional study lanes at Bedrock Creek site were established during 1990. Correction factors were applied to the 1989 data (Connor et al. 1990) to make the 1990 fish densities directly comparable. Corrected habitat type areas, lane assignments, and lengths are in Appendix A (Tables A.2 and A.3). Corrected direct observation lanes are in Appendix A (Figures A.1-A.4).

Lane widths were measured to the middle of the channel thalweg. Therefore, as discharge increased, lane width increased and vice versa. The actual placement of the lanes was done by superimposing a numbered grid over site photographs and drawing random numbers.

In the field, study lanes were cross-sectionally stratified based on water depth into snorkeling and SCUBA corridors (Figure 6.1). Snorkeling corridors were up to 1.2 m (4.0 ft) deep and SCUBA corridors ranged from 1.2 to 7.6 m (4.0 to 25.0 ft) deep. Dive buoys were used to mark the boundaries of both strata and to provide guidance for the divers. We used hand held range finders and survey tapes to measure distances from the shore to each of the four buoys and total channel width.

Collection of Fish Density Data

During 1989, we sampled each lane at each study site approximately bi-weekly from July through November and once in December. During 1990, we sampled the same lanes, plus the three new lanes, once in July and August for summer density estimates and once in September and October for fall density estimates. We did not conduct density estimates in the winter of 1990. Because of poor water visibility during the 1990 sampling period, SCUBA was only conducted during the August counts. We conducted one counting pass in each study lane during each daylight sampling period.

Two snorkelers completely sampled the inshore shallow snorkeling corridor by creeping downriver (Figure 6.1). The SCUBA team covered the deeper SCUBA corridor by drifting, crawling, and walking a diagonal downriver descent pattern. Prior to the dive we assessed the maximum underwater visibility. We used the maximum underwater visibility to establish the observation distance within which to count fish. To do so, we first multiplied the maximum underwater visibility by a reduction factor of 0.6. Secondly, we cut a piece of cable twice this calculated length and marked its midpoint with flagging. During the dive we held the cable taut between divers to insure that spacing was kept constant. The cable also regulated the observation distance within which fish were counted. Each diver counted fish which passed between himself and the ribbon on the cable and within half a cable length to his left or right (Figure 6.1). Fish species, size, nose depth, and association with other fishes were recorded immediately on slates after sighting.

Divers wore up to 30 Kg (66 lbs) of lead and felt soled wading boots to facilitate control during downriver descent. This technique proved executable in water with bottom velocities less than 1.2 m/sec (4.0 ft/sec). Each study site contained swift water sampling lanes with bottom velocities exceeding 1.2 m/sec (4.0 ft/sec). Therefore,

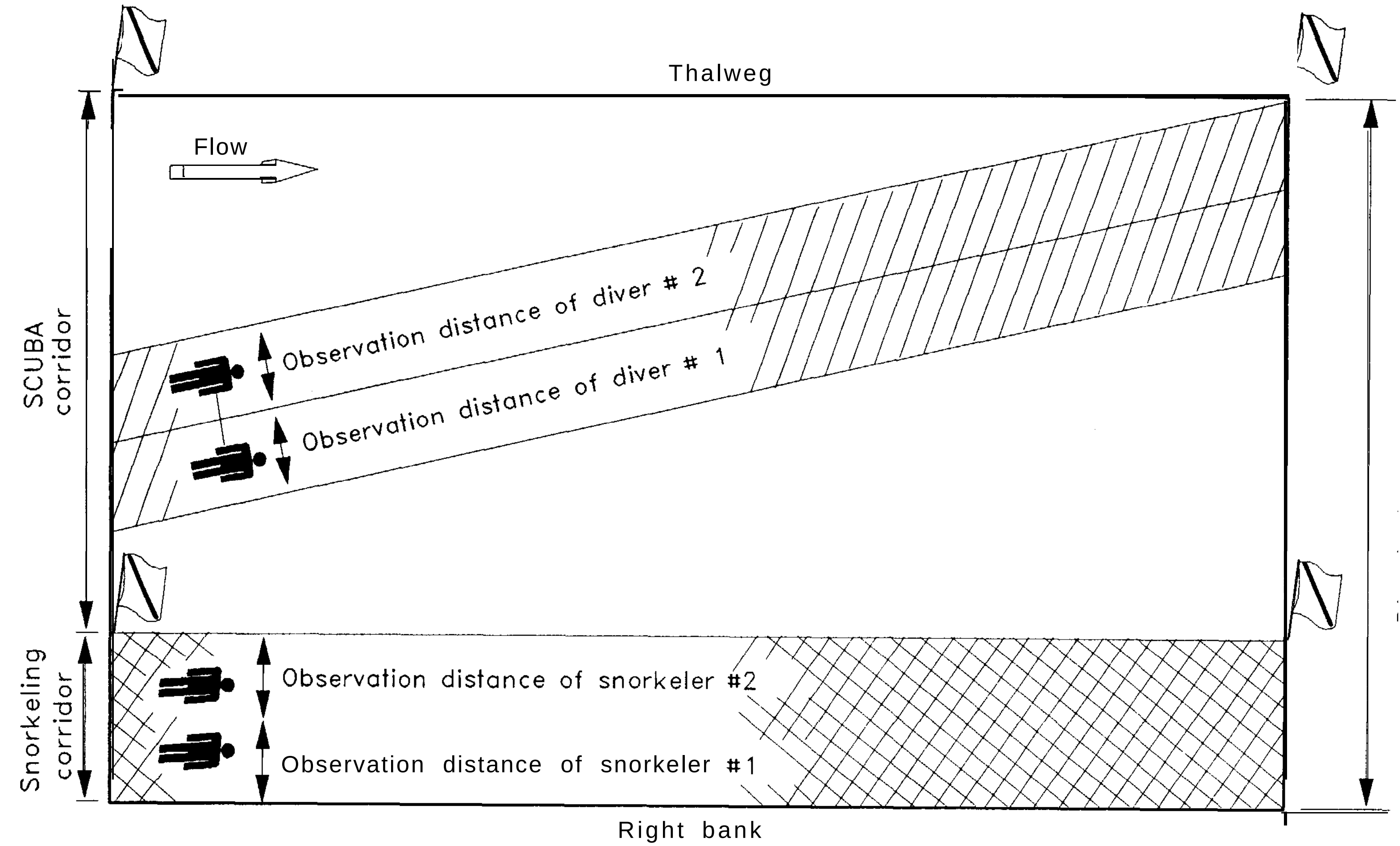


Figure 6.1. Direct observation lane divided into the SCUBA sublane, snorkeling sublane, and observation area by technique (SCUBA = ▨ and snorkeling = ▩).

swift water lanes were sampled using a pass through technique similar to that described by Schill and Griffith (1984). We sampled swift water lanes by dropping two snorkelers off a support boat at the top of the SCUBA corridor. These snorkelers counted fish within their respective observation distance while floating downriver through the buoy marked boundaries of the corridor.

Fish Density Data Analvsis

We calculated fish densities in each snorkeling corridor by dividing the number of each species observed by the snorkeling corridor area. SCUBA corridor densities were calculated by dividing the number of each species observed on SCUBA or pass through by the observation area. We calculated observation area by multiplying the total observation distance (the sum of both divers observation distances) by the length of the median diagonal that bi-sected the SCUBA corridor (Figure 6.1).

Once density estimates were calculated for each species and observation technique, a composite lane weighted mean density was calculated by combining the snorkeling and SCUBA corridor (or pass through) data using the following formula:

$$\frac{(SnSp/m^2 \times Snm^2) + (ScSp/m^2 \times Scm^2)}{Snm^2 + Scm^2}$$

Where: $SnSp/m^2$ = species density in snorkeling corridor

Snm^2 = snorkeling corridor area

$ScSp/m^2$ = species density-in the SCUBA observation area

Scm^2 = SCUBA corridor area

Because of the similarity of the upriver sites (North Fork and Big Canyon), composite lane means were summed and averaged by species, size, and season. We also calculated average densities for the same categories on data from lower river sites (Bedrock Creek and Potlatch River). Age for size groupings of wild rainbow/steelhead trout was determined using data collected during our tributary study (Connor et al. 1990). Hatchery residualized rainbow/ steelhead trout were all age 1+ and identifiable from wild fish by a missing adipose fin. We classified redside shiners ***Richardsonius balteatus*** < 5.0 cm as age 0+ and those > ***5.0*** cm as age 1+. We did not separate mountain whitefish

Prosopium williamsoni and largescale ***Catostomus macrocheilus*** and bridgelip C. ***columbianus*** suckers into size classes. However, we combined both species of suckers during direct observation to calculate total sucker densities.

Results

Chinook salmon juveniles were more abundant during the summer and fall during 1990 than in 1989 at both the upper and lower river study sections (Tables 6.1 and 6.2, Figure 6.2). A total of 56 chinook juveniles were observed in study lanes during 1990 compared to only 1 in 1989. During 1990, chinook juveniles declined from 19.0 to 1.8/ha at the upriver sites and from 4.9 to 1.3/ha in the lower river sites in the summer and fall, respectively. We did not observe any chinook salmon fry in either years.

Wild rainbow/steelhead trout fry (age 0+) and juveniles (age 1+), and residualized hatchery smolt densities were highest in the summer and declined in the fall during both years at both study sections (Tables 6.1 and 6.2, Figure 6.3). Highest 1990 summer densities were 14.5, 16.5, and 25.8/ha for wild rainbow/steelhead fry, wild juveniles, and hatchery juveniles, respectively. Like chinook salmon parr, densities of wild rainbow/steelhead fry and juveniles at both study sections were considerably higher during 1990 than 1989. Hatchery rainbow/steelhead densities in the upper river were higher in the summer during 1990, however declined below 1989 densities in the fall (Table 6.1, Figure 6.3). Hatchery rainbow/steelhead densities were similar in the lower river in both the summer and fall comparing both years (Table 6.2, Figure 6.3). Wild rainbow/steelhead fry, wild juveniles, and hatchery juveniles were more abundant in the upriver study sites than downriver sites during both years. No rainbow/steelhead trout were observed in the winter during 1989.

Age 0+ and age 1+ redside shiners were more abundant at both study sections during 1990 than 1989 (Tables 6.1 and 6.2, Figure 6.4). Densities were also higher during the summer compared to the fall with no age 1+ shiners observed in the fall, 1990. Conversely to 1989 densities, age 0+ shiners were more abundant downriver than upriver in 1990. During both years, age 0+ shiner densities were higher than age 1+ densities. Age 0+ shiner densities were as high as 24,966/ha in the summer, 1990 and far outnumbered any other species. Only a few age 0+ shiners were observed in the winter during 1989.

Sucker densities were higher during the summer than fall at both study sections for both years (Tables 6.1 and 6.2, Figure 6.5). Sucker densities were lower during 1990

Table 6.1. Mean fish densities expressed as numbers/ha and standard error (#) for selected species at the North Fork and Big Canyon Creek study sites, lower mainstem Clear-water River, Idaho, 1989-90.

Species	Summer 1989	Summer 1990	Fall 1989	Fall 1990	Winter 1989
Chinook 1+	0.0(0.0)	19.0(10.3)	0.0(0.0)	1.8(1.8)	0.0(0.0)
Wild rainbow/ steelhead 0+	2.8(0.2)	14.5(6.9)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Wild rainbow/ steelhead 1+	1.9(0.2)	16.5(13.2)	0.2(0.0)	3.7(2.5)	0.0(0.0)
Hatchery rainbow/ steelhead 1+	7.6(0.5)	25.8(18.7)	5.6(0.7)	1.8(1.8)	0.0(0.0)
Redside shiners 0+	2006(202)	5548(2302)	0.0(0.0)	372(325)	0.0(0.0)
Redside shiners 1+	9.3(0.9)	1887(1272)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Suckers	160(11.6)	53.3(25.4)	19.2(2.8)	0.0(0.0)	2.5(0.5)
Mountain whitefish	51.7(3.7)	14.7(5.7)	65.8(8.1)	3.7(2.5)	8.8(0.7)

than 1989 in the summer and fall at both study sections. The highest sucker density was 160/ha at the upriver sites in the summer 1989. During the winter 1989, sucker densities declined considerably and were similar to whitefish densities when averaging the upriver and downriver study sites.

Mountain whitefish densities were highest during the fall than summer, 1989, however the opposite was observed in 1990 (Tables 6.1 and 6.2, Figure 6.5). The highest whitefish density was 72.5/ha at the lower river sites in the fall 1989. Like sucker densities, overall whitefish densities were higher in 1989 than in 1990. Whitefish was the most numerous species observed during the winter when averaging both study sections.

Table 6.2. Mean fish densities expressed as numbers/ha and standard error (#) for selected species at the Potlatch River and Bedrock Creek study sites, lower mainstem Clearwater River, Idaho, 1989-90.

Species	Summer 1989	Summer 1990	Fall 1989	Fall 1990	Winter 1989
Chinook 1+	0.0(0.0)	4.9(3.3)	--------[a]	1.3(1.3)	0.0(0.0)
Wild rainbow/ steelhead 0+	0.5(0.0)	5.7(4.3)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Wild rainbow/ steelhead 1+	0.9(0.2)	3.0(2.3)	0.0(0.0)	0.1(0.1)	0.0(0.0)
Hatchery rainbow/ steelhead 1+	2.1(0.2)	1.4(1.3)	0.2(0.0)	0.2(0.2)	0.0(0.0)
Redside shiners 0+	897(163)	24,966 (13,292)	0.0(0.0)	494(242)	1.6(0.2)
Redside shiners 1+	54.9(6.5)	157(132)	9.5(0.0)	0.0(0.0)	0.0(0.0)
Suckers	43.8(3.0)	36(11.1)	73.7(5.3)	25(10.4)	10.9(0.9)
Mountain whitefish	26.9(3.2)	31.7(19.8)	72.5(6.0)	5.6(2.8)	7.0(0.7)

[a] Density was not calculated, only 1 fish was observed.

Other fishes observed in the LMCR in low numbers included the northern squawfish ***Pytochelius oregonensis,*** smallmouth bass ***Micropterus dolomienui,*** dace ***Rhinichthys*** sp, sculpin *Cottus* sp, kokanee 0. ***nerka,*** and common carp ***Cyprinus carpio.***

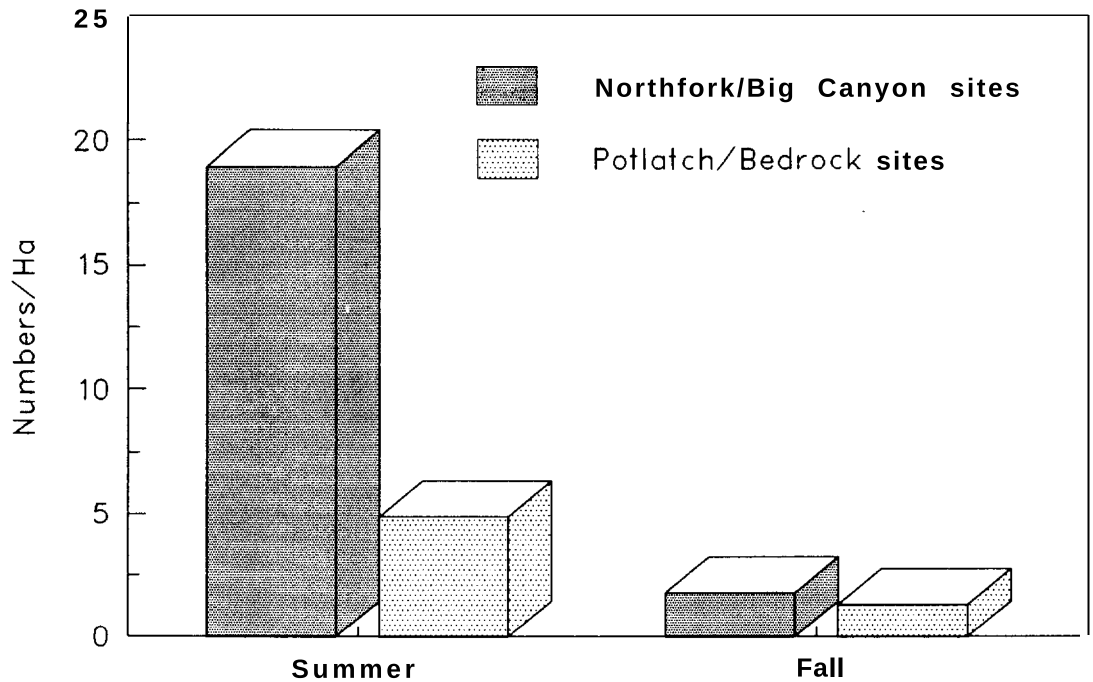


Figure 6.2. Mean chinook salmon juvenile densities by study sites on the lower mainstem Clearwater River, 1990.

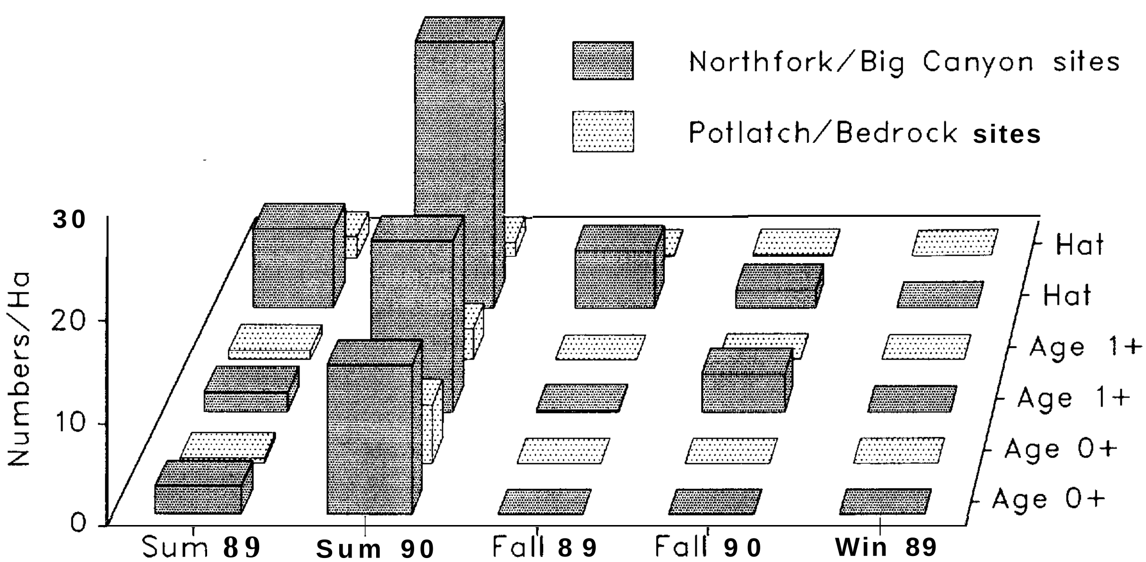


Figure 6.3. Mean rainbow/steelhead trout wild fry (age 0+ , wild juveniles (age 1+), and hatchery juveniles (hat3 by study sites on the lower mainstem Clearwater River, 1989-90.

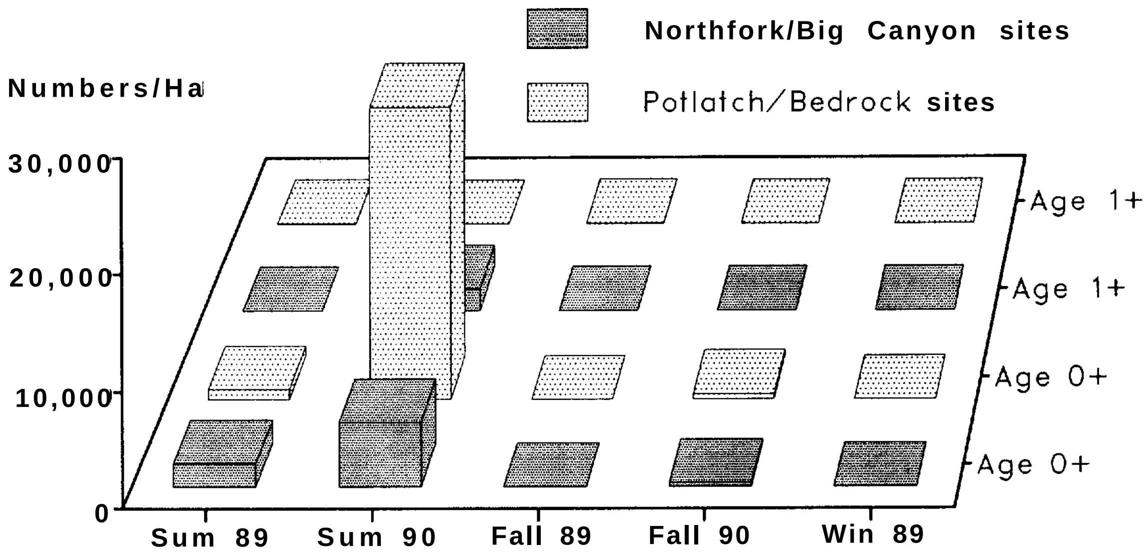


Figure 6.4. Mean redside shiner fry (age 0+) and adult (age 1+) densities by study sites on the lower mainstem Clearwater River, 1989-90.

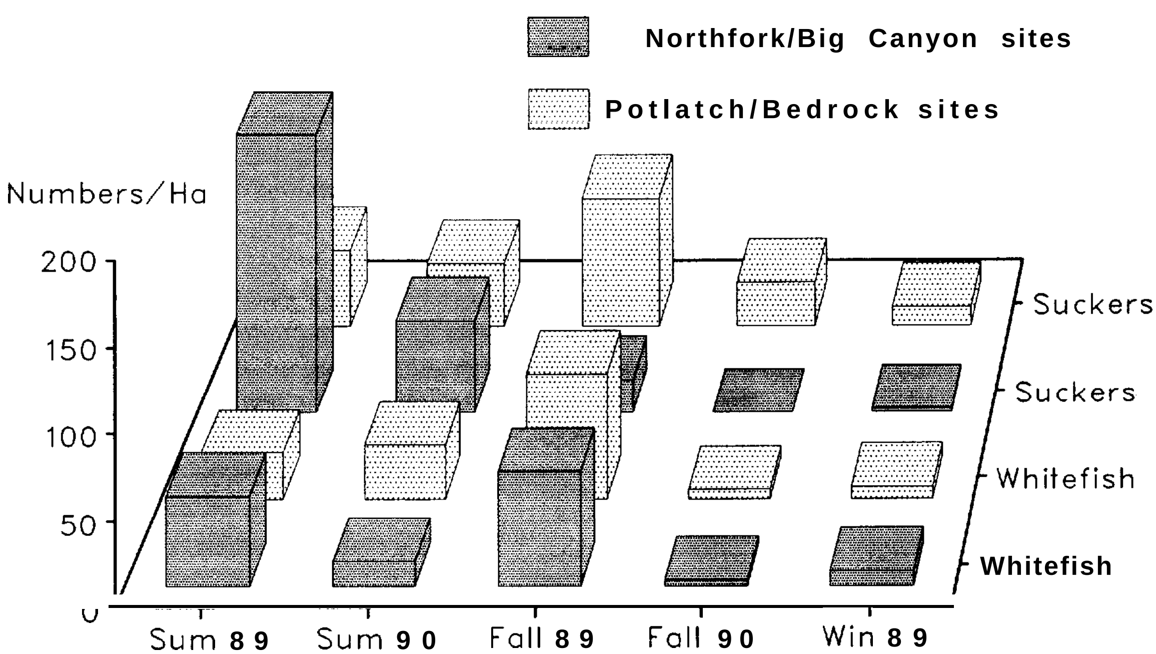


Figure 6.5. Mean whitefish and sucker densities by study sites on the lower mainstem Clearwater River, 1989-90.

Discussion

Anadromous fish densities in the LMCR were extremely low in both 1989 and 1990. Higher chinook salmon densities in the summer 1990 were probably slow outmigrating or residualized smolts from Dworshak National Fish Hatchery. Also, almost all of these smolts were found in the upper river study section which was closer to the hatchery. Petrosky and Holubetz (1988) felt that "excellent" stream habitat in Idaho supported juvenile chinook salmon and steelhead trout densities of 108 and 20 fish/ha, respectively. Although these estimates were for smaller tributary streams, densities of chinook and steelhead in the LMCR were far below these capacities. After Dworshak Dam construction, Brusven and MacPhee (1976) reported the LMCR was very rich in aquatic insects, however fluctuating flows could potentially have an affect on insect inhabitants in zones of fluctuations. Bjornn and Riser (1991) contend that temperature, productivity, suitable space, and water quality (turbidity, dissolved oxygen, etc.) are some parameters regulating the general distribution and abundance of fish within a stream. Of these parameters, a limiting factor for rearing salmonids in the LMCR may be warm July and August water temperatures (Connor 1989). This is addressed in greater detail in Chapter 12.

Suckers and whitefish were the second and third most abundant species present in the LMCR. Overall, suckers and whitefish outnumbered juvenile salmonids approximately 10 to 1 during the summer and fall when averaging both years. Although we did not separate out age classes, suckers and whitefish were mostly observed as adults.

Higher densities of salmonids and lower densities of suckers and whitefish during 1990 than 1989 may have been a result of sampling dates and number of samples taken. We sampled more intensively throughout the summer and fall in 1989, which would better represent the overall seasonal average estimate of density. Due to poor water visibilities during our 1990 counts, we sampled primarily by snorkeling which may presented a bias in overestimating salmonid densities in the entire river. We found more salmonids along the shoreline and more suckers and whitefish in mid-channel. This would also explain why densities of suckers and whitefish were lower in 1990 compared to 1989. Also, fish densities in the LMCR may be somewhat variable from one year to the next.

Study lanes differed in water depth, velocities, and substrate and hence species abundances. Therefore, confidence limits on density estimates when averaging different study lanes would be wide in some cases. Redside shiners densities, for example, varied considerably which was partly due to differing study lane habitats but was mostly the result of their schooling nature. We observed 1,000 or more shiners in a single school and usually they were found in slower pools. Rainbow/steelhead trout fry and juveniles were almost always encountered within riffle and rapid/riffle study lanes and were seldom found in slower runs and pools.

Conclusions

Due to the lack of data on rearing anadromous fish densities in large Idaho rivers, the LMCR could not be directly compared. Also, low anadromous fish densities in the LMCR may also be a result of the declining numbers of wild fish in the Clearwater River Subbasin. A major difference in the LMCR and smaller tributary streams is the lack of shade, woody debris, and boulder cover in the LMCR. The LMCR may better exemplify a migration corridor than an "excellent" rearing river. However, based on the high productivity, the LMCR should be favorable for rearing salmonids. Although water quality was found to be suitable for salmonids in the LMCR (Connor 1989), high water temperatures in July and August may be a limiting factor for rearing salmonids. Alternative discharge and temperature releases at Dworshak Dam during these months could dramatically improve salmonid rearing habitat in the LMCR (Chapter 12).

CHAPTER 7

SMOLT OUTMIGRATION TIMING AND SURVIVAL

Abstract-The original goal of this study was to document outmigration timing of Snake River fall chinook Oncorhynchus tshawytscha (Lyon's Ferry Hatchery) from a spring/summer release of PIT-tagged (Passive Integrated Transponder) parr in the lower mainstem Clearwater River (LMCR). Unfortunately, we were unable to obtain fall chinook and alternatively used spring chinook subyearlings (parr) from Dworshak National Fish Hatchery (DNFH). We PIT-tagged and panjet marked 3,956 spring chinook parr and released them into a side channel on the LMCR in October. Another 3,990 non-tagged parr served as a control to assess effects of tagging on mortality and behavior. Tagging did not contribute to any short-term mortality. Emigration of parr out of the side channel was immediate. Snorkeling counts resulted in only 106 parr observed one day following release. A total of 526 (13.3%) of our PIT-tagged parr were electronically detected the following spring at Lower Granite, Little Goose, and McNary Dams. Peak migration was April 14, April 25, and May 4 at these dams, respectively. Based on a fish guidance efficiency of 57.3% and turbine mortality was 11% at all Snake River dams, overwinter survival of PIT-tagged chinook parr in the LMCR and/or Snake River pools was conservatively estimated at 25%.

Introduction

The original goal of this study was to document outmigration timing of Snake River fall chinook salmon Oncorhynchus *tshawytscha* (Lyon's Ferry Hatchery) through a spring/summer release of PIT-tagged (Passive Integrated Transponder) subyearlings (parr) in the LMCR. However, authorization from the Idaho Department of Fish and Game (IDFG) to obtain Lyon's Ferry fall chinook was not obtained until after eggs hatched. Subsequently, hatched eggs were not allowed to be brought to into the state. Therefore, we opted to substitute Dworshak National Fish Hatchery (DNFH) spring chinook parr which were released in the LMCR during the fall. The objectives of this study were to: 1) investigate the carrying capacity of physical habitat in the side channel based on parr emigration and distribution: 2) obtain microhabitat preferences of hatchery chinook parr for PHABSIM analysis; 3) explore the assumption that PIT tags do not affect fish behavior in the natural environment by comparing microhabitat preferences of tagged versus non-tagged fish; and 4) obtain a conservative estimate of parr-to-smolt survival for outplanted chinook parr based on the numbers of fish interrogated through smolt collection facilities at Lower Granite, Little Goose, and McNary Dams.

Methods

On September 25 and 26, 1990, we assisted experienced IDFG personnel with PIT-tagging (Prentice et al. 1990) of 3,980 spring chinook parr at DNFH. IDFG personnel anesthetized parr with MS-222 and injected PIT tags into the body cavity using a 12-gauge hypodermic needle. Fork length was measured to the nearest mm and fish were weighed to the nearest 0.1 g using an electronic balance. After each fish was PIT-tagged, we injected Alcian blue dye into the upper caudal fin with a panjet marker (Hart and Pitcher 1969). The PIT-tagged and panjet marked fish were placed in a holding tank inside DNFH. In an identical holding tank, another 4,016 parr, that were not tagged or marked, served as a control. Parr were held at the DNFH facility for two weeks to examine mortality of the PIT-tagged and control groups, retention of PIT tags, and retention of panjet marks.

On October 9, 1990 we transported, via truck with oxygen tanks, both groups of parr to the LMCR Potlatch River study site (Hog Island complex, river km 8) and released them into a side channel (Figure 7.1). A total of 3,956 PIT-tagged and 3,990 non-tagged parr were released. Water temperatures in the tank and the LMCR were measured to see if acclimation was required. We recorded transportation and/or handling parr mortalities and condition of both groups before release.

PIT tag numbers were cataloged under ten tag file names consisting of WPC90267.DW1 through DW4 and WPC90268.DW1 through DW6. All tagging information was sent to the Columbia River Basin PIT Tag Information System (PITAGIS). We also provided PITAGIS a mortality list of PIT-tagged fish for extraction from their records.

We snorkeled the side channel and main river channel edge (Figure 7.1) for two days (October 10 and 11) following release and counted parr. We also snorkeled on October 31, 22 days after parr release. Microhabitat preference data were collected on all parr counted.

We collected outmigration timing on PIT-tagged parr the following spring at PIT-tag interrogation (detection) facilities at Lower Granite and Little Goose Dams (first two dams downstream on the lower Snake River), and at McNary Dam (first Columbia River dam downstream from the Snake River confluence). We calculated percent recovery of PIT-tagged fish at each dam. Based on interrogation numbers at the dams, fish guidance efficiencies to collection facilities, and estimated dam turbine mortalities, we estimated parr-to-smolt overwinter survival.

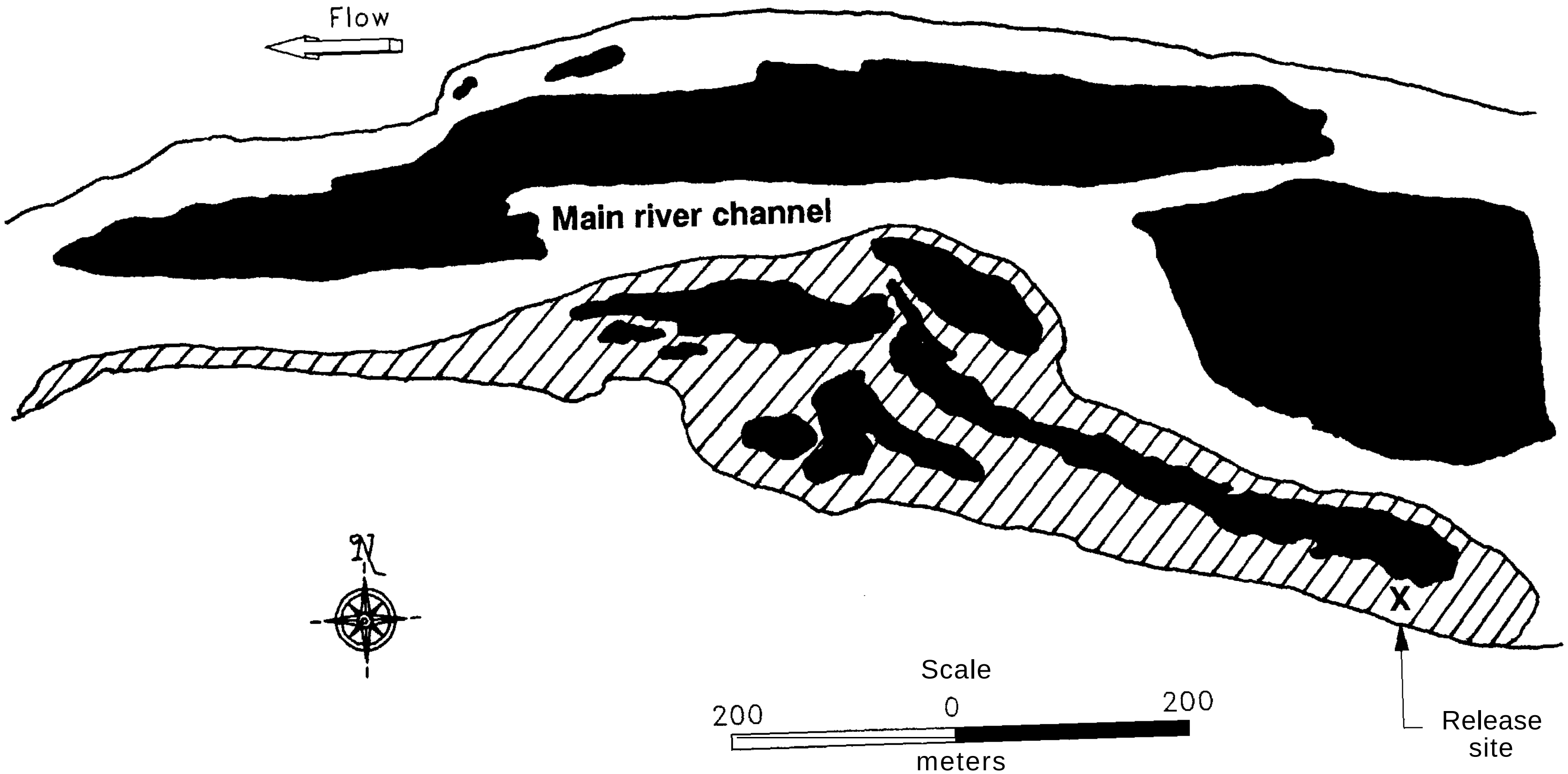


Figure 7.1. Release site of PIT-tagged spring chinook salmon and snorkeling area [hatched] at the Potlatch River site (Hog Island complex, river km 8) on the lower mainstem Clearwater River, Idaho.

We also examined outmigration timing and growth rates of PIT-tagged fall chinook on the Snake River during 1991 (Connor, unpublished data). We compared thermograph data in the Snake and LMCR during 1990-91 and calculated daily temperature units (DTU's) for fall chinook emerging fry (Chapter 4). Using growth rates and outmigration data observed on the Snake, we calculated anticipated fall chinook growth rates and outmigration timing for the LMCR. Finally, we compared projected fall chinook outmigration timing on the LMCR with that observed for the Snake River and discussed implications.

Results

Parr fork lengths ranged from 77 mm to 139 mm and averaged 98.8 mm for the PIT-tagged group. PIT tag and panjet mark retention of parr in holding tanks were high at 99.8 and 93.5%, respectively. Mortality of PIT-tagged parr at DNFH was lower (0.43%) than the control group (0.65%), therefore PIT-tagging and panjet-marking did not contribute to any added short-term mortality. Transportation mortality the day of release accounted for only three PIT-tagged fish or 0.04%. Water temperature in the LMCR at time of release was 11.5 °C, no acclimation was required, and fish appeared in excellent condition.

Emigration of parr out of the side channel from the release site was immediate. We observed only 106 parr the day following release during snorkeling of approximately 1.4 km of side channel and main river channel edge (Figure 7.1). Approximately 100 parr observed were in one school and the rest were observed as singles, therefore sample size for microhabitat preference data was inadequate. Panjet marks were nearly impossible to distinguish due to caudal fin movement. None of the 7,946 parr released into the side channel could be found by snorkeling two days after release. Snorkeling 22 days after release again produced no parr observations. Carrying capacity of the side channel could not be evaluated because of the unforeseen emigration behavior of the hatchery parr. No obvious water velocity or food limitations were noted in the side channel habitat.

Only one PIT-tagged fish was collected in the spring at the IDFG smolt trap located on the LMCR approximately 3 km downstream from the release location.

PIT tag interrogation began on March 25 at Lower Granite and McNary Dams and April 3 at Little Goose Dam. A total of 526 PIT-tagged parr (13.3%) were interrogated at Lower Granite, Little Goose, and McNary Dams (Figure 7.2). No single PIT-tagged fish was interrogated at any two dams, suggesting that captured smolts were subsequently

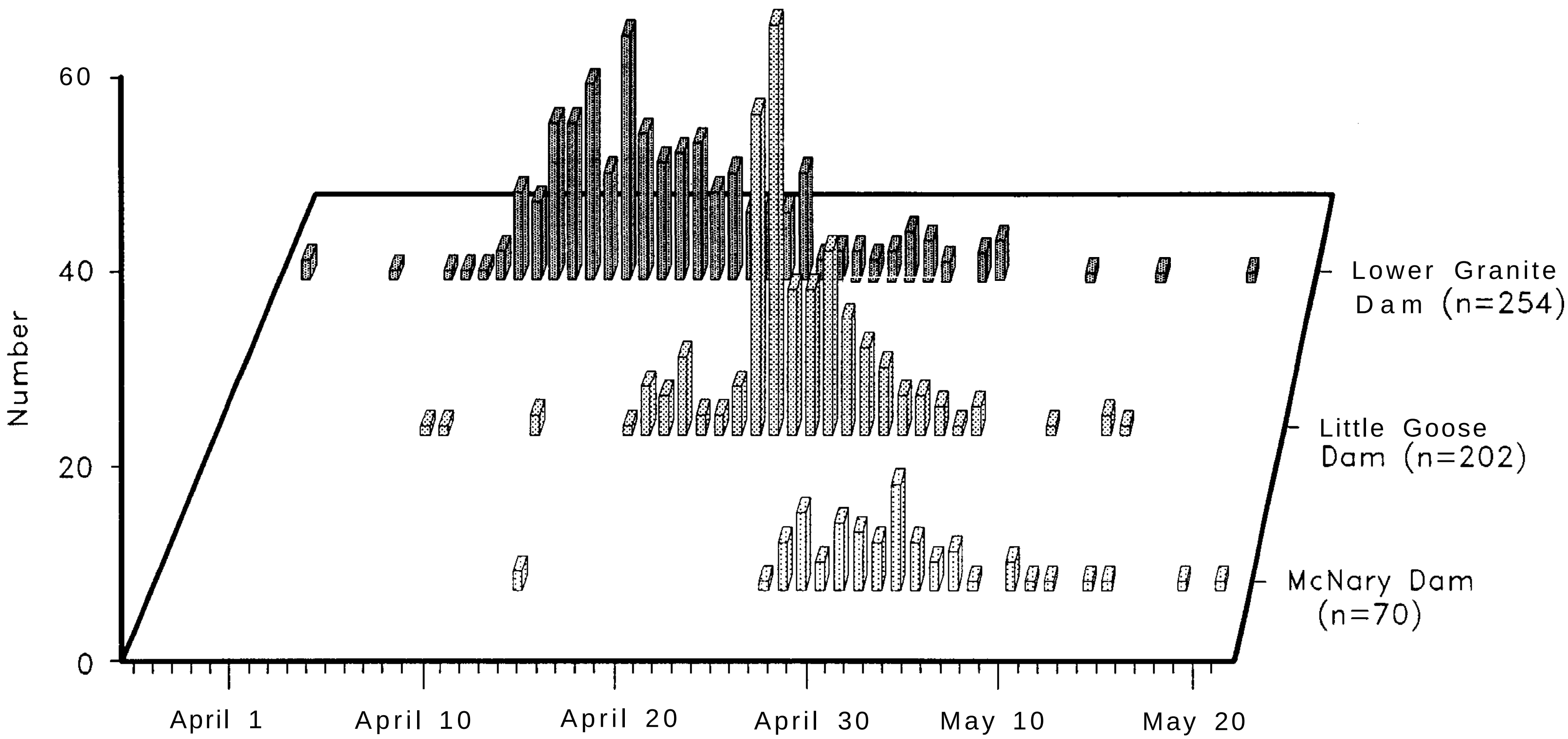


Figure 7.2. Timing and number of PIT-tagged spring chinook salmon smolts detected at dam interrogation facilities during 199 1 for 3,956 parr released October 9, 1990 at Potlatch River site on the lower mainstem Clearwater River, Idaho.

transported to the lower Columbia River. Peak migration was April 14, April 25, and May 4 at Lower Granite, Little Goose, and McNary Dams, respectively. Peak migration was more than two weeks after interrogation start-up at the dams. Very few smolts were interrogated early (Figure 7.2).

Reported fish guidance efficiency (FGE) for yearling chinook smolts into collection facilities at Lower Granite Dam averaged 57.3% during 1989 (Swan et al. 1990). No tests on FGE were conducted since that time. Chapman et al. (1991) reported that 11% mortality of smolts through the turbines on the Snake River dams has received wide acceptance. If this FGE's and turbine mortalities were the same in 1991 at all Snake River dams, parr-to-smolt overwinter survival could be conservatively estimated at 25%. Assuming non-tagged parr survival was the same as PIT-tagged parr, a total of 1,987 parr out of 7,946 released survived and over-wintered in the LMCR or Lower Granite pool.

PIT-tagged fall chinook presmolts on the Snake River (between Hells Canyon and Lower Granite Dam) during 1991 indicated this stock takes between 1 to 3 months to outmigrate as subyearlings (Connor, unpublished data). Outmigration of fall chinook to Lower Granite Dam began approximately June 1, peaked July 25, and declined in September. From our incubation timing study (Chapter 3), calculated Snake River fall chinook emergence was May 2 compared to May 22 observed for fall chinook in the LMCR. Observed growth rates from recaptured PIT-tagged fall chinook on the Snake River averaged 1.36 mm total growth/day (Connor, unpublished data). These PIT-tagged fish passed Lower Granite Dam at an average size of 127.9 mm. From our incubation study on the LMCR, fall chinook emerged at an average total length of 39 mm. Using this starting length and the above growth rate, fall chinook on the LMCR would reach 127.9 mm by July 26. Snake River PIT-tagged fall chinook outmigration timing peaked at Lower Granite Dam on July 25 (Connor, unpublished data).

Discussion

The original objectives of this study were not accomplished because we were unable to obtain Lyon's Ferry fall chinook salmon for experimental purposes. A summer release of fall chinook presmolts may have provided better estimates of our objectives. Fall chinook may have dispersed and stayed in the side channel or slowly outmigrated. Since the released spring chinook emigrated out of the side channel immediately, we could not investigate the carrying capacity of physical habitat, obtain sufficient microhabitat preferences of chinook parr, or observe PIT-tagged fish behavior. Although a survival estimate for fall chinook age 0+ outmigrants in the LMCR could not be obtained, we did obtain a conservative estimate of parr-to-smolt survival for fall outplanted spring chinook subyearlings from PIT tag fish recoveries at the dams.

We concluded that most spring chinook parr overwintered in the lower portion of the LMCR or in Lower Granite pool since only 1 PIT-tagged fish was collected at the IDFG smolt trap the next spring. However, PIT tag detection efficiency was reported to be only 1.87% at the IDFG smolt trap during 1990 (Buettner and Nelson 1990). If 1991 detection efficiency was the same, there could have been approximately 60 PIT-tagged parr not detected by the IDFG trap.

Since peak migration of PIT-tagged spring chinook parr was over two weeks after interrogation facilities began operating at dams and few smolts interrogated early, it appeared that outmigration did not occur earlier in the spring. Unfortunately, interrogation facilities were not operating during the fall and winter and passage during that time could not be monitored. Therefore, total survival past Snake River dams could not be calculated. However, the overwinter survival estimate of 25% was relatively high for the fall released spring chinook parr in the LMCR. Keifer and Forster (1991) estimated 5.2% parr-to-smolt survival from Crooked River (a tributary of the South Fork Clearwater River) to Lower Granite Dam for age 0+ spring chinook parr PIT-tagged in August, 1989. This estimate was based on a 55.6% detection efficiency at Lower Granite Dam from PIT-tagged smolts released at the IDFG smolt trap on the LMCR. The U.S. Fish and Wildlife Service (Roseburg et al., unpublished data) found that a 1988 experimental fall release of spring chinook in the LMCR resulted in an average II-ocean adult return rate back to DNFH of only 0.034% compared to 0.125% for a spring release. However, overwinter survival of parr was not readily available from this study.

The FGE at Lower Granite Dam during April 1991 appeared to be only around 41.8% efficient instead of 57.3% based on the high numbers of our PIT-tagged parr interrogated at Little Goose Dam. Fish discrepancies cannot be attributed to spill since it did not occur at Lower Granite during 1991. However, there is a possibility that some fish overwintered in Little Goose Reservoir or outmigrated earlier than interrogation start-up at Lower Granite Dam. The total number of PIT-tagged parr interrogated at McNary Dam (n = 70) was very close to what we predicted (n = 69), based on 11% turbine mortality at Little Goose, Lower Monumental, and Ice Harbor Dams and a 57.3% FGE at Little Goose and McNary Dams.

The 25% over-winter survival estimate of our fall released spring chinook did not take into account other factors such as predation at the dams, PIT tag detection efficiency, PIT tag malfunction, percent tag retention, and percent parr residualization. Uremovich et al. (1980) and Vigg (1988) reported that northern sguawfish *Pytochelius* oregonensis predation on chinook salmon smolts at dams **can** be extensive. Although Prentice et al. (1990) reported 100% PIT tag retention in yearling chinook salmon, we found 0.2% tag loss within 2 weeks after tagging. Interrogation facilities at dams can provide tag detection efficiency above 95% and reading accuracy above 99% (Prentice et al. 1990). Residualization of parr in the reservoirs has not been evaluated independently (Chapman et al. 1991), however, the degree of residualization probably fluctuates year-to-year based on differences in reservoir discharges and other variables. Therefore, considering these factors, overwinter survival of spring chinook parr was probably higher than the 25% estimated.

Even though we calculated that fall chinook on the LMCR would smolt about the same time as peak outmigration on the Snake River, temperatures on the Snake were below normal during 1991 (Connor, unpublished data). The average peak outmigration usually occurs approximately three weeks earlier than what was observed in 1991. Unlike the Snake, which is subject to variation in water temperatures resulting from tributary influence, the LMCR is relatively similar year to year. Therefore, in most years, fall chinook produced naturally in the LMCR would most likely outmigrate after the Snake River peak. If fall chinook would outmigrate over a 1 to 3 month period in the LMCR as in the Snake River, temperatures and discharges may be limiting factors in July and August in the LMCR and in the rest of the Columbia River system. However, summer conditions in the LMCR could be enhanced for fall chinook juveniles by alternative Dworshak Dam releases (Chapter 12).

Conclusions

Based on survival estimates from our study, it appears the LMCR and/or lower Snake River pools could provide overwintering habitat with acceptable survival levels for age 1+ outmigrating spring chinook salmon. Survival of age 0+ outmigrating Snake River fall chinook salmon in the LMCR may be enhanced given alternative Dworshak Dam release scenarios outlined in Chapter 12. Additional research is needed regarding fall chinook growth and outmigration timing on the LMCR.

CHAPTER 8

HYDRAULIC MODEL

Abstract-Hydraulic modeling was conducted on the lower mainstem Clearwater River (LMCR) in order to predict the velocity, depth, and substrate characteristics of the river at discharges ranging from 85 to 1,416 cms (3,000 to 50,000 cfs). The PHAPSIM hydraulic simulation model IFG4 was employed for this purpose. Cross-sectional transect measurements were obtained at three instream flow study sites in the LMCR. Velocities measurements were obtained at each transect for a single flow of approximately 11,400 cfs, while six stage-discharge measurements were obtained at each transect at discharges ranging from 3,000 to 48,000 cfs. Initial calibration and simulation modeling of the LMCR hydraulic model are described in our 1989 annual report (Connor et al. 1990). The LMCR hydraulic model was relatively complex because two of the three study sites included a large number of transects located in islanded reaches. Special methods and procedures were developed for the LMCR hydraulic model to predict changes in the apportionment of flow among the multiple channels in islanded reaches, as well as transect water surface elevations in these reaches, over the entire range of total river discharges modeled. These modeling procedures resulted in accurate predictions of hydraulic characteristics of the LMCR over a wide range of flows. The results of the hydraulic model were then employed in habitat simulation modeling.

Introduction

The Instream Flow Incremental Methodology (IFIM), developed and supported by the U.S. Fish and Wildlife Service's National Ecology Research Center (NERC), provides a comprehensive collection of computer models and analytical procedures to predict changes in hydraulic conditions and corresponding fish habitat characteristics with incremental changes in streamflow (Bovee 1982). PHABSIM, the Physical Habitat Simulation System, is the habitat analysis component of IFIM, and provides the computer based hydraulic and habitat simulation programs required for analysis of habitat-discharge relationships (Milhous et al. 1989). The objective of our hydraulic modeling was to simulate hydraulic and habitat characteristics of the LMCR and to quantify and analyze relationships between anadromous fish holding, spawning, and rearing habitat versus discharge. Results of hydraulic and habitat modeling were subsequently used to evaluate effects of current Dworshak Dam operating conditions on anadromous fish habitat in the LMCR, as well as to explore alternative flow regimes which might benefit existing and potential anadromous fish stocks.

Methods

We modeled the hydraulic characteristics of our LMCR study sites (Chapter 1) using IFG4 (Milhous et al. 1989) for a range of discharges from 85 to 1,416 cms (3,000 to 50,000 cfs). IFG4 simulates the distributions of velocities, depths, and substrate across cross-sectional transects, and provides the necessary hydraulic data for PHABSIM habitat modeling.

Velocity, depth, and substrate measurements were obtained at 31 transects located among 3 IFIM sites on the LMCR: the Potlatch, Bedrock, and Big Canyon study sites (Connor et al. 1990). These study sites were selected to represent hydraulic and habitat conditions of the Potlatch, Bedrock, and Big Canyon segments of the LMCR (see Chapter 1, Figure 1.1). In addition, six pairs of stage-discharge measurements were acquired on the LMCR at each transect location. Instream flow study segmentation, site selection, transect placement, field measurement methods, hydraulic model calibration, and results of IFG4 hydraulic model simulation runs are described in our 1989 annual report (Connor et al. 1990).

Final hydraulic calibration procedures for the LMCR involved three basic steps. First, errors in water surface elevation and discharge calculations were identified and corrected. Most hydraulic model discharge errors were corrected by improving flow apportionment estimates among multiple channels at islanded sites. Second, a linear interpolation procedure was developed to improve predictions of water surface elevations from discharge, since the default log-linear method used by IFG4 was not appropriate for a substantial number of transects. This empirical model, based upon linear interpolation of simulation discharges between the six measured stage-discharge pairs, was then used to determine river stage at each transect. Third, velocity predictions along the edges of the river were improved by modifying roughness values in IFG4 data files on a cell by cell basis. This provided a more realistic simulation of velocities in overbank areas at higher flows. Modifications to the stage-discharge model and in cell roughness values were incorporated in a final set of IFG4 calibration data files.

The next two sections will describe transect grouping procedures and flow apportionment methods for islanded sites. Final calibration procedures of the instream flow hydraulic model implemented since the publication of the 1989 report are described in Appendix B.

Transect Groupings at Study Sites

The initial basis for grouping transects into separate data files was the selection of 3 IFIM study sites representing 3 segments of the LMCR: Potlatch, Bedrock, and Big Canyon. A single IFG4 data file would normally be sufficient for a study site having a single river channel and uniform discharge conditions. For multiple channel reaches, however, separate hydraulic input data files must be created for each channel (Milhous et al. 1984). Transects located within the same channel in a multiple channel IFIM study site can be grouped into the same IFG4 data file because they possess a common discharge regime. An IFG4 data file was created for each channel located within multiple channel (islanded) sites of the Bedrock and Potlatch segments.

The Potlatch study site required the greatest number of hydraulic model input files because of the relatively large number of transects placed at this site and the extreme complexity of islanded channels. The Potlatch study site was divided into two sub-sites: Upper Potlatch and Lower Potlatch. A total of 18 transects were grouped into 10 hydraulic data files due to the complicated layout of this study site (Table 8.1). The lower Potlatch site, located downstream from U.S. Highway 95 Bridge, represented the most complex islanded section on the LMCR and could be divided into seven channels undergoing different discharge conditions (Figure 8.1). Because of these islanded channels, 7 separate hydraulic simulation input files were required for the lower study site which quantified a main channel reach (LPMC), an intermittent left island channel reach (LPLC), three center island channel reaches (LPCC1, LPCC2, LPCC3), and two island right channel reaches (LPRC1, LPRC2). The Upper Potlatch sub-site consisted of only a single island with a main channel reach, right channel reach, and a left channel reach. Consequently, only 3 files were required for the upper study site (Table 8.1). The Upper Potlatch site included a main channel reach (UPMC), an island left channel reach (UPLC), and an island right channel reach (UPRC).

The Bedrock Segment contained 1 study site located upstream from Cherrylane Bridge, which included 8 transects grouped into 3 IFG4 data files (Table 8.1). This study site, although islanded, was considerably less complex in morphology and hydrology than the Potlatch Segment sites. IFG4 data files were developed for a main channel reach (BCMC), an island left channel reach (BCLC), and an island right channel reach (BCRC).

Table 8.1. Transect groupings employed in IFG4 hydraulic simulations for the lower mainstem Clearwater River, Idaho.

Code	Description	Cross-sections
LPMC	Lower Potlatch Main Channel	1,8
LPLC	Lower Potlatch Left Channel, upper section	10,11
LPCC1	Lower Potlatch Center Channel, upstream section	2,3
LPCC2	Lower Potlatch Center Channel, middle section	4,5,6
LPCC3	Lower Potlatch Center Channel, lower section	7
LPRC1	Lower Potlatch Right Channel, upper section	15,16
LPRC2	Lower Potlatch Right Channel, lower section	12,13
UPMC	Upper Potlatch Main Channel	1,3
UPLC	Upper Potlatch Left Channel	2
UPRC	Upper Potlatch Right Channel	4
BRMC	Bedrock Main Channel	2,3,7
BRLC	Bedrock Left Channel	8,9
BRRC	Bedrock Right Channel	4,5,6
BCMC	Big Canyon Main Channel and	1,2,3
	North Fork Main Channel (combined)	1

note: Lower Potlatch transect locations 9 and 14 not measured.

The Big Canyon Segment had the simplest channel morphology and hydrology of the three river segments, since it only included single channel (i.e. non-islanded) habitat. The Big Canyon Segment contained 2 study sites: Big Canyon and North Fork. The Big Canyon site was represented by 3 transects and the North Fork site was represented by 1 transect (Table 8.1). These transects were combined into a single IFG4 data deck (BCMC) due to similarity in channel structure and hydrology and the close physical proximity of the 2 study sites.

Flow Apportionment at Multiple Channel Sites

Two steps were employed to accurately apportion total river discharge among islanded channels. First, errors in discharge apportionment for low flow conditions were corrected. This was achieved by measuring discharge at multiple channel sites during low flow conditions occurring on August 8, 1990. Total river flow on this date was 96 cms (3,380 cfs) at the USGS gaging station at Spalding. Field crews obtained cross-sectional depth and velocity measurements in the left and right channel of the Bedrock study site, and the center and right channel of the Lower

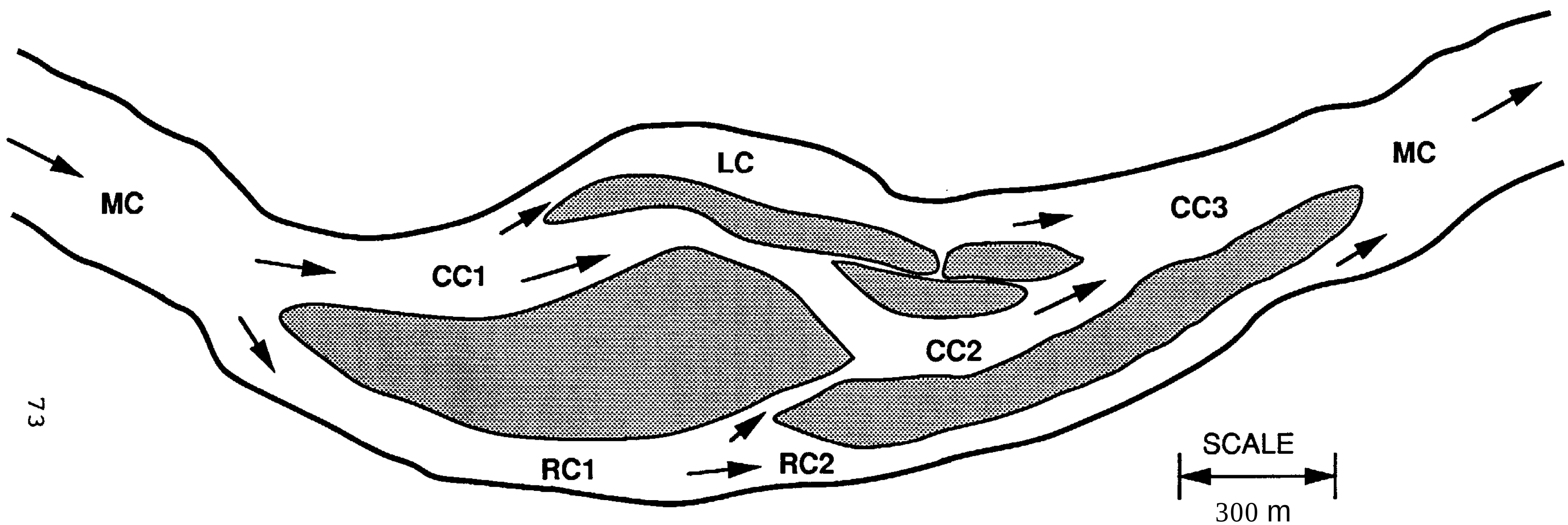


Figure 8.1. Hydraulic subdivision of lower Potlatch island complex on the lower mainstem Clearwater River: MC = main channel; CC1, CC2, and CC3 = center channel reaches; LC = left intermittent channel; and RC1 and RC2 = right channel reaches (arrows indicate direction of flow).

Potlatch study site during this period. The left channel of the Lower Potlatch site was isolated from the main channel at this low flow, but contained enough retention water to provide limited fish habitat. Cross-section measurements were used to calculate discharges for island channels. Partial discharges were multiplied by a constant so that the sum of discharges equaled the total river discharge obtained from the gaging station.

Partial island discharges at higher flows were calculated by two different methods. First, discharge was directly obtained from measurements of velocity and depth along selected transects during velocity calibration measurements. Velocity calibration measurements were obtained at a total river discharge of 323 cms (11,400 cfs). Second, Manning's equation was used to calculate flow apportionment among islanded channels for total river discharges of 453 cms (16,000 cfs), 1,019 cms (36,000 cfs), and 1,303 cms (46,000 cfs) (Connor et al. 1990). Partial discharge calculations were based upon hydraulic radius and channel slope values obtained from selected instream flow transects located within each islanded channel site. For both direct measurement and Manning's equation methods, calculated discharges were multiplied by a constant so that the sum of individual channel discharges for a given island equaled the total river discharge obtained from the gaging station.

A total of 5 partial discharges were calculated at each multiple channel site using the procedures described above. Partial discharges intermediate to these 5 values were calculated using a linear interpolation method. A computer program was written to calculate partial discharges, which were required for input in both calibration and production of IFG4 data files. This program reads a data file containing the 5 paired partial and total river discharges. Total river discharges from which partial discharge predictions are required are then read from the same data file. Partial discharge calculations, based upon linear interpolation between appropriate total and partial discharge pairs, are then written to an output file. This program employs the following linear interpolation formula:

$$PQ = PQ1 + ((PQ2 - PQ1) * (TQ - TQ1) / (TQ2 - TQ1))$$

Where:
- PQ = partial discharge to be calculated
- TQ = total discharge for which partial discharge is required
- PQ1 = partial discharge measurement less than PQ
- TQ1 = corresponding total discharge measurement less than TQ

PQ2 = partial discharge measurement greater than PQ

TQ2 = corresponding total discharge measurement greater than TQ

In IFG4 hydraulic simulations, partial discharges must be used instead of total river discharges in calibration and production data files for channels within islanded sites.

Results

Following completion of the final calibration procedures for the LMCR hydraulic model (Appendix B), the IFG4 hydraulic simulation program was used to simulate velocities, depths, and substrates at the three study sites for flows ranging from 85 to 1,416 cms (3,000 to 50,000 cfs). A review of velocities and depths predicted by the model over this range of flow regimes was provided in our 1989 annual report (Connor et al. 1990).

Discussion

The hydraulic model developed for the LMCR provided realistic predictions of velocities and depths across transects located in the Potlatch, Bedrock, and Big Canyon study sites for discharges ranging from 85 to 1,416 cms (3,000 to 50,000 cfs). A more detailed discussion of the hydraulic model is provided in our 1989 Annual Report (Connor et al. 1990). The LMCR hydraulic model was relatively complex because many of the transects employed in the instream flow study were located within islanded sites with multiple channels. Changes in water surface elevations, and in the apportionment of flow among island channels, with increasing river discharge were complex. Complicated field measurement and hydraulic modeling procedures were required to model the diversity of hydraulic conditions in the river over a range of flows appropriate for the habitat study. These measurements and modeling procedures, when combined with fish habitat suitability information, provided an accurate portrayal of habitat conditions in the LMCR.

CHAPTER 9

FISH SUITABILITY CURVES

Abstract-Suitability curves were developed for salmonid species and life stages present in the lower mainstem Clearwater River (LMCR). Type III suitability curves, or "preference curves", were constructed for rainbow/steelhead trout *Oncorhynchus mykiss* fry (age O-t) and juveniles (age 1+) from measurements of fish habitat utilization and habitat availability obtained in the LMCR. Preference curves for chinook salmon 0. *tshawytscha* fry were used from the Trinity River, California, due to low numbers in the LMCR. Composite preference curves were constructed for chinook salmon juveniles by combining limited measurements in the LMCR with appropriate literature sources. Due to the low numbers of spawning fall chinook salmon in the LMCR, we measured spawning utilization of summer chinook salmon in the South Fork Salmon River, Idaho and the Wenatchee River, Washington. Composite chinook salmon spawning preference curves were constructed by combining measurements on these two rivers with appropriate literature sources. Suitability curves for holding chinook salmon were also not available on the LMCR and were constructed by composing suitability curve values obtained from appropriate literature sources. Suitability curves for all rivers and life stages were developed to characterize habitat of large rivers.

Introduction

Physical habitat selected for fish can be described using suitability curves. Four types of curves are generally developed in instream flow studies for a given species or life stage of fish: velocity, depth, substrate, and cover (Bovee 1982; Milhous et al. 1984). These curves are scaled from 0 to 1 with a value of 0 corresponding to zero habitat suitability and 1 corresponding to maximum habitat suitability. The values are determined from professional judgement, field measurements of fish habitat utilization, or a combination of both. Microhabitat suitability criteria can be further refined by adjusting utilization curves for habitat available during field measurements. Curves based on professional judgment are often referred to as Type I curves, while utilization curves are referred to as Type II curves (Bovee 1986). Finally, utilization curves which have been adjusted for availability are referred to as Type III or "preference" curves. The purpose of this chapter is to describe preference curves we assembled for chinook salmon *Oncorhynchus tshawytscha* and rainbow/steelhead trout 0. *mykiss*.

Methods

Suitability curves were developed for a number of species and life stages of fish in the LMCR. Target species included the chinook salmon, with emphasis on the fall race of this species, and rainbow/steelhead trout. Microhabitat use of chinook salmon juveniles (age 1+) and rainbow/steelhead trout fry (age 0+) and juveniles was quantified on the LMCR by measurements made through direct observation (snorkeling and SCUBA diving) within established study lanes (Chapter 6). Study lanes were chosen randomly using a proportional sampling strategy (Connor et al. 1989). However, proportional sampling during 1989 was unproductive for the purpose of preference curve development due to the low density of chinook salmon and rainbow/steelhead trout observed in randomly placed study lanes. Therefore, additional observations of these species were obtained during 1989 and 1990 on the LMCR by using a "blanket" technique (Bovee 1986).

The blanket technique involved extending established observation lanes and creating additional lanes in higher fish density areas. Direct observation surveys conducted during 1989 indicated that juvenile salmonids in the LMCR preferred rapid and riffle areas dominated by boulder substrate, therefore we sampled these areas extensively. Observation reaches ranged from 536 to 1,640 m (1,760 to 5,280 ft) in length. The majority of salmonid microhabitat measurements on the LMCR were acquired at a river discharge of 340 cms (12,000 cfs) in 1989 and 255 cms (9,000 cfs) in 1990. Snorkeling was the primary method used for locating juvenile salmonids and obtaining microhabitat measurements, because extremely few observations of these species were made while SCUBA diving deeper sections of the LMCR.

Measurement of depth, velocity, and substrate over fall chinook redds was impossible due to extremely low adult escapement. Only 35 redds were observed from aerial redd surveys on the LMCR from 1988 to 1990 (Chapter 2). Consequently, microhabitat use criteria for spawning chinook salmon applied to the LMCR were developed from measurements obtained from mainstem spawning summer chinook salmon on the Wenatchee River, Washington, and the South Fork Salmon River (SFSR), Idaho. Nose velocity criteria were developed for LMCR chinook salmon spawning habitat modeling for reasons discussed in Appendix D. Nose velocity criteria for this study were obtained only from the Wenatchee River, since this was the only river from which nose velocity utilization and availability data could be obtained.

The Wenatchee River consisted of a single, continuous 2.5 km reach where spawning densities of fish were known to be high. The downstream end of this study reach was located adjacent to the town of Leavenworth, Washington. The SFSR consisted of multiple reaches along approximately 65 km of river, located downstream from Stolle Meadows, Idaho. We Snorkeled and waded to obtain most microhabitat measurements for spawning chinook salmon, however used SCUBA to measure deeper redds in the Wenatchee River. Location of spawning fish in these rivers was feasible due to the clarity of water. Chinook salmon spawning measurements were obtained on the Wenatchee River from October 16 to 18, 1990 at a consistent river discharge of 31 cms (1,100 cfs). Spawning measurements on the SFSR were obtained from September 5 to 7, 1990 at a consistent river discharge of 23 cms (800 cfs).

Microhabitat measurements on all rivers were obtained just after undisturbed chinook salmon were located on redds within the observation reaches. A description of this procedure was given by Bovee (1986) and Crance and Shoemaker (1986). Microhabitat variables measured at each observation point included mean column velocity, nose velocity, total depth, nose depth (i.e. distance of fish above streambed), and substrate composition. The Brusven substrate coding system as modified by Bovee (1982) was used to qualify dominant and subdominant substrates, as well as surface percent fines, at each position (Table 9.1).

Table 9.1. Brusven codes (as modified by Bovee 1982) applied to visual substrate measurements on the lower mainstem Clearwater and South Fork Salmon Rivers, Idaho and the Wenatchee River, Washington.

Code	Substrate description (secondary axis diameter)
1	Fines (< 4 mm)
2	Small gravel (4-25 mm)
3	Medium gravel (25-50 mm)
4	Large gravel (50-75 mm)
5	Small cobble (75-150 mm)
6	Medium cobble (150-225 mm)
7	Large cobble (225-300 mm)
8	Small boulder (300-600 mm)
9	Large boulder (> 600 mm)

Microhabitat measurements obtained in the LMCR, Wenatchee River, and SFSR were used to construct utilization (Type II) curves for all target species and life stages of fish. These were then converted into preference (Type III) curves after adjusting for habitat availability measured at each river. Preference curves developed from the different study rivers were combined to obtain a set of composite preference curves for each species and life stage. In several cases, literature preference values were used to extend our composite preference curves to make them more appropriate for large river conditions.

Results

We generated a lot of data, tables, and figures in the process of suitability curve analysis. With clarity in mind, we restricted the results to high points of the analysis. Detailed information is presented in Appendix C.

1. Chinook Salmon Spawning

Peak depth utilization by summer chinook salmon on the Wenatchee River was 85 cm (2.8 ft). Observed depths of summer chinook spawning ranged from 24 to 145 cm (0.8 to 4.8 ft). Depth availability for the Wenatchee River peaked at 46 cm (1.5 ft) and ranged from 9 to 335 cm (0.3 to 11.0 ft). The peak depth preference for spawners calculated from utilization and availability data was 85 cm (2.8 ft), the same as the utilization curve. After smoothing, the Wenatchee River preference curve extended from 24 to 162 cm (0.8 to 5.3 ft) with the highest preference (> 0.7) between 70 and 116 cm (2.3 and 3.8 ft).

Depth utilization by summer chinook salmon on the SFSR peaked at 37 cm (1.2 ft) and ranged from 6 to 98 cm (0.2 ft to 3.2 ft). Depth availability ranged from 6 to 98 cm (0.2 to 3.2 ft). The depth preference curve for the SFSR ranged from 6 to 67 cm (0.2 to 2.2 ft) with peak preference occurring at 37 cm (1.2 ft).

The depth preference curve developed for fall chinook salmon on the Trinity River ranged from 18 to 175 cm (0.45 to 5.75 ft) with a peak value occurring at 46 cm (1.5 ft) (Hampton 1988). Hampton's (1988) computed preference values for the Trinity River peaked between 23 to 69 cm (0.75 and 2.25 ft).

The composite depth preference curve for chinook salmon spawning peaked between 38 and 84 cm (1.25 and 2.75 ft) (Figure 9.1). Preference values were highest (> 0.7) between 23 and 114 cm (0.75 and 3.75 ft). Depths of 130 cm (4.3 ft) and beyond were assigned a preference value of 0.37

to reflect deep water spawning observed in the literature by chinook salmon (Swan 1989).

Peak nose velocity utilization on the Wenatchee River peaked at 40 cm/sec (1.3 ft/sec) and ranged from 9 to 116 cm/sec (0.3 to 3.8 ft/sec). Nose velocity availability peaked at 9 cm/sec (0.3 ft/sec) and ranged from 9 to 116 cm/sec (0.3 to 3.8 ft/sec). The resulting nose velocity preference curve peaked at 55 cm/sec (1.8 ft/sec) and ranged from 9 to 131 cm/sec (0.3 to 4.3 ft/sec), (Figure 9.1). Highest nose velocity preference (> 0.7) occurred between 40 and 85 cm/sec (1.3 and 2.8 ft/sec).

Peak substrate utilization for chinook salmon spawning in the Wenatchee River occurred on small cobbles (Figure 9.1). Substrate use on this river ranged from medium gravels to medium cobbles. The most available substrate on this river was also small cobbles. Available substrates on the Wenatchee River ranged from fines to large boulders. However, the majority of substrates available in this river were those suitable for spawning (i.e. medium gravels to medium cobbles). Substrate preference criteria calculated from utilization and availability also peaked for medium cobbles.

Spawning chinook salmon on the SFSR used similar substrates to those on the Wenatchee River. Small cobbles also represented the dominant substrate used by spawning fish in the SFSR. Salmon in this river utilized a wider range of substrates from small gravels to medium cobbles. Available substrate sizes on the SFSR ranged from small gravels to large boulders. Like the Wenatchee River, the most available substrate on the SFSR was small cobbles. Large gravels had the highest calculated preference value for substrates in this river. High substrate preference values (> 0.7) for spawning salmon on the SFSR were calculated for substrates ranging from medium gravels to small cobbles.

Substrate preference criteria developed on the Trinity River (Hampton 1988) were broader than those calculated on either the Wenatchee or SF Salmon Rivers. Chinook salmon spawning was observed on the Trinity River among substrates ranging from small gravels to large cobbles. Preference for medium cobbles was much higher on this river than the Wenatchee and SF Salmon Rivers. This is important because the much of the LMCR is dominated by medium cobbles.

The composite substrate preference curve had a peak value (1.0) for large gravels and small cobbles (Figure 9.1). High preference values (> 0.7) were obtained only for these two substrate sizes, although small gravel and medium

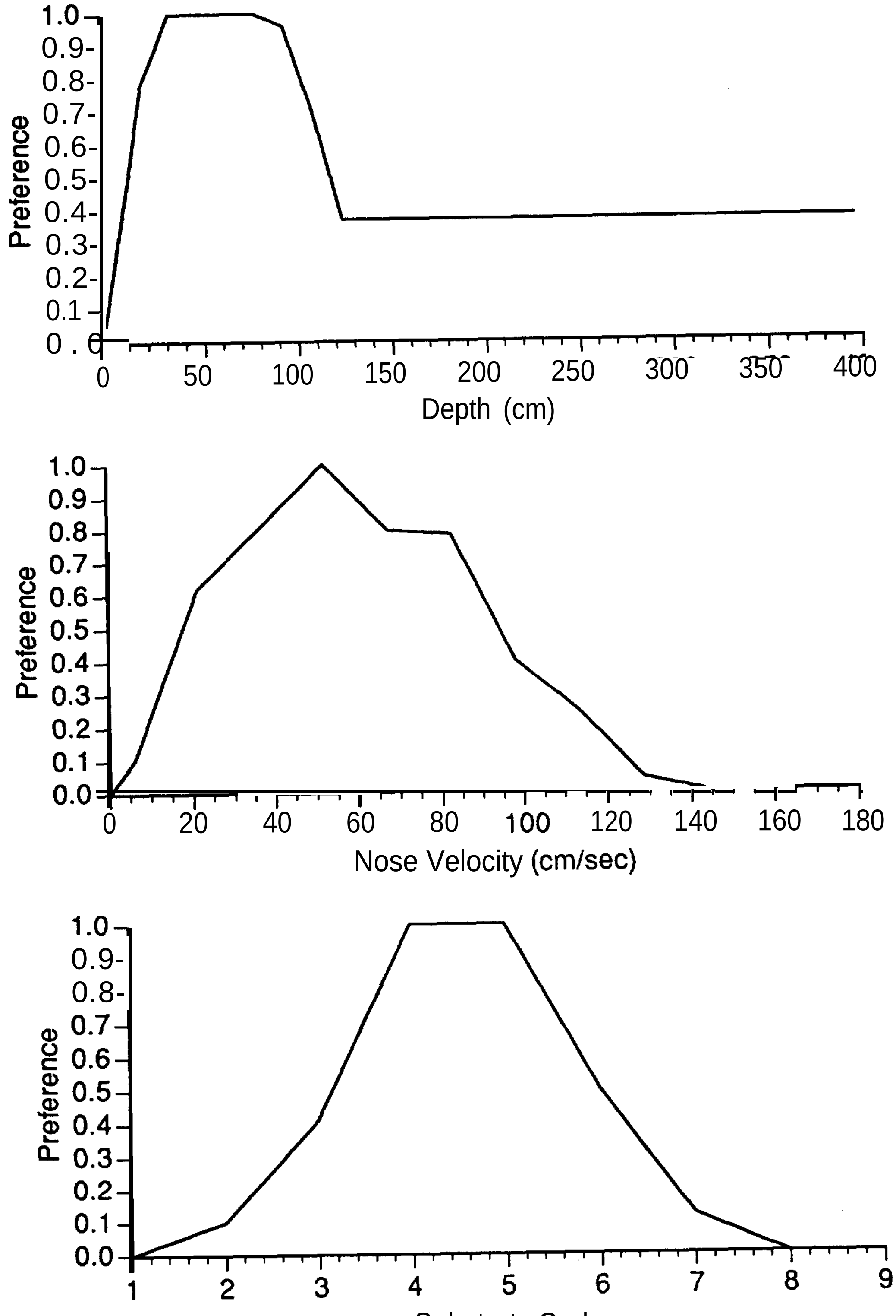


Figure 9.1. Composite preference curves for chinook salmon spawning for the lower mainstem Clearwater River, Idaho, based on the SF Salmon River, Idaho, Wenatchee River, Washington, and the Trinity River, California.

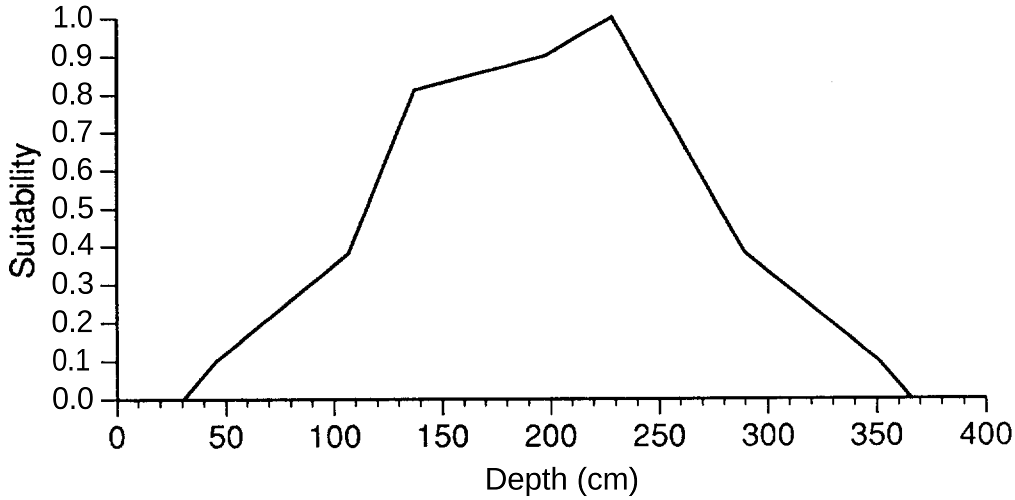
cobbles had moderate suitability values of approximately 0.5.

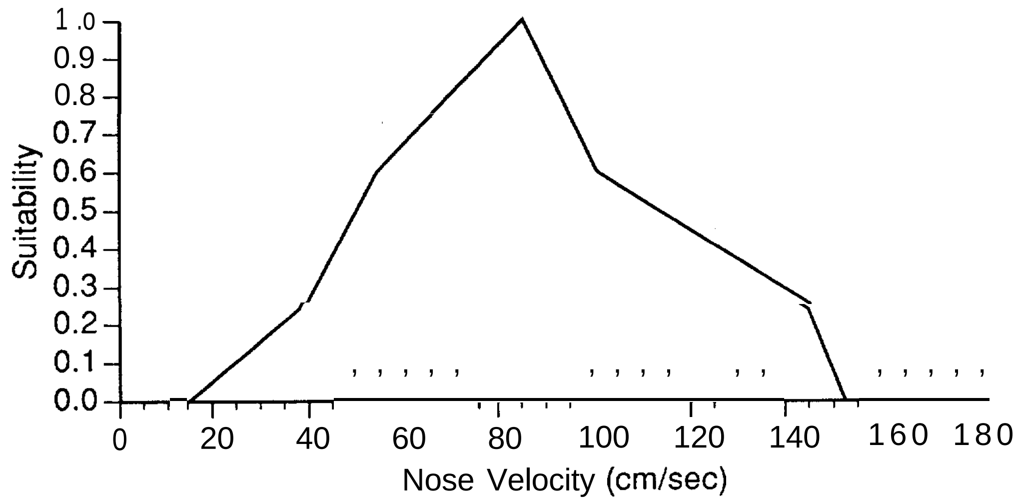
2. Chinook Salmon Holding

Depth utilization by summer chinook salmon on the Kenai River, Alaska (Burger et al. 1982) and spring chinook on the Wind River, Washington (Wampler 1986) peaked around 230 cm (7.5 ft) and extended from 46 to 350 cm (1.5 to 11.5 ft) (Figure 9.2). High depth suitability (> 0.7) occurred between 137 and 259 cm (4.5 and 8.5 ft). Nose velocity utilization curves obtained from these rivers peaked at 85 cm/sec (2.8 ft/sec) and ranged from 24 to 146 cm/sec (0.8 to 4.8 ft/sec) (Figure 9.2). Habitat availability data was not obtained in either of these studies, consequently, preference (Type III) criteria could not be developed. Peak depth and nose velocity suitability values for holding fish were substantially higher than those developed for spawning fish. Due to a lack of adequate substrate utilization data, we assumed that all substrate sizes would be equally suitable to holding salmon (Figure 9.2) for habitat simulation modeling.

3. Chinook Salmon Juveniles

Peak depth utilization for chinook salmon juveniles on the LMCR occurred at 52 cm (1.7 ft). Depth utilization on the LMCR ranged from 21 to 113 cm (0.7 to 3.7 ft). Depth availability, predicted at 255 cms (9,000 cfs) on the LMCR, peaked at 82 cm (2.7 ft) and ranged from 6 to 660 cm (0.2 to 21.7 ft). Preference values for chinook salmon juveniles peaked at 52 cm (1.7 ft), like the utilization curve. High preference values (> 0.7) occurred at depths between 37 and 98 cm (1.2 and 3.2 ft). The highest depth preference in the Trinity River study (Hampton 1988) was observed at 68 cm (2.2 ft). Depth preference criteria developed for the Trinity River were extended with values of 1.0 assigned to all depths beyond 68 cm. We decided not to extend depth preference criteria for the LMCR in this way, because few juvenile chinook salmon were observed at depths greater than 145 cm (4.7 ft), even though depths of up to 660 cm (21.6 ft) occurred in the river when microhabitat measurements were obtained. Consequently, only LMCR preference criteria were used in defining composite curves for depths beyond 68 cm (2.2 ft). The composite preference curve for depth peaked (i.e. value of 1.0) from 53 to 68 cm (1.7 to 2.2 ft) (Figure 9.3). High depth preference values (> 0.7) were calculated between 38 and 100 cm (1.2 to 3.2 ft). Depth preference ranged from 7 to 145 cm (0.2 to 4.7 ft).





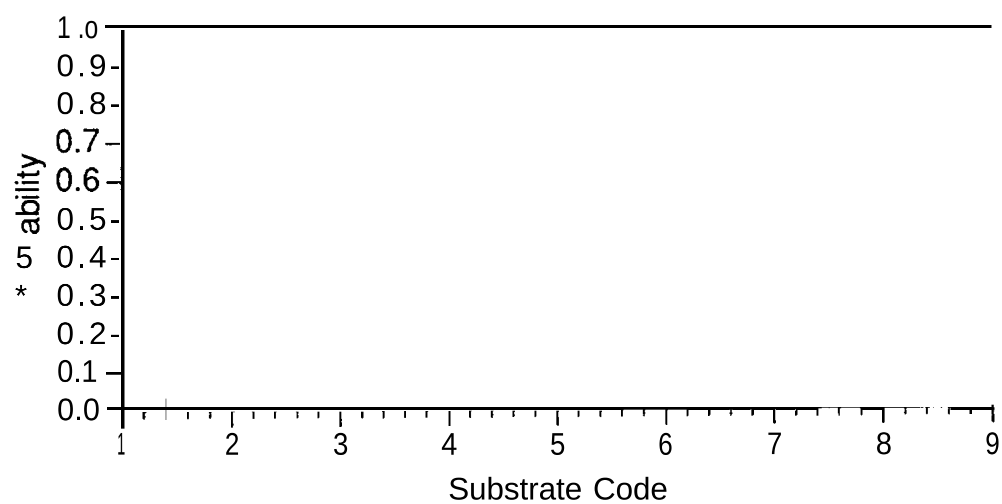


Figure 9.2. Composite suitability curves for adult chinook salmon holding for the lower mainstem Clearwater River based on the Kenai River, Alaska and Wind River, Washington.

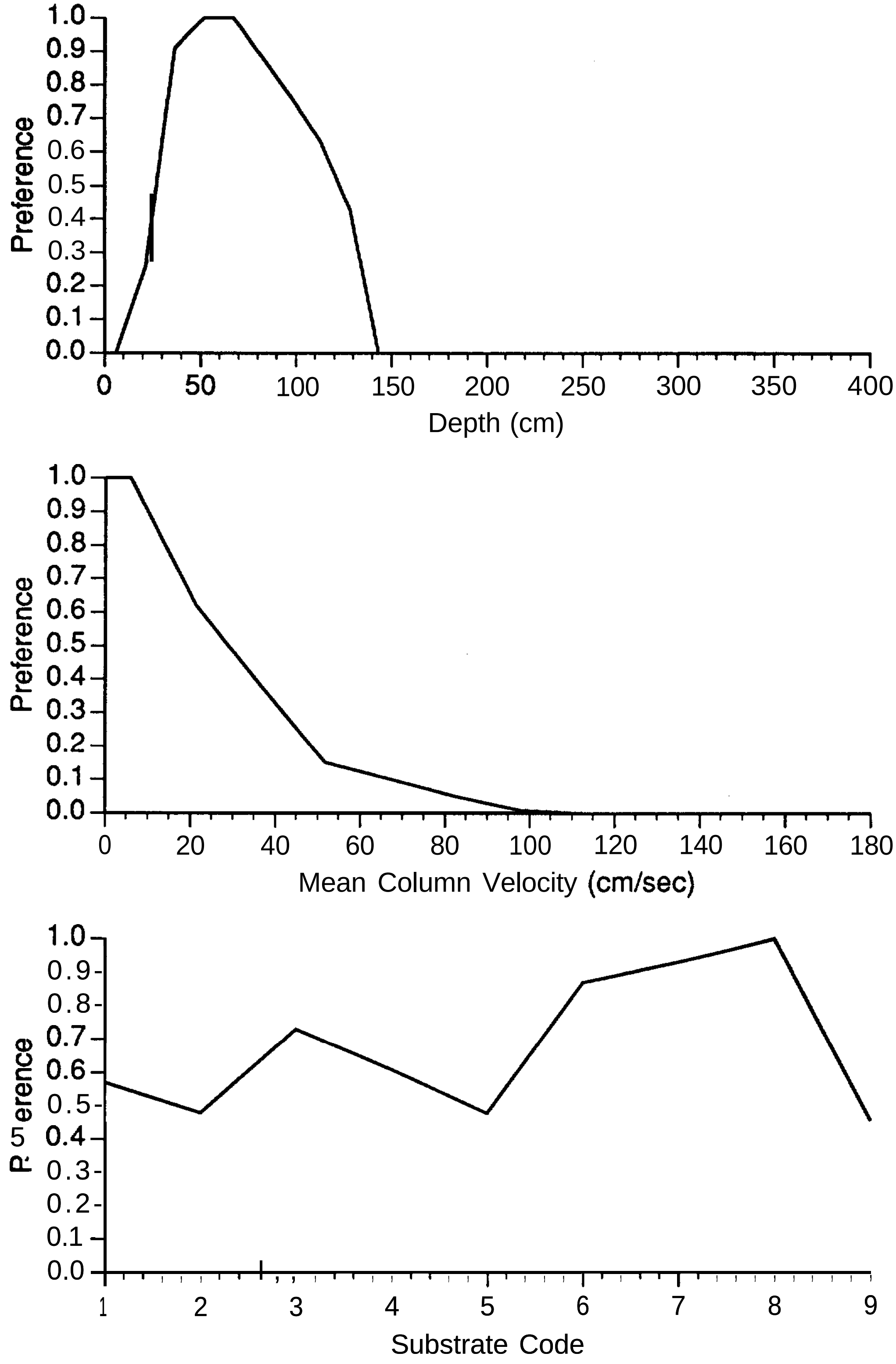


Figure 9.3. Composite preference curves for chinook salmon juveniles for the lower mainstem Clearwater River based on the lower mainstem Clearwater River, Idaho and Trinity River, California.

Velocity utilization for chinook salmon juveniles was measured on the LMCR between 0 to 61 cm/sec (0.0 to 2.0 ft/sec). Peak utilization was observed at velocities between 0 and 15 cm/sec (0 and 0.5 ft/sec). The availability of mean water column velocity predicted at 255 cms (9,000 cfs) peaked at 76 cm/sec (2.5 ft/sec) and ranged from 0 to 253 cm/sec (0 to 8.3 ft/sec). Calculated velocity preference for the LMCR peaked at 0 cm/sec and declined above 8 cm/sec (0.3 ft/sec) to a preference value of 0.0 at 76 cm/sec (2.5 ft/sec). The velocity preference curve for the Trinity River (Hampton 1988) exhibited a very similar shape but with a slightly higher upper velocity limit. The Trinity River curve peaked at 0 cm/sec and then progressively declined to 0 preference at 100 cm/sec (3.3 ft/sec). The composite velocity preference curve developed for the LMCR had maximum values for velocities from 0 to 8 cm/sec (0 to 0.26 ft/sec) (Figure 9.3). Above this, preference values formed a steadily declining curve, reaching 0 at 100 cm/sec (3.3 ft/sec).

Measured substrate utilization for juvenile chinook salmon on the LMCR occurred for substrates ranging in size from small cobbles to large boulders. Peak utilization was observed for large cobbles. Substrate availability measurements indicated that the most substrates on the LMCR ranged from medium gravels to large boulders. Small and large cobbles were the most dominant substrates measured in the LMCR. Calculated substrate preference values for juvenile chinook salmon indicated the highest preference for small boulders, with high values (> 0.7) for substrates ranging in size from medium cobbles to small boulders. The substrate curve for chinook salmon juveniles developed for the Trinity River (Hampton 1988) showed a much wider range of preference values than that calculated from the LMCR data. This is most likely caused by a much broader range of available substrates on the Trinity River which possessed substrates ranging in size from fines to large boulders. Like the LMCR, small boulders were the preferred substrate of juvenile chinook salmon. The composite curves consequently showed a broader range of substrates than that calculated from the LMCR data alone (Figure 9.3). The composite curve for juvenile chinook salmon indicated that substrates ranging from medium cobbles to small boulders were most preferred (preference > 0.7). All substrate sizes had at least a moderate preference (> 0.5).

4. Chinook Salmon Fry

Maximum depth preference for chinook salmon fry occurred at 34 cm (1.1 ft) and ranged from 0 to 207 cm (0 to 6.8 ft) (Hampton 1988) (Figure 9.4). High preference (> 0.7) was predicted for depths from 12 to 60 cm (0.4 to 2.0

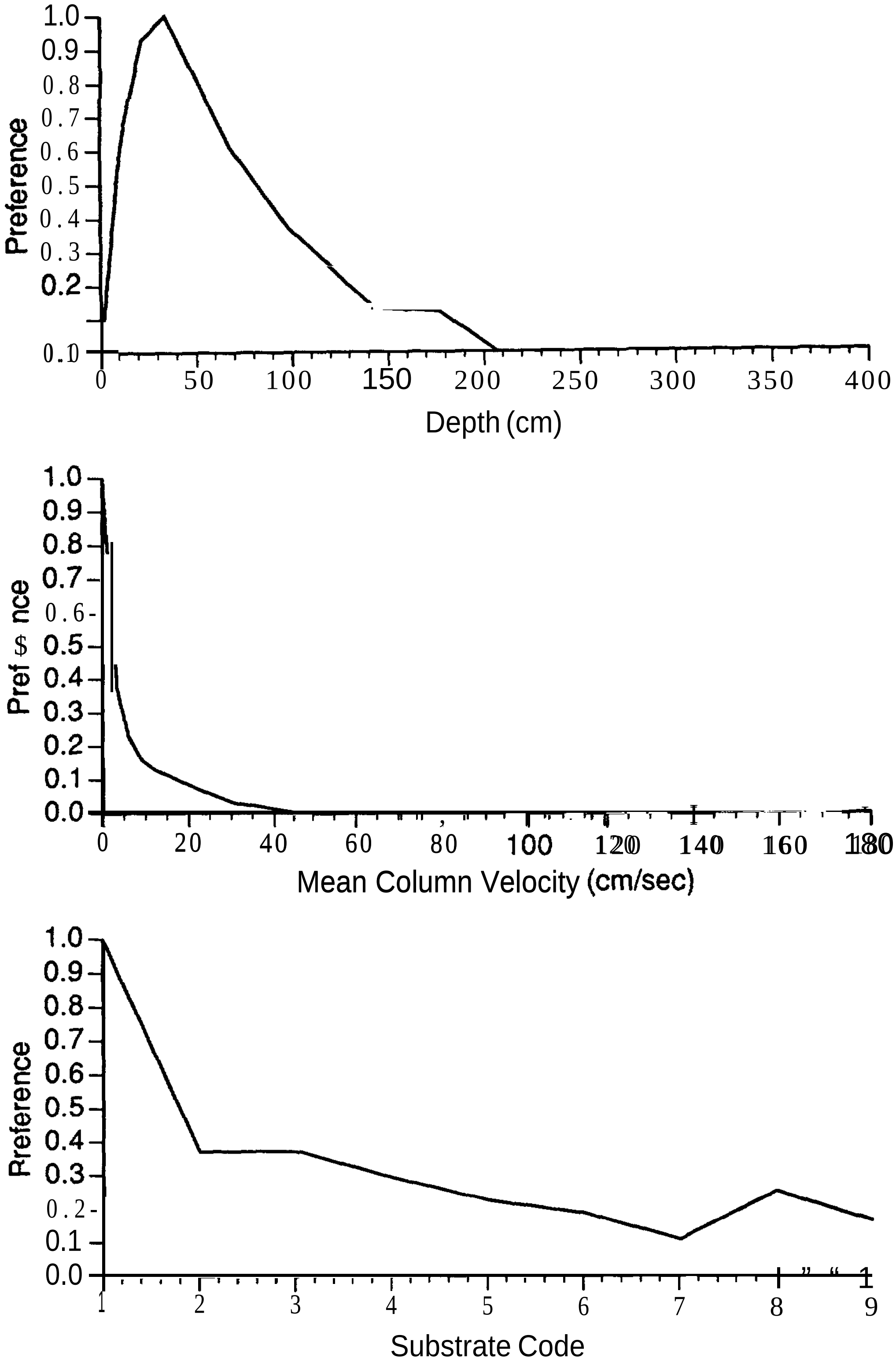


Figure 9.4. Composite preference curves for chinook salmon fry for the lower mainstem Clearwater River based on the Trinity River, California.

ft). Velocity preference was highest at 0 cm/sec and declined rapidly with increasing velocity (Figure 9.4). Velocities beyond 46 cm/sec (1.5 ft/sec) were found to be unsuitable for chinook salmon fry. The most preferred substrate predicted by this study was fines (Figure 9.4). Preference values gradually declined for larger substrates with substrates larger than small cobbles having a relatively low preference (< 0.2).

5. Rainbow/Steelhead Trout Juveniles

Peak depth utilization by rainbow/steelhead trout juveniles on the LMCR was 85 cm (2.8 ft). Juvenile rainbow/steelhead trout were observed using depths ranging from 24 to 137 cm (0.8 to 4.5 ft). Depth availability at 255 cms (9,000 cfs) was greatest at 82 cm (2.7 ft) and ranged from 6 to 660 cm (0.2 to 21.7 ft). The calculated preference curve had a maximum value of 85 cm (2.8 ft) (Figure 9.5). Preference values were highest (> 0.7) for depths between 45 and 100 cm (1.5 and 3.3 ft) and ranged from 24 to 177 cm (0.8 to 5.8 ft).

Peak velocity utilization was 40 cm/sec (1.3 ft/sec). Juvenile rainbow/steelhead trout were observed using velocities ranging from 0 to 152 cm/sec (0.0 to 5.0 ft/sec). Mean column velocity availability at a discharge of 255 cms (9,000 cfs) peaked at 76 cm/sec (2.5 ft/sec) and ranged from 0 to 253 cm/sec (0 to 8.3 ft/sec). Velocity preference was highest at 24 cm/sec (0.8 ft/sec) (Figure 9.5). High preference values (> 0.7) were calculated for velocities ranging from 0 to 55 cm/sec (0 to 1.8 ft/sec). Velocity preference ranged from 0 to 162 cm/sec (0 to 5.3 ft/sec).

Substrate utilization for rainbow/steelhead juveniles was highest for small boulders. Substrate availability measurements on the LMCR indicated that most substrate ranged in size from medium gravels to large boulders, with medium cobbles the most available substrate class. Small boulders were the most preferred substrate class (Figure 9.5). Preference calculations for substrate indicated that substrates ranging in size from large cobbles to large boulders were the most suitable (preference > 0.7) for juvenile fish.

6. Rainbow/Steelhead Trout Fry

Peak depth utilization by rainbow/steelhead trout fry on the LMCR was 24 cm (0.8 ft). Fry used depths that ranged from 9 to 100 cm (0.3 to 3.3 ft). Depth availability at a discharge of 255 cms (9,000 cfs) was greatest at 82 cm (2.7 ft) and ranged from 6 to 660 cm (0.2 to 21.7 ft). The preference curve calculated for rainbow/steelhead trout fry

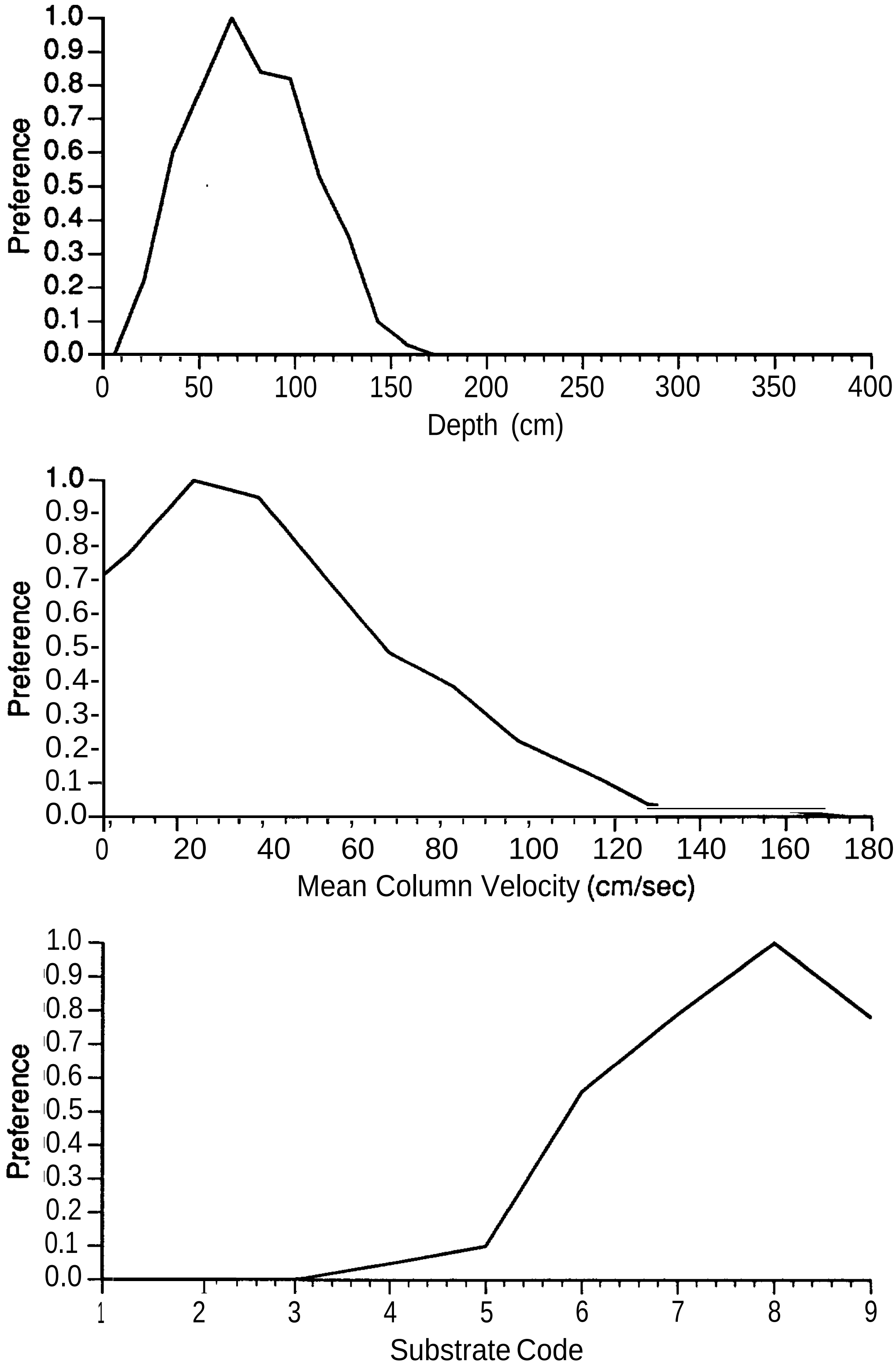


Figure 9.5. Preference curves for rainbow /steelhead trout juveniles based on data collected from the lower mainstem Clearwater River.

peaked at 24 cm (0.8 ft) (Figure 9.6). Preference values were highest (> 0.7) for depths between 24 and 40 cm (0.8 and 1.3 ft) and ranged from 9 to 100 cm (0.3 to 3.3 ft).

Peak velocity utilization was 0 cm/sec. Fry were observed using velocities ranging from 0 to 55 cm/sec (0 to 1.8 ft/sec). Mean water column velocity availability at a discharge of 255 cms (9,000 cfs) peaked at 76 cm/sec (2.5 ft/sec), and ranged from 0 to 253 cm/sec (0 to 8.3 ft/sec). The velocity preference curve peaked at 0 to 10 cm/sec (0 to 0.3 ft/sec) (Figure 9.6).

Substrate utilization for rainbow/steelhead fry was highest for medium cobbles. Substrate availability measurements on the LMCR indicated that most substrates ranged in size from medium gravels to large boulders, with medium cobbles the most available substrate class. Small boulders were the most preferred substrate (Figure 9.6) after adjusting for substrate availability. Preference calculations for substrate indicated that substrates ranging in size from medium cobbles to large boulders were the most suitable (preference > 0.7) for fry in the LMCR.

Discussion

Suitability curves for fall chinook salmon spawning emphasized greater depths and higher velocities than observed in other studies. We used nose velocity criteria instead of mean column velocity criteria in developing chinook salmon spawning curves. This was necessary to account for the larger differences between mean column and bottom velocities observed in the deep waters of large rivers. Suitability curves for chinook salmon and rainbow/steelhead trout fry indicated a preference for relatively low velocities in shallow water. Suitability criteria for juvenile chinook salmon and rainbow/steelhead trout indicated a preference for higher velocities and greater depths than that of fry, as well as a definite preference for large cobble and boulder substrates. The preference of large substrates by juvenile salmonids is likely a result of velocity refuges provided by these larger substrates within the main channel habitat of the LMCR. Main channel habitat velocities in the LMCR generally exceed tolerated values for juvenile salmonids. Consequently, the highest densities of juvenile salmonids were found in association with boulders, though this habitat type is found in relatively low abundance when compared to medium cobble substrates which dominate the LMCR.

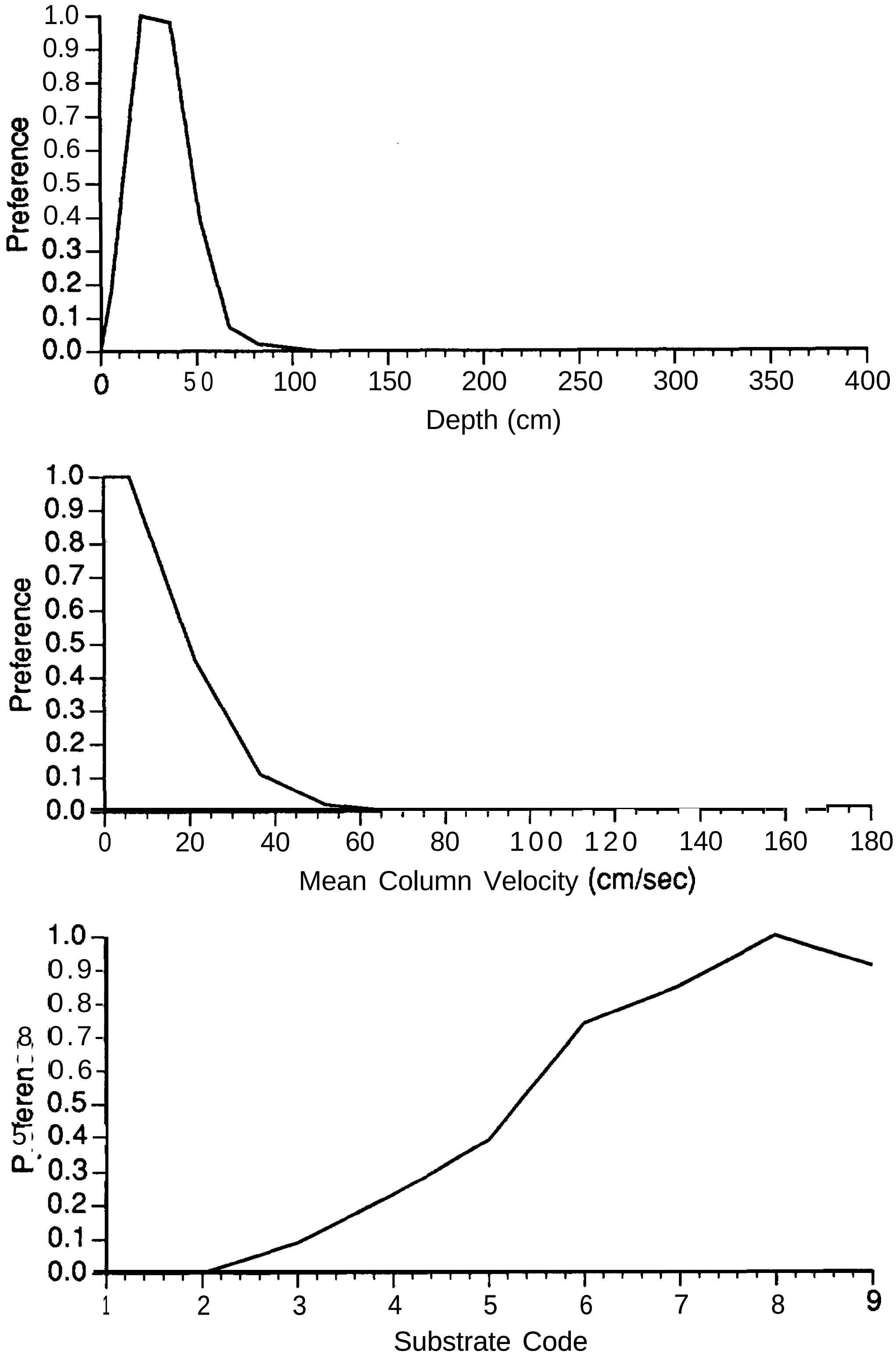


Figure 9.6. Preference curves for rainbow /steelhead trout fry based on data collected on the lower mainstem Clearwater River, Idaho.

CHAPTER 10

HABITAT SIMULATION MODELING

Abstract-Habitat simulation modeling was conducted to describe habitat characteristics of the lower mainstem Clearwater River (LMCR) for river discharges ranging from 85 to 1,416 cms (3,000 to 50,000 cfs). The PHABSIM habitat simulation model was used for this purpose. The program employed hydraulic information obtained from the LMCR hydraulic model and habitat suitability criteria developed for the LMCR to simulate habitat conditions for chinook salmon *Oncorhynchus tshawytscha* adult holding and spawning, and chinook salmon and rainbow/steelhead trout 0. *mykiss* fry and juvenile rearing. Habitat simulation modeling was used to describe changes in weighted usable area (WUA) and habitat area (HA) as a function of total river discharge. A habitat time series analysis was then employed to describe habitat conditions on the LMCR on a month-to-month basis. This habitat time series was developed from daily discharge information obtained from the LMCR. WUA and HA values for chinook salmon and rainbow/steelhead trout fry and juveniles were highest at relatively low flows (85 cms or 3,000 cfs), a result of high velocities which dominate the LMCR at moderate and high discharges. WUA and HA values were also highest at these same low flows for spawning chinook salmon, also a result of higher velocities. WUA and HA values for chinook salmon and steelhead trout adult holding were highest at moderate discharges (453 cms or 16,000 cfs).

Introduction

A typical instream flow study generates an enormous volume of data, which at first glance, is overwhelming and presents and unclear picture. The objective of this study segment was to interface our fish population periodicity, hydraulic, and fish habitat preference data to define changes in fish habitat with fluctuations in discharges from Dworshak Dam.

Methods

Habitat Versus Discharge Relationships

We used our calibrated hydraulic simulation model (Chapter 8) to predict velocity, depth, and substrate conditions at the Potlatch, Bedrock, and Big Canyon study sites for discharges ranging from 85 to 1,416 cms (3,000 to 50,000 cfs). Results of hydraulic simulations at these sites were then employed in HABTAT (Milhous et al. 1989). HABTAT defined weighted usable area (WUA) versus flow relationships for each species and life stage in each segment of the LMCR.

Habitat modeling for the LMCR consisted first of calculating WUA versus discharge relationships for the Potlatch, Bedrock, and Big Canyon IFIM study sites (Appendix D). Habitat-discharge relationships were developed for chinook salmon ***Oncorhynchus tshawytscha*** holding, spawning, juveniles, and fry, and rainbow/steelhead trout 0. ***mykiss*** juveniles and fry. WUA versus discharge curves were calculated using the HABTAT habitat simulation model which incorporated the hydraulic simulation data and microhabitat preference curves developed for the LMCR.

We converted WUA versus discharge relationships into habitat area (HA) versus discharge relationships for the three river segments (Appendix D). HA values reflect the total weighted habitat provided to fish for given simulation flows and were expressed in hectares (10,000 m^2 or 107,639 ft^2). HA values for chinook salmon and rainbow/steelhead trout fry and juveniles were modified using summer critical temperature criteria for predicting total habitat in the LMCR for July and August (Appendix D). Relatively high water temperatures have been observed during these months coinciding with periods of low flow in the LMCR. Resulting HA versus discharge relationships for the three river segments were then used to identify optimal flows for target species and lifestages and used for the habitat time series analysis.

Habitat Time Series Analvsis

A habitat time series analysis was employed to quantify and analyze habitat conditions on the LMCR resulting from existing flow conditions. The month-to-month use of the LMCR by each target species and life stage was first defined before proceeding to the time series analysis, since modeling habitat conditions for months in which a given species was not present would be meaningless. Habitat statistics were developed on a month-to-month basis for key life stages of species on this timeline. Based upon this timeline, habitat statistics were calculated for fall chinook salmon spawning from November through mid-December, while chinook salmon holding habitat was calculated from June to September. Habitat statistics for spring chinook salmon juveniles were calculated from January to June. Habitat statistics for steelhead trout holding were calculated from August through March. Finally habitat statistics for rainbow/steelhead trout rearing were calculated from January to December, since they are present in the river throughout the entire year.

The habitat area curves developed for target species in the Potlatch, Bedrock, and Big Canyon segments of the LMCR were used to calculate daily habitat values from river discharge data. We developed a microcomputer program to calculate daily habitat values, since IFIM programs developed by the U.S. Fish and Wildlife Service calculates habitat values using a monthly time-step (Bovee 1982). A monthly time-step would be too long to realistically access effects of flows on habitat values, because flows in the LMCR vary considerably during any given month. This variable flow pattern is caused by variable release schedules of Dworshak Dam to meet short-term energy demands (e.g. hot summer periods), as well as by natural runoff patterns of the upper mainstem Clearwater River and its tributaries.

Files of daily discharge values were first read by our microcomputer program for each the three segments of river. Discharge files contained daily discharge records from 1973 to the present. This corresponds to the time period when flows in the LMCR were influenced by Dworshak Dam operation. Dworshak Dam was completed in 1972, with normal reservoir operation attained in March, 1973 (USACE 1986). Separate discharge records were developed for each segment to account for differences in flow due to tributary inflows, groundwater accretion, and irrigation diversions and returns. Discharge records for the Potlatch Segment were obtained from the Spalding gaging station, while those for the Big Canyon Segment were obtained from the Peck gaging station. A discharge record was simulated for the Bedrock Segment from watershed area based interpolation of daily discharge values recorded at the Spalding and Peck gaging stations.

A file containing coordinates of the habitat area (HA) versus discharge curve for each species and life stage was also read by our microcomputer program. The program then converted each daily discharge value in the 17-yr record into a daily habitat value using the appropriate coordinates in the habitat versus discharge curve file. A linear interpolation algorithm was used to calculate habitat values when daily discharge values fell between those provided in the HA versus discharge coordinate data file. Habitat values were calculated in separate program runs for each target species. The output of this procedure was a database of daily habitat values for each target species and life stage for each of the three river segments.

The resulting databases of daily habitat values were analyzed using a microcomputer statistics package. Frequency values, including 10th, 50th, and 90th percentile values, were used to characterize daily habitat conditions existing in the river as influenced by reservoir releases and natural runoff patterns. Daily habitat values were calculated on a month-to-month basis to identify those months in which habitat conditions were the best, and those which were the poorest, under current reservoir operating conditions. The 50th percentile (median) value was used to describe the center of the habitat frequency distribution resulting under historic conditions. This value is the most intuitive for comparing differences in habitat from month to month, since it describes whether the center of the frequency distribution is relative high or low. The 10th percentile value gives a good indication of the poorest habitat conditions occurring for any given month, while the 90th percentile value describes the best habitat conditions occurring for the same month.

Results

Habitat Versus Discharge Relationships

WUA values calculated for main channel habitat at the Potlatch, Bedrock, and Big Canyon study sites were highest at the lowest discharges modeled (Figure 10.1). The highest WUA values occurred at 85 cms (3,000 cfs). WUA values declined at higher discharges. WUA values for chinook salmon spawning habitat for Potlatch site main channels peaked at 85 cms (3,000 cfs) while WUA values for side channels were maximum at approximately 283 cms (10,000 cfs) and WUA values for intermittent channels were maximum at about 708 cms (25,000 cfs).

A similar pattern was observed for rainbow/steelhead trout juveniles. WUA values for these fish were highest at 85 cms (3,000 cfs) and declined rapidly at flows above this at the Potlatch site main channel. WUA values in the side channels were greatest at approximately 453 cms (16,000 cfs), while WUA values in the intermittent channel were greatest at 120 cms (36,000 cfs) (Figure 10.2).

HA versus discharge relationships for chinook salmon spawning were highest at 85 cms (3,000 cfs) for the Potlatch, Bedrock, and Big Canyon segments (Figure 10.3). The greatest area of spawning habitat (120 ha) was provided by the Potlatch Segment. This results from a higher availability of suitable spawning substrates in the Potlatch Segment. Also, this segment contains the highest density of islanded channels on the LMCR. Nearly maximum spawning habitat values were maintained in the Potlatch and Bedrock segments to about 170 cms (6,000 cfs). HA values for spawning declined to 45 and 15 ha in the Potlatch and Bedrock segments, respectively, at about 850 cms (30,000 cfs). Spawning HA values for the Bedrock Segment were

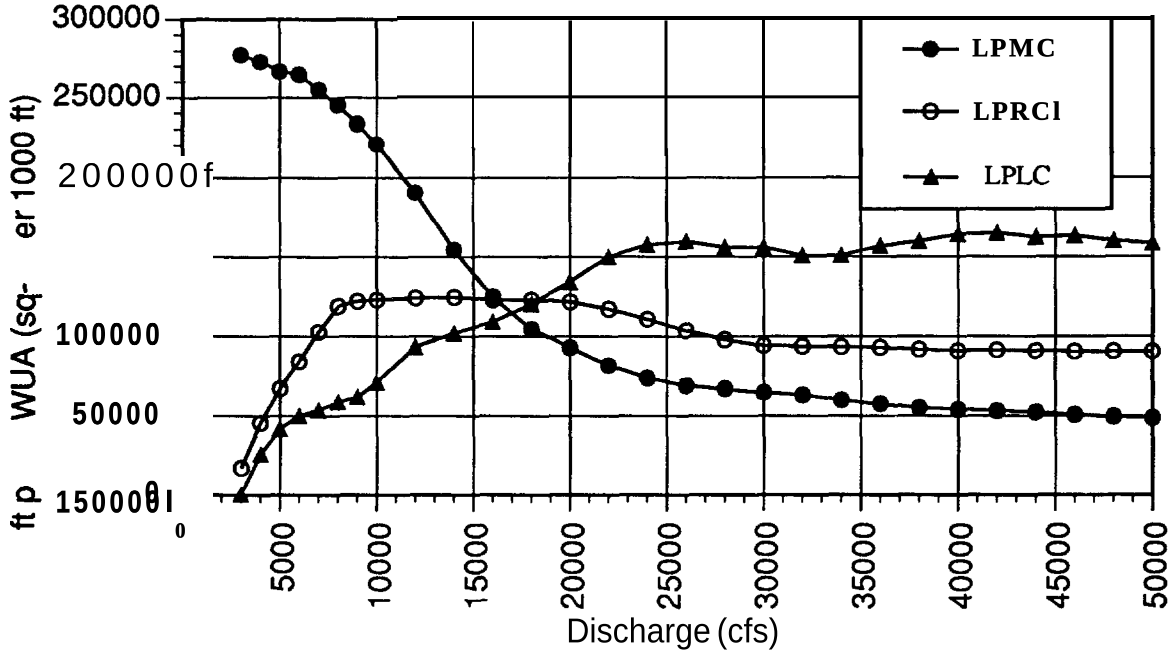


Figure 10.1. Weighted usable area versus discharge curves for spawning chinook salmon at main channel (LPMC), side channel (LPRCl), and intermittent channel (LPLC) reaches of the lower Potlatch study site of lower mainstem Clearwater River.

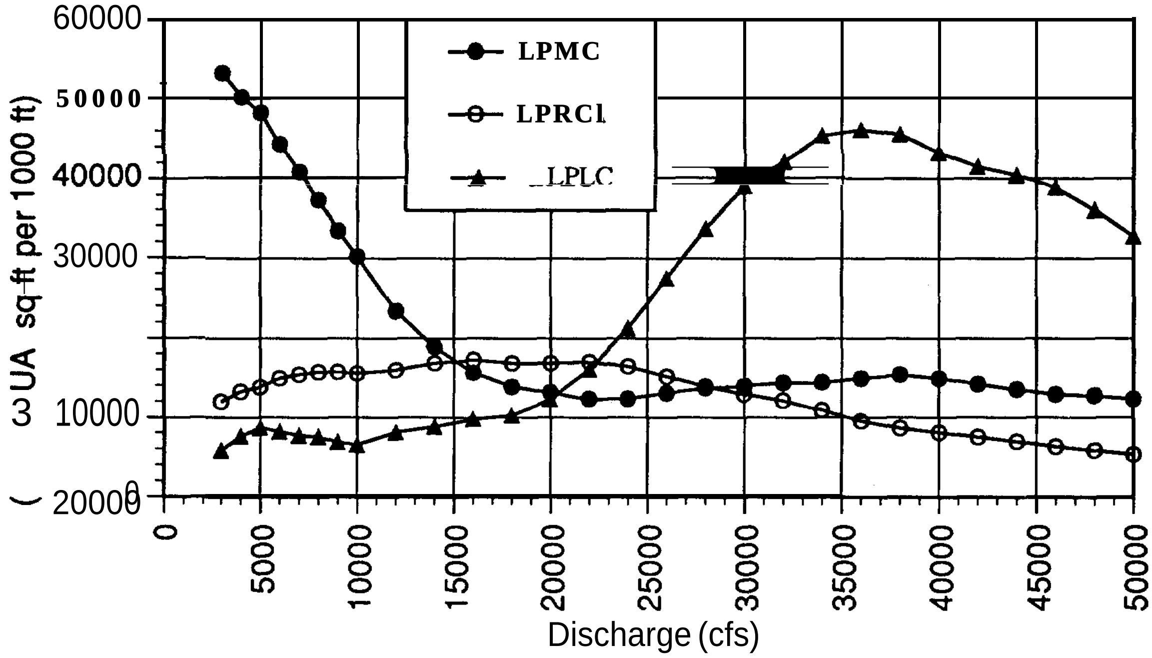


Figure 10.2. Weighted usable area versus discharge curves for rainbow and steelhead trout juveniles at main channel (LPMC), side channel (LPRCl), and intermittent channel (LPLC) reaches of the lower Potlatch study site of lower mainstem Clear-water River.

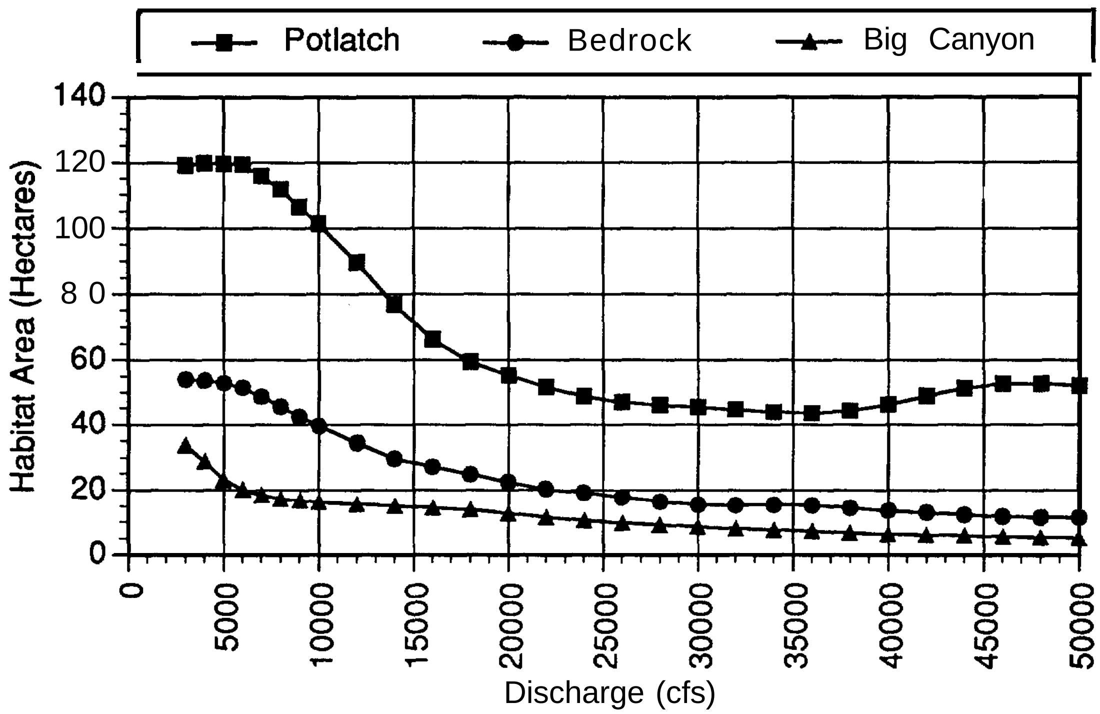


Figure 10.3. Habitat area versus discharge relationships for chinook salmon spawning at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Cleat-water River.

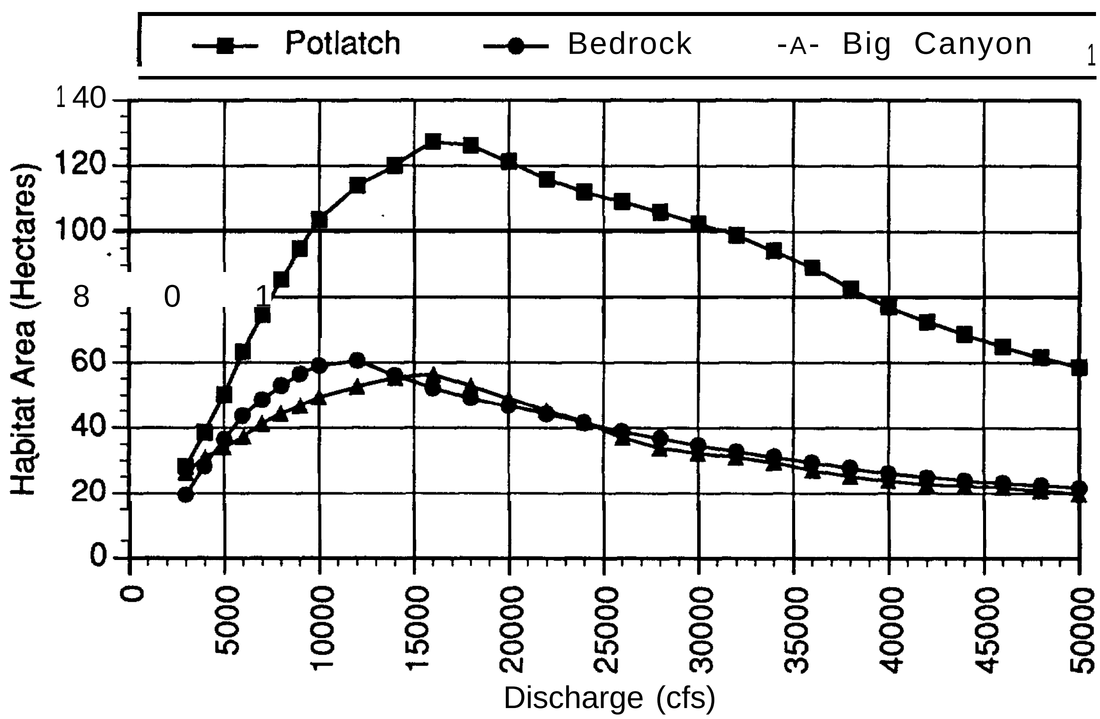


Figure 10.4. Habitat area versus discharge relationships for adult chinook salmon and steelhead holding at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Cleat-water River.

relatively low and declined rapidly below maximum values of 35 ha for discharges above 85 cms (3,000 cfs).

HA values for holding chinook salmon peaked at much higher flows at all segments: 453 cms (16,000 cfs) in the Potlatch and Big Canyon segments, and 340 cms (12,000 cfs) in the Bedrock Segment (Figure 10.4). Maximum holding habitat values occurred at much higher discharges as a result of greater depth and nose velocity suitability criteria when compared to spawning habitat. The Potlatch Segment provided the most holding habitat in the LMCR. A maximum habitat value of 130 ha was predicted for the Potlatch Segment, while values of 60 and 55 ha were predicted for the Bedrock and Big Canyon segments, respectively. Holding habitat values in all segments were relatively low at discharges of 85 cms (3,000 cfs), but increased rapidly at higher discharges. HA values at all sites progressively declined beyond peak values attained from 340 and 453 cms (12,000 and 16,000 cfs) (Figure 10.4). Holding habitat values at a flow of 1,416 cms (50,000 cfs), the highest flow modeled, were 60, 22, and 20 ha for the Potlatch, Bedrock, and Big Canyon segments, respectively.

HA values for chinook salmon fry were extremely low with maximum habitat values of only 1.2 ha attained in the Potlatch Segment (Figure 10.5). Maximum HA values for the Bedrock and Big Canyon segments were 0.5 and 0.7 ha, respectively. The magnitude of these values become apparent when considering that the LMCR has a total wetted area of approximately 1,000 ha at 85 cms (3,000 cfs). These values are only about 1/100th of the total habitat value for all segments combined and are greatest at the lowest modeled flow of 85 cms (3,000 cfs) (Figure 10.5). Habitat values then rapidly declined until about 198 cms (7,000 cfs), beyond which the response of habitat to discharge is relatively flat. Habitat values slightly increased beyond 963 cms (34,000 cfs) in all segments, suggesting that greater amounts of critical edge habitat for fry may be provided at these flows.

The summer HA versus discharge relationships for fry resemble those calculated for non-summer periods except that values were lower for discharges between 85 and 283 cms (3,000 and 10,000 cfs) (Figure 10.6). Habitat values for lower discharges were reduced because of decreased suitability of river temperatures provided by these flows during months of July and August (Chapter 12). Maximum HA values of approximately 0.4 ha occurred at the Potlatch site at 85 cms (3,000 cfs), 736 cms (26,000 cfs), and again at 1,189 cms (42,000 cfs). HA values for the Bedrock and Big Canyon segments decreased slightly at flows above 85 cms (3,000 cfs).

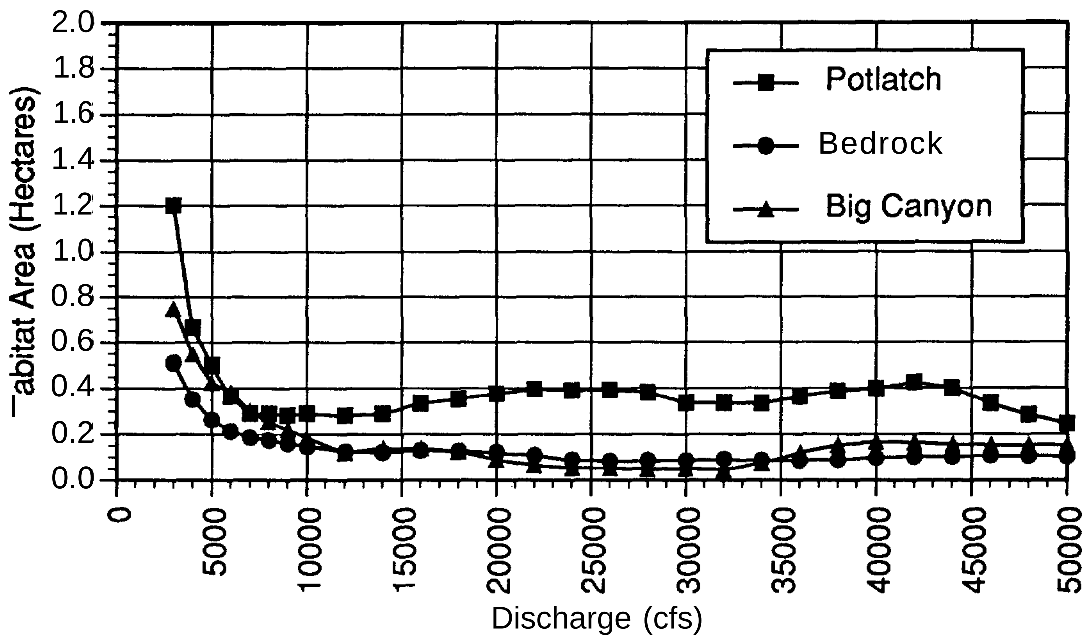


Figure 10.5. Habitat area versus discharge relationships for chinook salmon fry at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Clear-water River.

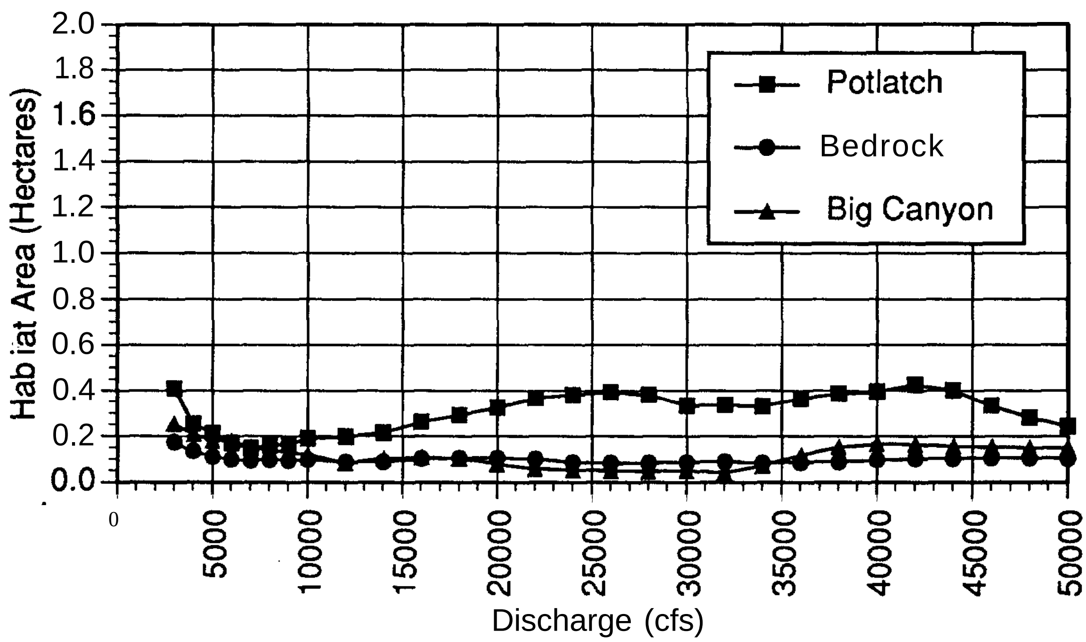


Figure 10.6. Critical temperature habitat area versus discharge relationships for chinook salmon fry at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Clear-water River.

HA values for chinook salmon juveniles were approximately ten times greater than those observed for fry (Figure 10.7). Maximum HA values for all segments occurred at the lowest simulated discharge of 85 cms (3,000 cfs). HA values at this discharge were 22, 24, and 12 ha for the Potlatch, Bedrock, and Big Canyon segments, respectively. HA values decreased rapidly at discharges above 85 cms (3,000 cfs), but leveled at approximately 425 cms (15,000 cfs) in all segments. HA values increased in the Potlatch Segment from 425 to 793 cms (15,000 to 28,000 cfs), suggesting the importance of island habitat at higher flows. Habitat values also increase slightly in the Bedrock Segment from 510 to 680 cms (18,000 to 24,000 cfs).

Temperature-modified (Chapter 12) HA values for juvenile chinook salmon were substantially reduced from those predicted under non-critical climatic conditions for discharges between 85 and 283 cms (3,000 and 10,000 cfs) (Figure 10.8). As with fry, this reduction was the result of high water temperatures which occur during low flows in July and August. The HA versus discharge curves were identical to those predicted under non-critical temperature conditions for discharges above 283 cms (10,000 cfs), indicating that flows above this level provided temperatures that are highly suitable for chinook salmon juveniles.

The HA versus discharge curves for rainbow/steelhead trout fry (Figure 10.9) in the LMCR resembled those for chinook salmon fry, except that HA values are approximately 5 times higher for the same discharges. HA values for rainbow/steelhead trout fry were greatest at the Potlatch Segment, with a maximum HA value of 10 ha occurring at 85 cms (3,000 cfs). Habitat conditions in the Bedrock and Big Canyon segments were also greatest at 85 cms (3,000 cfs) with values of 7 and 8 ha, respectively. Like the chinook fry curve, the rainbow/steelhead trout fry HA versus discharge curve declined rapidly from 85 cms (3,000 cfs) to approximately 283 cms (10,000 cfs). HA values for rainbow/steelhead trout fry then slightly increased from 283 to 510 cms (10,000 to 18,000 cfs) in the Big Canyon Segment, and from 283 to 566 cms (10,000 to 20,000 cfs) in the Pqtlatch and Bedrock segments. HA values under summer habitat conditions were also reduced considerably for rainbow/steelhead trout fry for discharges between 85 and 283 cms (3,000 and 10,000 cfs) (Figure 10.10). This reduction occurred for the same reasons explained for chinook salmon fry and juveniles.

Habitat values for rainbow/steelhead trout juveniles were higher than those predicted for rainbow/steelhead trout fry, as well as for chinook salmon juveniles and fry. At 85 cms (3,000 cfs), HA values for rainbow/steelhead trout

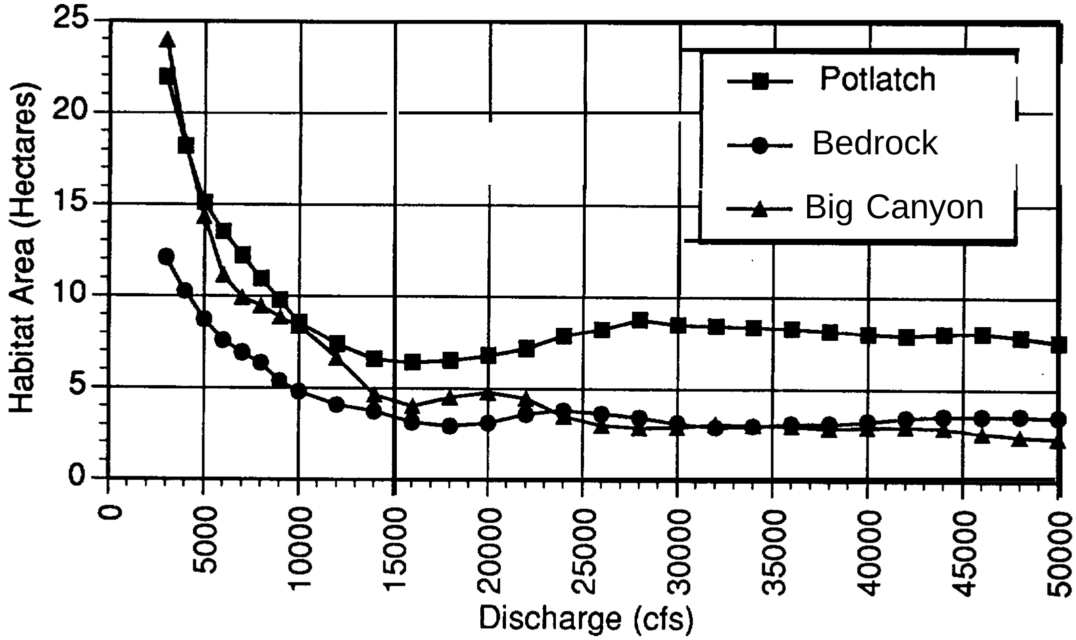


Figure 10.7. Habitat area versus discharge relationships for chinook salmon juveniles at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Clearwater River.

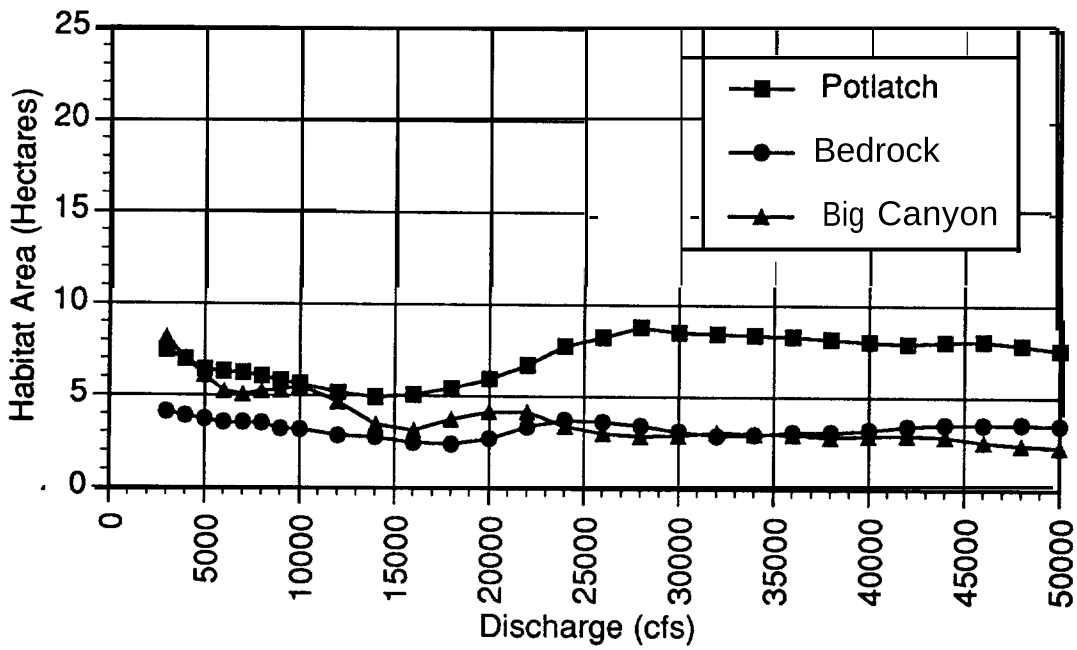


Figure 10.8. Critical temperature habitat area versus discharge relationships for chinook salmon juveniles at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Clear-water River.

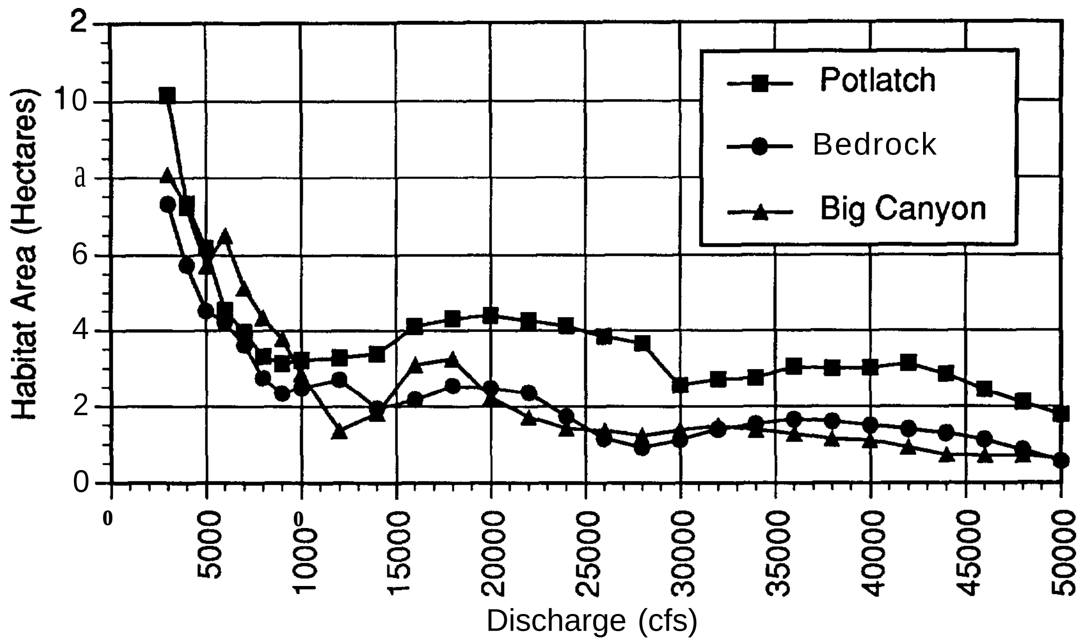


Figure 10.9. Habitat area versus discharge relationships for rainbow/steelhead trout fry at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Clearwater River.

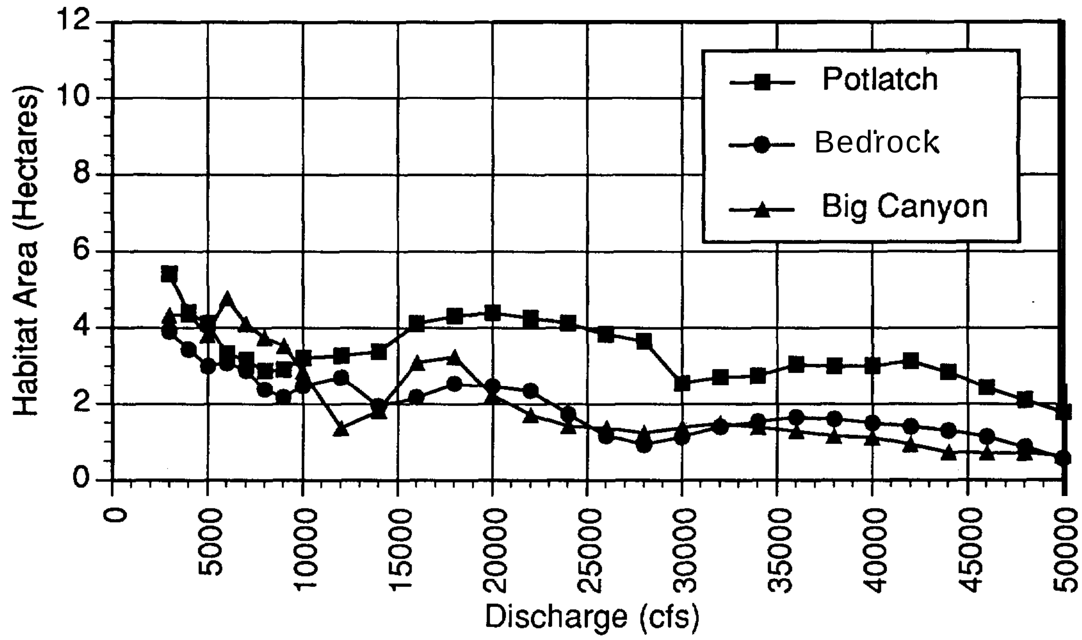


Figure 10.10. Critical temperature habitat area versus discharge relationships for rainbow /steelhead trout fry at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Cleat-water River.

juveniles attained a maximum value of 22 ha in the Potlatch Segment, 12 ha in the Bedrock Segment, and 42 ha in the Big Canyon Segment (Figure 10.11). The HA versus discharge curve for critical summer conditions resulted in lowered HA values for discharges between 85 and 170 cms (3,000 and 6,000 cfs) (Figure 10.12).

Total HA versus discharge relationships were obtained by adding the HA values for the three segments of the river at every flow. These curves resulted in an overall description of the relationship between habitat and flow in the LMCR. Total habitat curves are expressed as a percentage of maximum possible habitat.

Maximum habitat in the river was provided at 85 cms (3,000 cfs) for chinook salmon spawning (Figure 10.13). Flows from 85 to 198 cms (3,000 to 7,000 cfs) provide 90% or more of maximum habitat. The 70 and 50% levels of maximum habitat were provided by discharges of 312 and 481 cms (11,000 and 17,000 cfs), respectively. The chinook salmon spawning curve flattened out beyond 850 cms (30,000 cfs) which provides about 30% of maximum possible habitat.

Unlike spawning habitat, the holding habitat versus discharge relationship had a shape which is skewed to the right (Figure 10.14). Maximum holding habitat was provided by a river discharge of 453 cms (16,000 cfs). Discharges between 283 and 566 cms (10,000 and 20,000 cfs) provided habitat values that equal or exceed 90% of maximum possible habitat. Discharges between 198 and 878 cms (7,000 and 31,000 cfs) provided 70% or more of maximum possible habitat. Finally, discharges between 142 and 1,218 cms (5,000 and 43,000 cfs) provided habitat values equalling or exceeding 50% of maximum habitat.

The total habitat curve for fry shows that habitat conditions were more beneficial to fry in the LMCR at the lowest discharges modeled. Maximum habitat occurred at 85 cms (3,000 cfs) and dropped rapidly to about 340 cms (12,000 cfs), beyond which habitat changed relatively little with discharge (Figure 10.15). Discharges between 85 and 142 cms (3,000 and 5,000 cfs) provided habitat values which equal or exceed 50% of maximum values. The total habitat curve for critical summer conditions resulted in higher habitat values for all flows than those under the non-critical curve (Figure 10.16).

The total habitat versus discharge curves for chinook salmon juveniles closely resembled that calculated for fry, except that higher habitat values were provided by higher discharges (Figure 10.17). Maximum possible habitat was provided by a discharge of 85 cms (3,000 cfs). Discharges

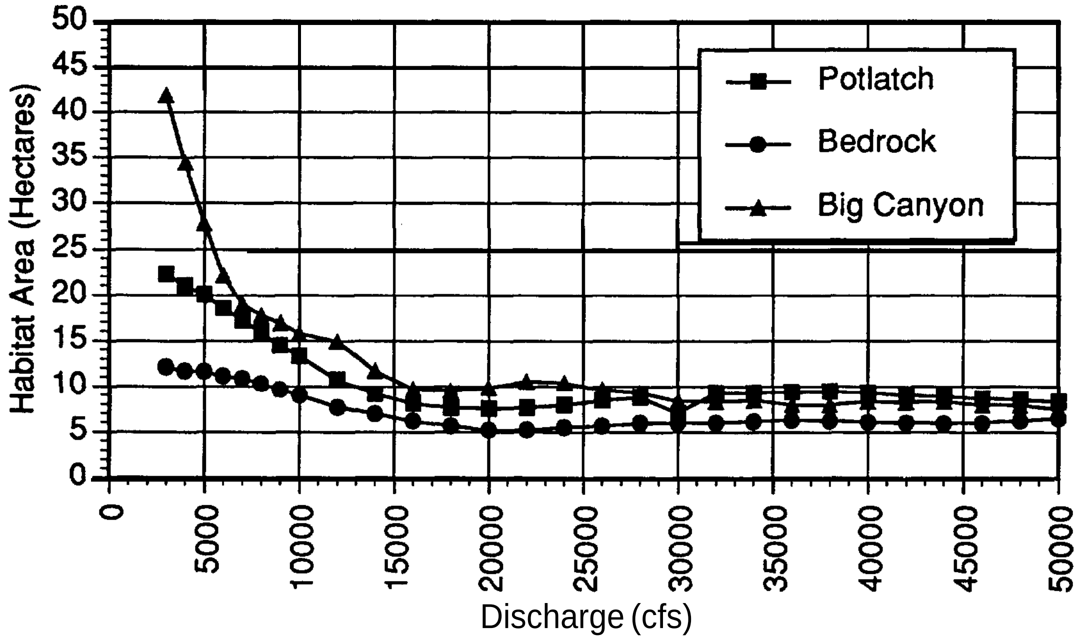


Figure 10.11. Habitat area versus discharge relationships for rainbow/ steelhead trout juveniles at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Clear-water River.

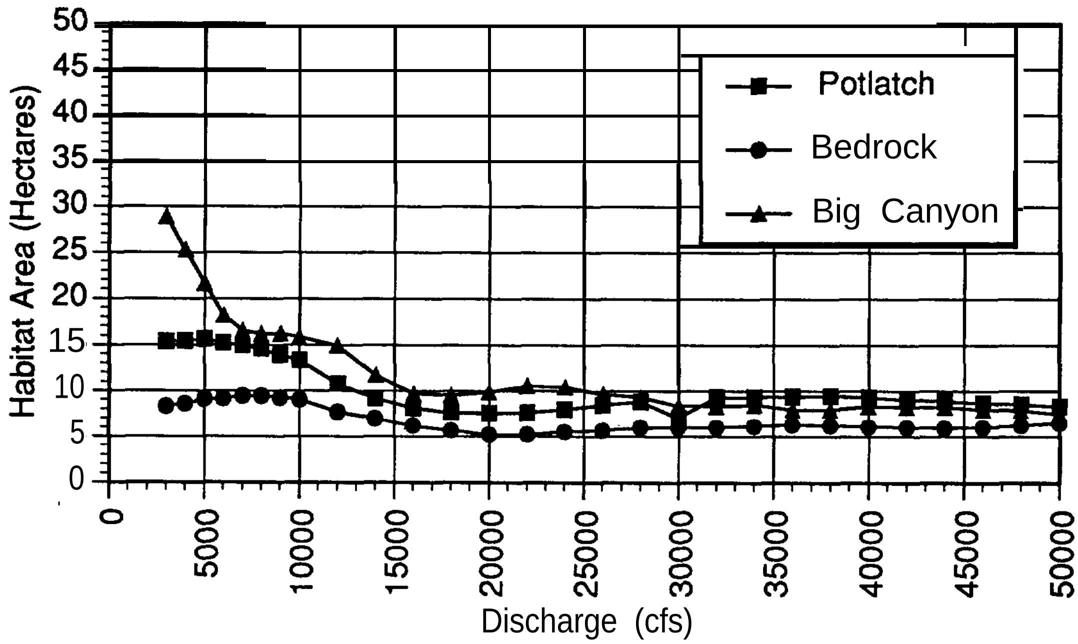


Figure 10.12. Critical temperature habitat area versus discharge relationships for rainbow/steelhead trout juveniles at Potlatch, Bedrock, and Big Canyon Segments, lower mainstem Clearwater River.

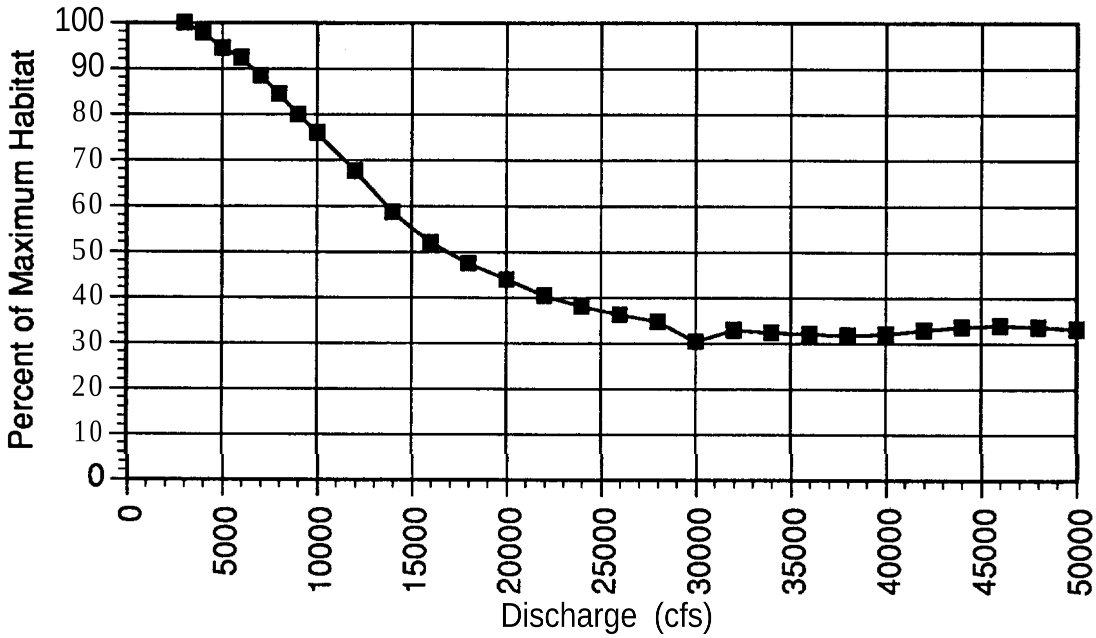


Figure 10.13. Total habitat area versus discharge curve for chinook salmon spawning in lower mainstem Clearwater River.

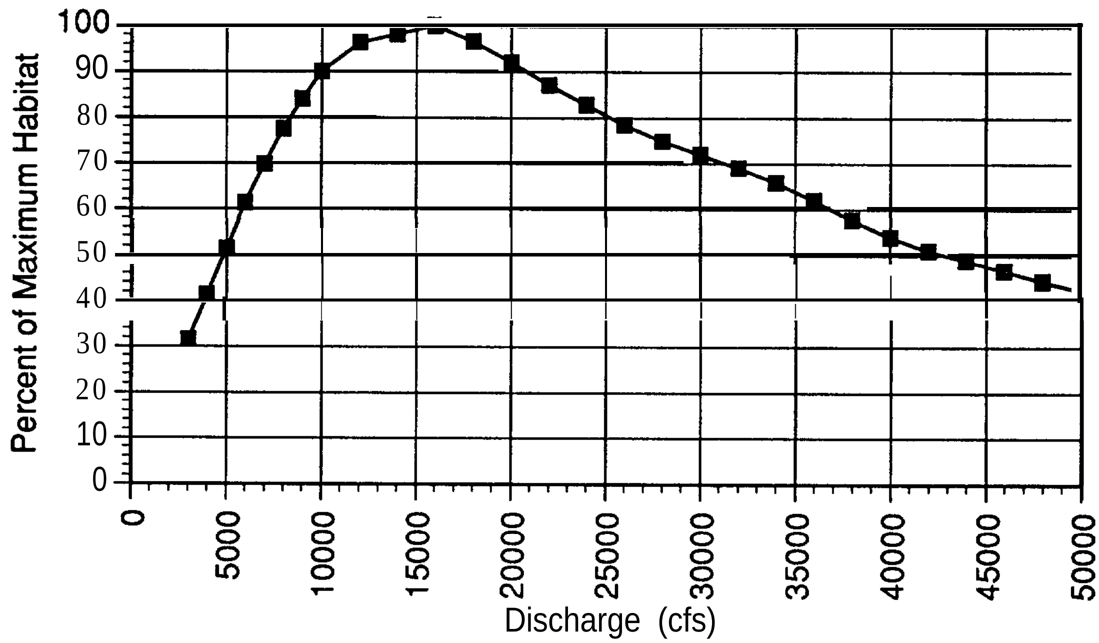


Figure 10.14. Total habitat area versus discharge curve for adult chinook salmon and steelhead holding in lower mainstem Cleat-water River.

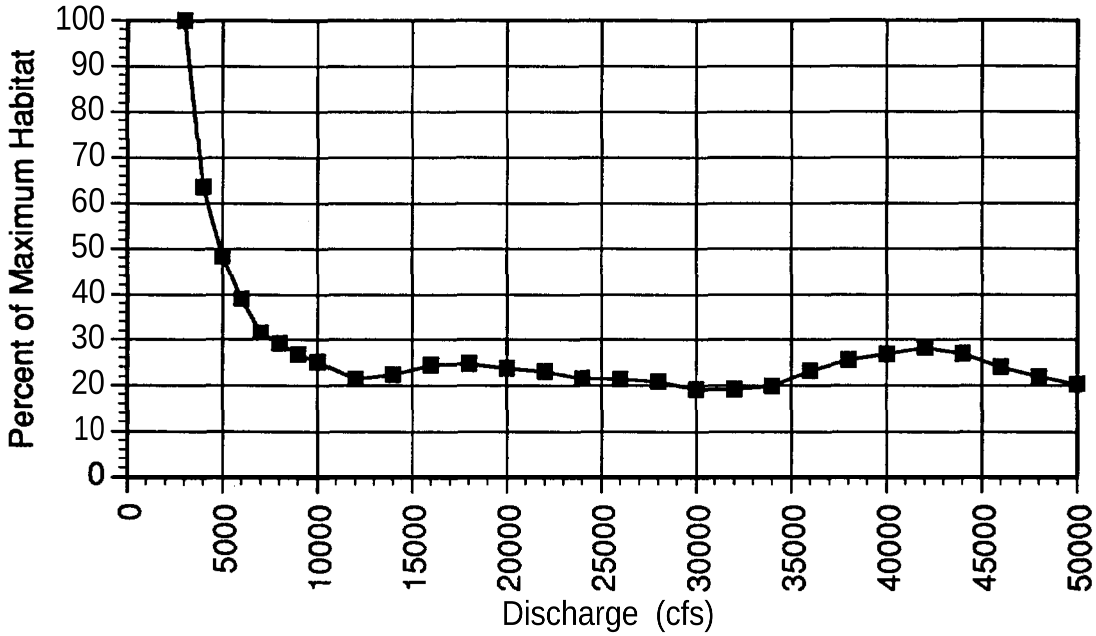


Figure 10.15. Total habitat area versus discharge curve for chinook salmon **fry** in lower **mainstem** Cleat-water River.

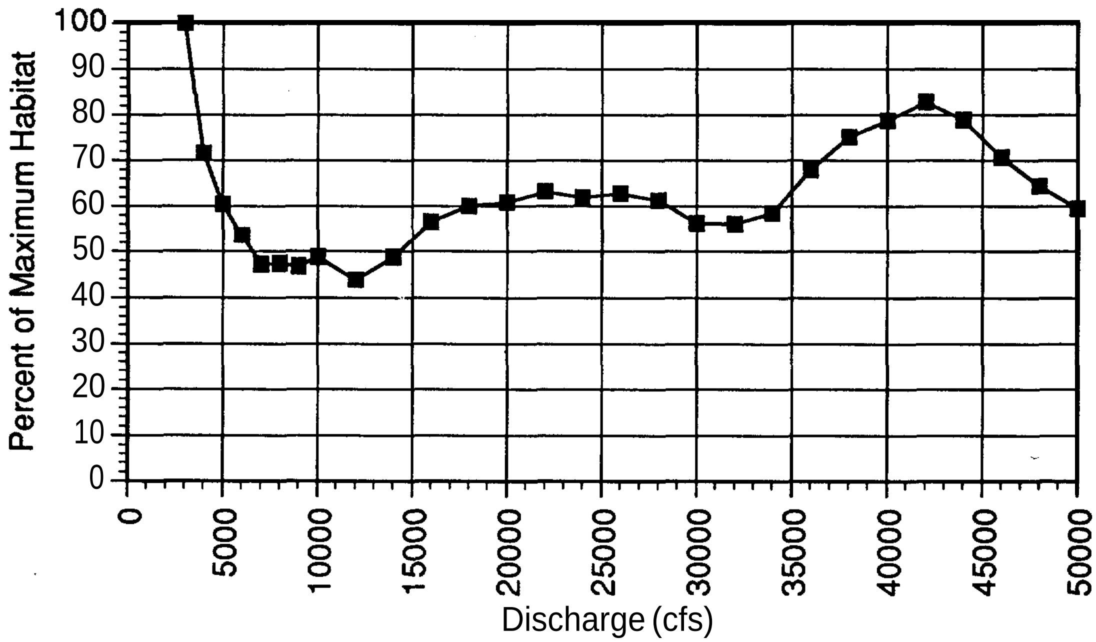


Figure 10.16. Critical temperature total habitat area versus discharge curve for chinook salmon fry in lower **mainstem** Clearwater River.

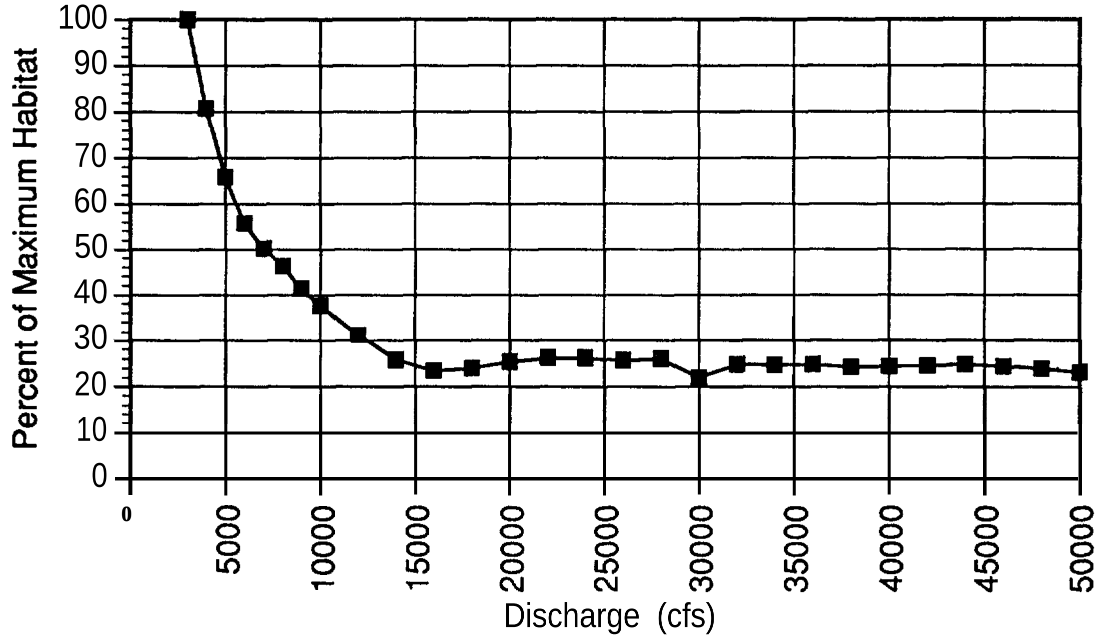


Figure 10.17. Total habitat area versus discharge curve for chinook salmon juveniles in lower mainstem Clearwater River.

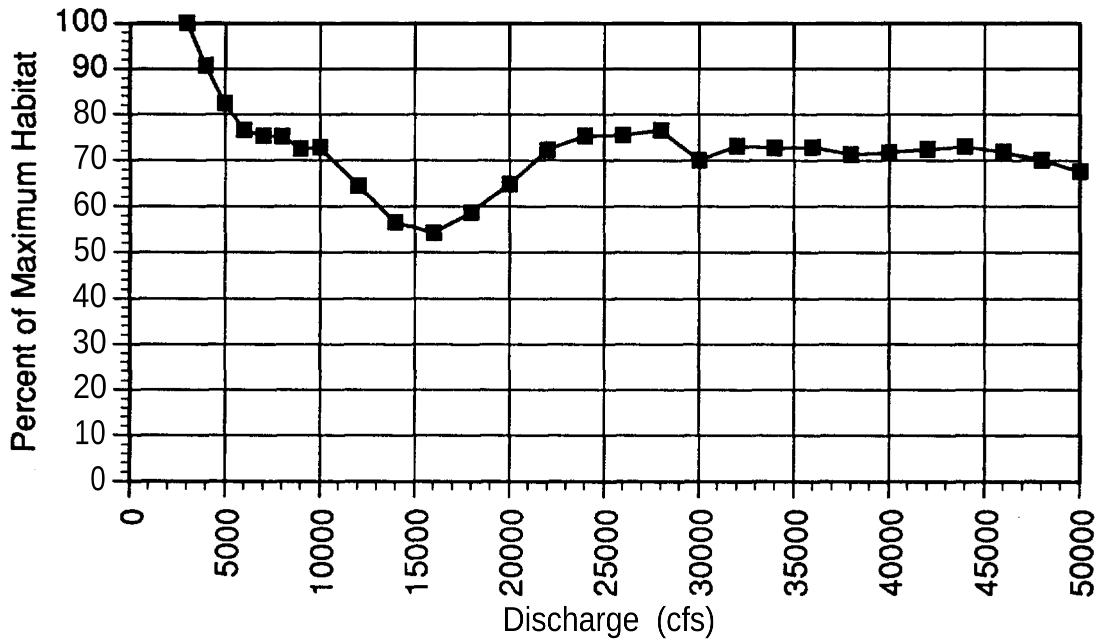


Figure 10.18. Critical temperature total habitat area versus discharge curve for chinook salmon juveniles in lower mainstem Cleat-water River.

less than 127 cms (4,500 cfs) provided 70% or more of maximum habitat, while discharges less than 198 cms (7,000 cfs) provided 50% or more of maximum habitat. For the summer critical temperature total habitat curve, maximum possible habitat was still provided by a discharge of 85 cms (3,000 cfs) (Figure 10.18).

Maximum total habitat for rainbow/steelhead trout fry (Figure 10.19) was also provided at a discharge of 85 cms (3,000 cfs). Flows less than 113 cms (4,000 cfs) provided 70% or more of maximum habitat, while flows less than 198 cms (7,000 cfs) provided 50% of maximum habitat. Maximum habitat under critical summer temperature criteria also occurred at 85 cms (3,000 cfs) (Figure 10.20).

Total habitat values for rainbow/steelhead juveniles (Figure 10.21) were considerably higher for the same flows compared to those for fry. Flows less than 170 cms (6,000 cfs) provided 70% or more of maximum habitat, while' flows less than 283 cms (10,000 cfs) provided 50% or more of maximum habitat. For the summer critical temperature habitat versus discharge relationship, maximum possible habitat was also provided by a discharge of 85 cms (3,000 cfs) (Figure 10.22).

Habitat Time Series Analysis

Habitat values were generated on a daily basis for each life stage and calculated from daily flows measured in the LMCR from 1973 to 1990. Under the influence of Dworshak Dam, river discharges in January and February have a median flow value of 283 cms (10,000 cfs) (Figure 10.23). Flow progressively increased through March and April until yearly high flows were achieved in May and June. These latter two months had a median flow value of 906 cms (32,000 cfs). By inspecting 90 and 10% exceedance statistics, it is apparent that discharge variation was greatest during months having high median flow values (Figure 10.23). Flows rapidly dropped in July to a median value of 255 cms (9,000 cfs). Discharge was lowest during August and October, in which both months had a median flow value of about 142 cms (5,000 cfs). September flows and had a median value of 255 cms (4,000 cfs). Higher flows in September resulted from increased reservoir releases, which were used to reduce pool elevations in Dworshak Reservoir for flood control purposes. Monthly flows progressively increased from October to a median value of 283 cms (10,000 cfs) in December.

The habitat time series analysis conducted for target species and life stages resulted in a database of daily habitat values for the Potlatch, Bedrock, and Big Canyon segments. Median (i.e. 50% exceedance) values define the

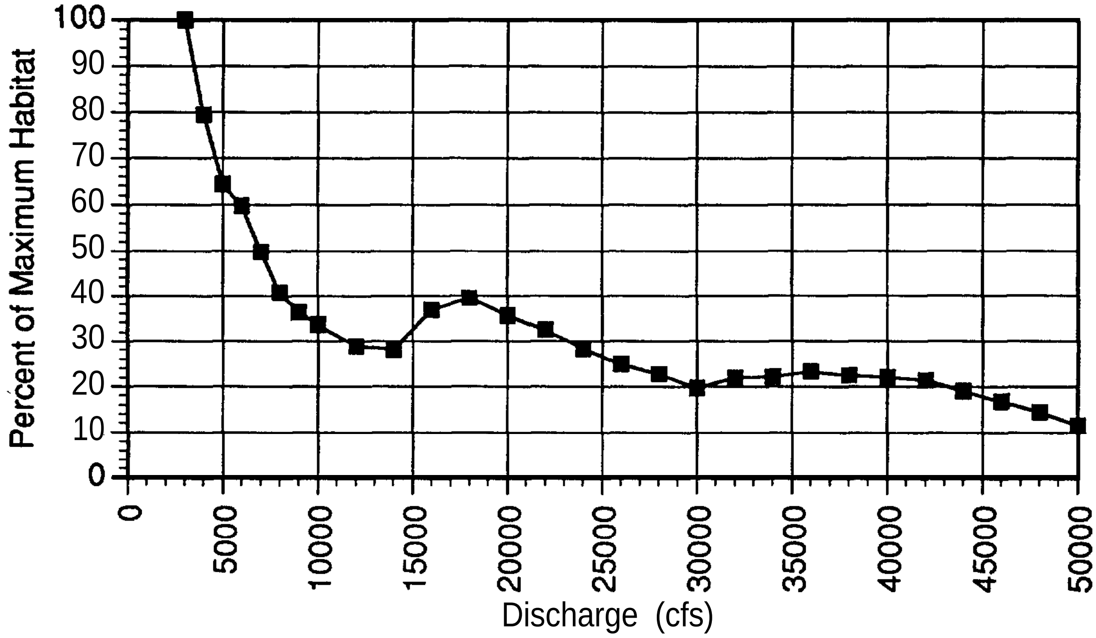


Figure 10.19. Total habitat area versus discharge curve for rainbow /steelhead trout fry in lower mainstem Clear-water River.

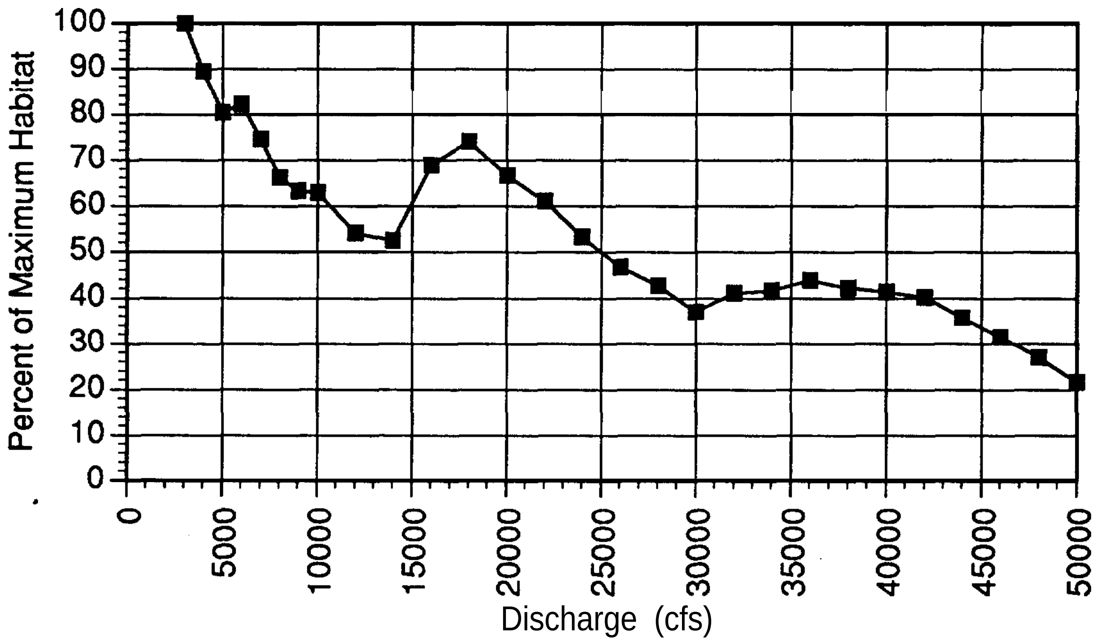


Figure 10.20. Critical temperature total habitat area versus discharge curve for rainbow/ steelhead trout fry in lower mainstem Clearwater River.

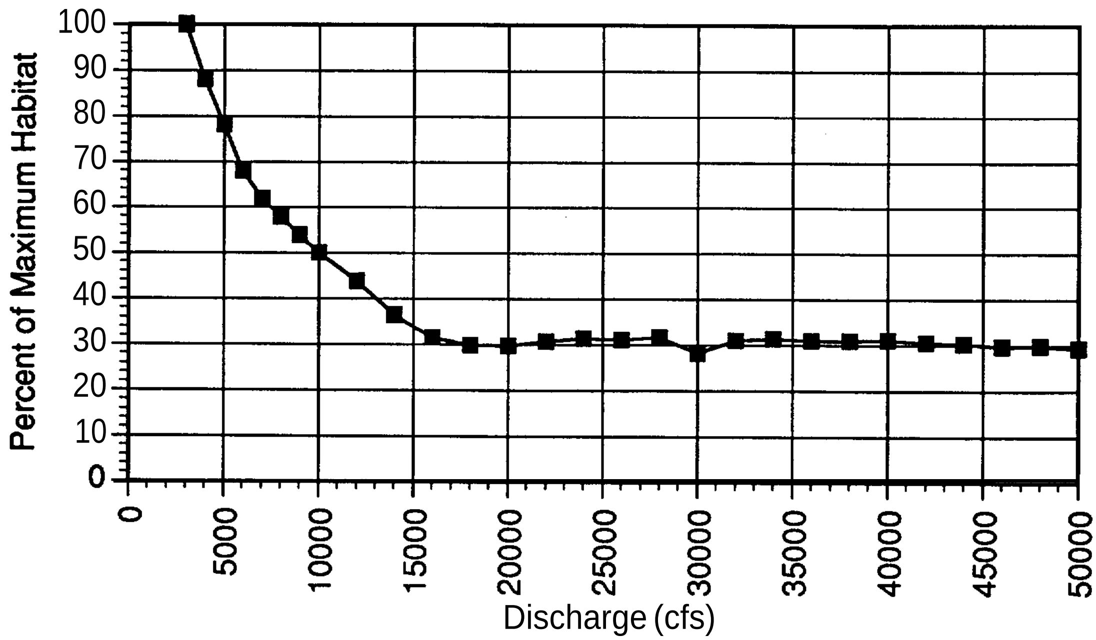


Figure 10.21. Total habitat area versus discharge curve for rainbowkteelhead trout juveniles in lower mainstem Cleat-water River.

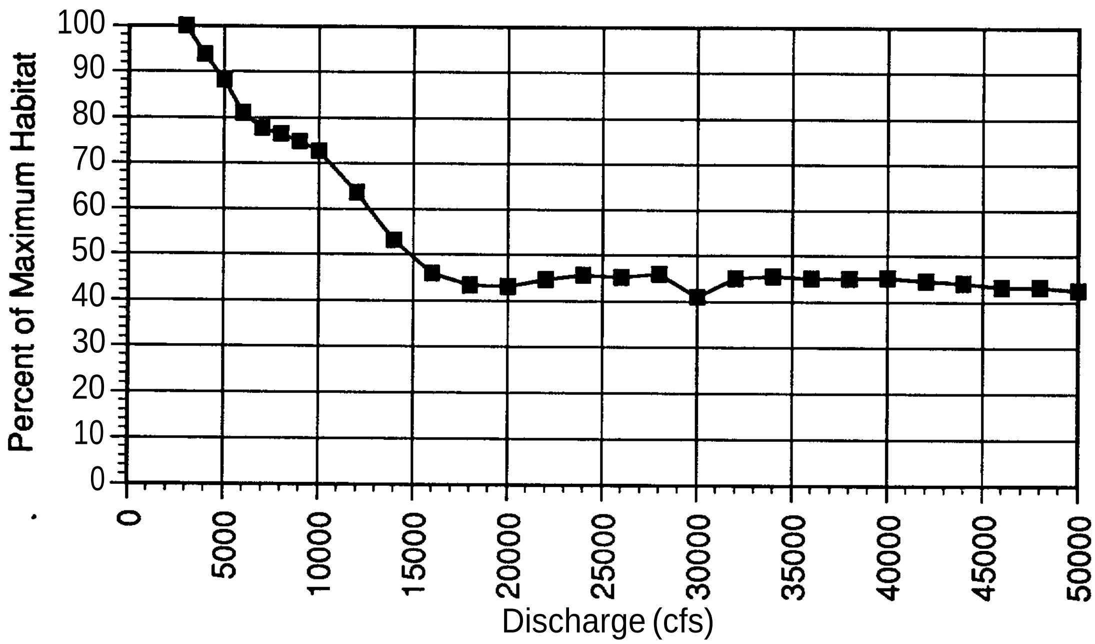


Figure 10.22. Critical temperature total habitat area versus discharge curve for rainbow/steelhead trout juveniles in lower mainstem Clearwater River.

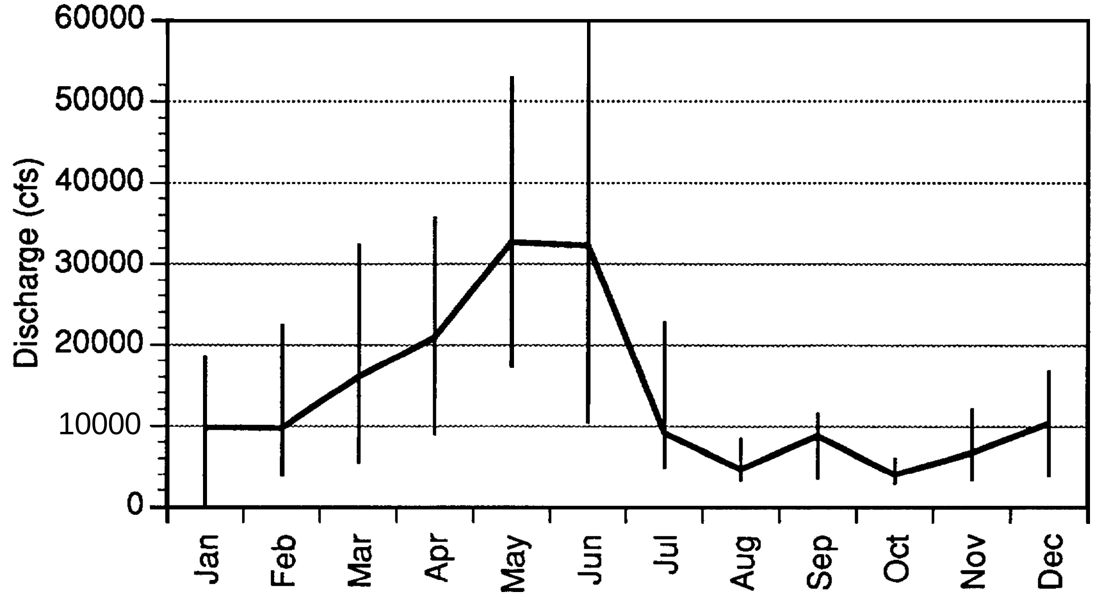


Figure 10.23. Monthly statistics of daily flows for the lower mainstem Clearwater River; 1973 - 1990. Line represents median flow values; bars represent range of discharges between 90 percent and 10 percent exceedance values (source: Spalding USGS gaging station records).

center of frequency distribution and was used to describe average habitat conditions. The 90% exceedance level describes the lower end of a frequency distribution, and was used to describe poor habitat conditions. Exceedance values were only calculated if a species or life stage was present or potentially present in the LMCR for a given month. A monthly lifestage timeline for target species in the LMCR is provided in Figure 10.24.

Median habitat values for chinook salmon spawning were relatively high for November and December (Table 10.1). Habitat values were highest at the Potlatch Segment and lowest in the Big Canyon Segment. Total habitat provided by all three segments was 181.9 ha in November and 151.3 ha in December. These values represent 88 and 73% of the maximum possible value for spawning, indicating that flows during these months were highly suitable for spawning. Ninety percent exceedance values were also highest for the Potlatch Segment and lowest for the Big Canyon Segment. Total 90% exceedance values for November and December were 135.9 and 102.9 ha, respectively. These values correspond to 66 and 50% of maximum possible habitat and suggest that habitat conditions for spawning is better in November than December.

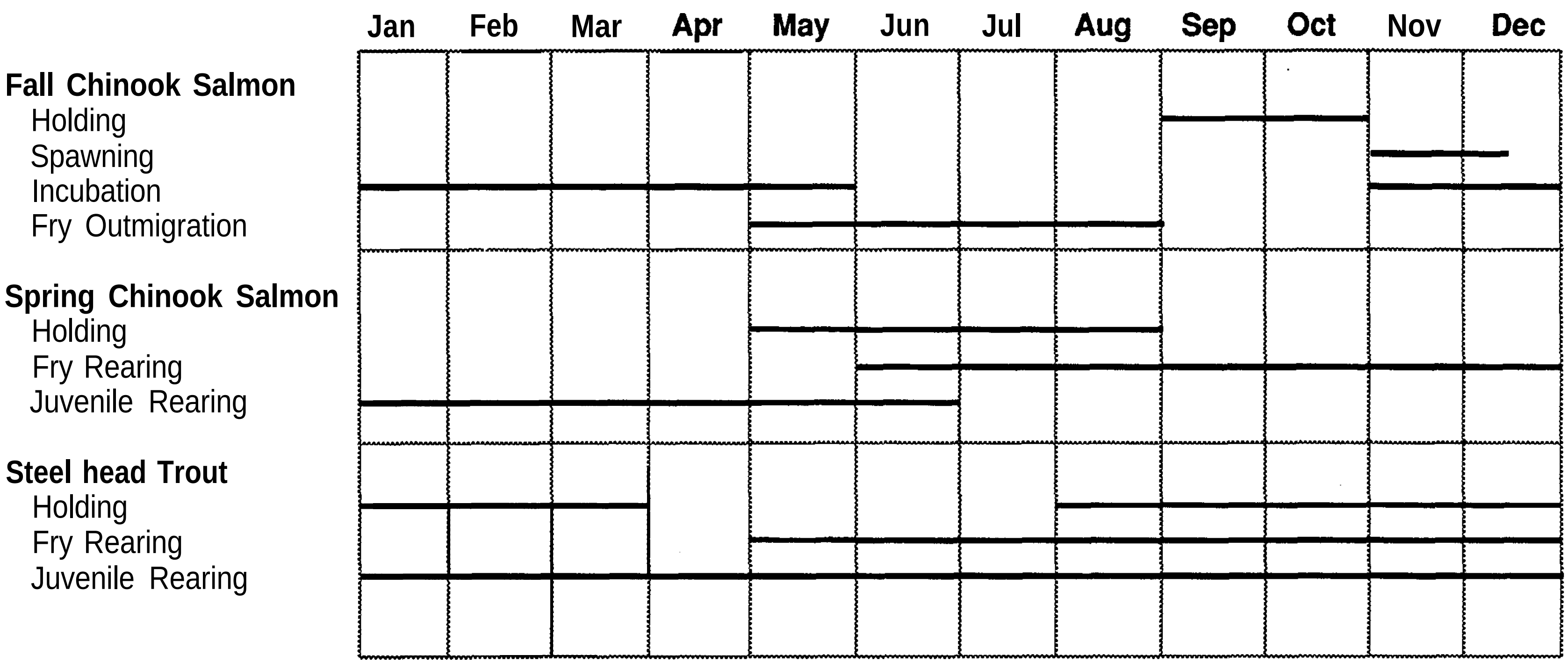


Figure 10.24. Monthly timeline for target species in the lower mainstem Clear-water River.

Table 10.1. Habitat exceedance values for chinook salmon spawning; lower mainstem Clearwater River.

Month	Potlatch	Bedrock	Bio Canyon	Total	Percent of Maximum
	MEDIAN VALUE (HECTARES)				
October	119.5	53.4	27.8	200.7	0.97
November	114.9	48.4	18.7	181.9	0.88
December	96.9	38.1	16.3	151.3	0.73
	90 PERCENT EXCEEDANCE VALUE (HECTARES)				
Month	Potlatch	Bedrock	Bia Canyon	Total	Percent of Maximum
October	112.4	49.3	19.7	181.4	0.88
November	86.8	33.4	15.7	135.9	0.66
December	61.7	26.7	14.5	102.9	0.50

Table 10.2. Habitat exceedance values for holding adult chinook salmon; lower mainstem Clearwater River.

Month	Potlatch	Bedrock	Bia Canyon	Total	Percent of Maximum
	MEDIAN VALUE (HECTARES)				
June	93.5	32.6	31.5	157.6	0.67
July	93.0	50.5	44.3	187.8	0.80
August	47.3	34.8	33.5	115.6	0.49
September	93.7	56.1	47.1	196.8	0.84
	90 PERCENT EXCEEDANCE VALUE (HECTARES)				
Month	Potlatch	Bedrock	Bia Canyon	Total	Percent of Maximum
June	58.6	21.7	19.7	100.0	0.42
July	48.5	32.8	31.9	113.3	0.48
August	30.0	20.8	26.5	77.3	0.33
September	33.2	23.9	31.3	88.5	0.38

Table 10.3. Habitat exceedance values for chinook salmon juveniles; lower mainstem Clearwater River.

Month	Pot la 8.8	Bedrock	Bia Canyon	Total	Percent of Maximum
	MEDIAN VALUE (HECTARES)				
January	8.8	5.0	8.6	22.4	0.39
February		5.2	9.1	23.1	0.40
March	8.0	3.8			
April	7.9	3.5	4.4 6.0	15.8 17.7	0.31 0.27
May	7.9	3.5	3.0	14.4	0.25
June	7.7	3.5	3.0	14.2	0.24
	90 PERCENT EXCEEDANCE VALUE (HECTARES)				
Month	Potlatch	Bedrock	Bia Canyon	Total	Percent of Maximum
January	6.5	3.1	4.3	13.9	0.24
February	6.6	3.1	4.2	13.8	0.24
March	[illegible]	3.0	3.0	12.6	0.22
April	6.6	3.0	2.9	12.4	0.21
May	6.7	3.0	2.3	12.0	0.21
June	6.6	3.0	2.3	12.0	0.21

Median habitat values for chinook salmon holding were relatively high during July and September, but considerably lower during June and August (Table 10.2). Total median habitat values ranged from 115.6 ha in August to 196.8 ha in September. These values corresponded to 49 and 84% of maximum possible habitat. In referring to the LMCR flow hydrograph (Figure 10.23), it is apparent that September provides the highest habitat values because flows during this month are closest to those which provide optimal habitat area (HA). In the case of chinook salmon holding, this corresponds to a discharge of 453 cms (16,000 cfs). Discharges in July are similar to those in September and consequently provide similar habitat values. Low values in August result from flows which are considerably lower than the optimal discharge, while low values in June result from flows which are considerable higher than the optimal discharge. Evaluation of 90% habitat exceedance values indicate that the poorest habitat conditions occur during August and September (Table 10.2).

Median habitat values for chinook salmon juveniles were consistently low in every month (Table 10.3). Median habitat values ranged from 14.2 to 23.1 ha, relatively low numbers compared to those obtained for spawning and holding chinook salmon. The best habitat conditions occurred within the Potlatch Segment while the poorest occurred within the Bedrock Segment. The best habitat conditions occurred in January and February, which had median habitat values which were 39 and 40% of maximum possible habitat, respectively. The poorest habitat conditions occurred in May and June. After referring to daily flow statistics for each month (Figure 10.23), the best flow conditions occurred during months having the lowest flows. This seems reasonable, considering that maximum habitat area is provided by a discharge of 85 cms (3,000 cfs). The 90% exceedance values also indicate that the poorest habitat conditions occurred during months having the highest daily flows (Table 10.3).

Habitat values for steelhead trout holding were relatively high during most months with total median habitat values ranging from 99.7 to 204.7 ha (Table 10.4). The highest habitat values were from January to March and during September and November. These months provide habitat values which were 79 to 87% of maximum possible habitat. Poorest habitat conditions were observed during August and October, which provided habitat values which were 49 and 42% of maximum, respectively. The 90% habitat exceedance values were also lowest during these two months with values corresponding to 33 and 29% of maximum habitat.

Table 10.4. Habitat exceedance values for holding adult steelhead trout; lower mainstem Clearwater River.

Month	MEDIAN VALUE (HECTARES) Potlatch	Bedrock	Bia Canyon	Total	Percent of Maximum
January	97.4	49.2	47.1	193.7	0.82
February	95.4	47.1	42.9	185.4	0.79
March	104.4	46.1	43.8	194.4	0.82
August	47.3	34.8	33.5	115.6	0.49
September	93.7	56.1	47.1	196.8	0.84
October	39.1	29.1	31.5	99.7	0.42
November	72.1	47.2	40.9	160.2	0.68
December	101.8	54.4	48.4	204.6	0.87

Month	90 PERCENT EXCEEDANCE VALUE (HECTARES) Potlatch	Bedrock	Bia Canvon	Total	Percent of Maximum
January	34.0	23.5	28.3	85.8	0.36
February	36.5	25.9	28.6	91 .0	0.39
March	56.6	29.8	30.9	117.3	0.50
August	30.0	20.8	26.5	77.3	0.33
September	33.2	23.9	31.3	88.5	0.38
October	26.6	18.1	24.8	69.5	0.29
November	31.2	21.7	29.7	82.6	0.35
December	37.0	26.0	30.9	93.8	0.40

Table 10.5. Habitat exceedance values for rainbow/steelhead trout juveniles; lower mainstem Clear-water River.

Month	MEDIAN VALUE (HECTARES) Potlatch	Bedrock	Big Canyon	Total	Percent of Maximum
January	13.5	8.8	15.8	38.1	0.50
February	13.6	9.4	17.0	40.0	0.52
March	9.3	7.1	14.6	31 .0	0.41
April	8.7	6.0	10.0	24.8	0.32
May	8.6	6:0	8.4	23.0	0.30
June	8.6	6.2	18.4	39.0 23.2	0.30
July	14.0	8.9			0.51
August	15.4	8.9	22.2	46.4	0.61
September	14.7	9.6	16.7	41.0	0.54
October	20.8	11.7	33.2	65.6	0.86
November	16.9	10.8	19.3	47.1	0.62
December	12.8	8.6	15.7	37.1	0.49

Month	90 PERCENT EXCEEDANCE VALUE (HECTARES) Potlatch	Bedrock	Bia Canvon	Total	Percent of Maximum
January	7.7	5.7	9.6	23.0	0.30
February	7.7	5.6	9.6	22.9	0.30
March	7.6	5.4	9.3	22.3	0.29
April	7.6	5.3	8.4	21.2	0.28
May	7.6	5.4	7.5	20.6	0.27
June	7.7	5.6	7.5	20.8	0.27
July	7.8	5.7	9.6	23.2	0.30
August	13.7	8.0	16.2	37.9	0.50
September	11.2	7.9	15.0	34.0	0.45
October	16.4	11 .0	21.3	48.7	0.64
November	10.6	7.5	14.3	32.4	0.42
December	8.6	6.2	10.4	25.1	0.33

Habitat values for rainbow/steelhead trout juveniles were low when compared to values obtained for chinook salmon spawning and holding, and steelhead trout holding, and were more comparable to those obtained for juvenile chinook salmon. Median habitat values for rainbow/steelhead trout juveniles ranged from 23.0 ha in May to 65.6 ha in October (Table 10.5). Highest habitat values were observed in the Big Canyon Segment except for May and June, when slightly higher habitat values were observed in the Potlatch Segment. The best habitat conditions were provided by flows in October resulting in median habitat values which were 86% of optimal. High habitat values in October were the result of low flows, since the flows in that month are the lowest during the year (Figure 10.23). Habitat values were considerably lower during other months of the year (Table 10.5).

Discussion

Weighted usable area versus discharge curves predicted by habitat simulation modeling substantially differed among single channel sites and islanded channel sites on the LMCR. Weighted usable habitat values for chinook salmon spawning were generally highest in main channel sections at the lowest river flows modeled. However, the WUA values for side channels and intermittent channels of the Potlatch and Bedrock sites peaked at much higher values. Similar patterns in WUA versus discharge curves were observed for chinook salmon and rainbow/steelhead trout fry and juveniles. Higher WUA values for islanded channels resulted from two factors: 1) the wetted area of islanded channels increased more than in the main channel at higher flows: and 2) islanded channels provided much lower velocities and depths than main channels at higher flows.

Habitat modeling was used to predict the response of the entire LMCR to discharge. Because main channel habitat represented much more of the LMCR by area than islanded habitat, the WUA versus discharge curves obtained at the Potlatch and Bedrock sites were highly weighted towards main channel habitat. If the WUA versus discharge relationships had been solely developed from the hydraulic conditions occurring within side channels and intermittent channels, maximum WUA values for all species and life stages would have corresponded to considerably higher discharge values. This is apparent after reviewing intermittent and side channel WUA values for the Potlatch and Bedrock sites.

Developing WUA versus discharge functions for islanded channels would be reasonable if they were identified as critical habitat to target species. Islanded sites in the Potlatch and Bedrock segments have some of the best hydraulic and substrate conditions for spawning chinook salmon in the LMCR. However, spawning observations on the LMCR have been extremely limited and chinook salmon have been observed spawning in main channel areas of the river (Chapter 2). Therefore, there is currently insufficient evidence that island channels in the LMCR are critical habitat for spawning fish. Habitat Area (HA) versus discharge relationships, which are calculated from composite WUA values for islanded sites, indicate that the majority of habitat in the LMCR is located in the main channel of the river.

HA values for spawning chinook salmon were highest at the lowest range of flows modeled. This was mainly a result of higher than preferred velocities that characterize the LMCR at all but low flows. HA values for chinook salmon and steelhead trout adult holding were much higher than those for spawning fish, a result of the greater depths required by holding fish.

Two conclusions can be reached from HA versus discharge relationships for chinook salmon fry in the LMCR: 1) HA is extremely limited for fry throughout the entire range of flows modeled for the river; and 2) the best habitat conditions, however limited, are provided by the lowest flows. HA values for salmon juveniles were considerably higher than values for fry at the same flows. This is because the relatively high velocities and depths on the LMCR are much more suitable for juveniles than for fry. Habitat values are highest for the Bedrock Segment, a likely result of the large proportion of cobble and small boulder substrates within this segment which are preferred by juvenile salmon.

Relatively flat or slightly increasing HA values at higher discharges emphasize the important role of edge habitat in the LMCR for both chinook salmon fry and juveniles. Most habitat in the LMCR is provided at the edges of the river, since velocities occurring throughout most of the channel usually exceed the velocity criteria of both juveniles and fry. Velocities are typically low along the edges of the river relative to the rest of the channel. As discharge increases, edge habitat on the LMCR apparently remains constant or slightly increases as indicated by the HA versus discharge curves for these fish.

Habitat area values for rainbow/steelhead trout juveniles were consistently highest in the Big Canyon Segment. The Big Canyon Segment contained higher amounts of small and large boulder dominated riffle and rapid/riffle habitat which is preferred by rainbow/steelhead trout juveniles in the LMCR. The greater velocities and depths associated with larger substrates in the Big Canyon Segment are within the suitability range of rainbow/steelhead trout juveniles, but not chinook salmon juveniles and rainbow/ steelhead trout fry. HA values for rainbow/steelhead juveniles are higher under critical summer temperatures than HA values for rainbow/steelhead fry and chinook salmon juveniles. This is because the upper limit of temperatures suitable for rainbow/steelhead juveniles is higher than that for fry and chinook salmon juveniles.

Flow conditions in November provide better habitat conditions than in December for chinook salmon spawning. Occasional high flows, likely a result of hydropeaking, would explain lower habitat levels during December. Spawning conditions could be improved by decreasing flows in December as well as avoiding high flow conditions. Habitat values for holding chinook salmon are lowest during the late summer and early fall in the LMCR. This is likely the result of low flow events during these months. Holding habitat would be improved by providing higher minimum flows during August and September. Habitat conditions would be improved for juvenile chinook salmon by providing lower flows during all months, especially April through June.

After comparing habitat values with the yearly hydrograph for the LMCR, it can be concluded that the poorest habitat conditions for steelhead holding results from low flows in August and October. Habitat conditions would be improved by increasing flows in the LMCR during these months.

The poorest habitat conditions for rainbow/steelhead trout rearing occurred during April through June and resulted from high flows during these months. Although habitat conditions for rainbow/steelhead trout rearing would be improved by reducing flows in the LMCR during this period, we realize that reduced flows during this time would not be compatible with salmonid smolt migration timing.

CHAPTER 11

SPAWNING HABITAT QUANTIFICATION

Abstract-We calculated the total number of chinook salmon ***Oncorhynchus tshawytscha*** redds the lower 57.3 km of the lower **mainstem** Clear-water River (LMCR) could potentially support. The IFIM hydraulic simulation model (Chapter 8) was used to define transect verticals where velocities, depths, and substrate were suitable for spawning. Spawning criteria used were 15 to 122 cm/s for velocity, 15 cm to infinity for depth, and dominant substrate of 50 to 150 mm. These criteria along with hydraulic simulation results were input into the HABTAT habitat simulation model to obtain total area of habitat suitable for spawning. The total suitable spawning area was divided by 20.1 m^2, the area required for each spawning pair, to obtain 95,489 redds. Based on one pair of spawners per redd, the LMCR could potentially support an estimated 190,978 spawning chinook salmon. This redd number is probably an overestimate since it does not consider downwelling hydraulics in the spawning substrate and all biological or behavioral aspects of production potential. A limiting factor for chinook salmon spawning on the LMCR may be armoring of substrate particles which typically occurs below dams. A possible spawning substrate enhancement strategy may be to mechanically loosen or break up the armor layering in key spawning areas to increase spawning habitat quality.

Introduction

Since the construction of Dworshak Dam and the elimination of the Washington Water Power Dam at Lewiston, the anadromous fish production potential of the lower mainstem Clearwater River (LMCR) has been dramatically changed. Ice flows that once may have scoured the LMCR streambed are now prevented by warmer water discharges from Dworshak Dam during the winter. Fish could also pass freely after the Washington Water Power Dam was removed on the LMCR. However, limited chinook salmon ***Oncorhynchus tshawytscha*** restoration efforts have been concentrated in more pristine headwater tributaries of the Clearwater drainage and none incorporated the production potential of the mainstem river (Connor 1989). Parkhurst (1950) did note that spawning gravel was abundant in the LMCR and recommended the mainstem river be restocked (Connor et al. 1990). Our objective was to calculate the total habitat area suitable for chinook salmon spawning and estimate the total number of redds the LMCR could potentially support. We also describe the LMCR spawning substrate characteristics and explore possible enhancement strategies from literature sources.

Methods

We calculated the quantity of chinook salmon spawning habitat on the LMCR to estimate redd numbers that potential spawning areas could support based on physical habitat area. The IFIM hydraulic simulation model, developed for the LMCR (Connor et al. 1990), was used to define transect verticals where velocities, depths, and substrate met spawning criteria. Spawning criteria were based on microhabitat preference curve data developed from this study (Chapter 9).

We assumed that spawning site selection by chinook salmon would occur over a range of microhabitat conditions (i.e. spawning sites could be selected in less than optimal habitat conditions). To meet this assumption, binary suitability criteria were developed for spawning site selection. Binary criteria provide for two possible conditions for each microhabitat variable: that each variable is either suitable or not suitable for fish (Bovee et al. 1986). Relatively broad criteria were developed for application to the LMCR and were based upon observed ranges of spawning in large rivers (Chambers et al. 1956; Swan 1989). The depth criteria used for this analysis had a lower range of 15 cm (0.5 ft). All depths greater than this value were assumed to be suitable for spawning. Swan (1989) reported the maximum depth of fall chinook spawning at the Hanford Reach on the Columbia River was 9.1 m and averaged 6.5 m. Most depths on the LMCR, especially within spawning areas, are much shallower than this. Mean column velocities of 15 cm/s (0.5 ft/s) to 122 cm/s (4.0 ft/s) were also assumed to be suitable for spawning. Finally, transect locations having dominant substrate sizes ranging from 50 to 150 mm were assumed suitable. Substrate codes used provided that subdominant substrates larger or smaller than this would be suitable, given that dominant substrates were within the range specified.

Spawning site selection criteria, along with hydraulic simulation results, were then input to the HABTAT habitat simulation model (Milhous et al. 1989) to calculate total habitat area at each IFIM study site suitable for spawning. Spawning habitat simulation modeling was conducted for a river discharge of 113 cms (4,000 cfs), a discharge identified by PHABSIM habitat simulation modeling as being near optimal for chinook salmon spawning in the LMCR (Chapter 10). The total area suitable for spawning calculated by this program for each site was expressed as weighted usable area (WUA) in units of sq-ft spawning habitat per 1000 linear ft of river. The WUA values for multiple channel sections at the Potlatch and Bedrock study sites were multiplied by appropriate weighting factors (Chapter 10), and added to obtain a single WUA value for each site. WUA values for the Potlatch, Bedrock, and Big Canyon sites were then multiplied by the length of each segment to obtain a total spawning habitat area value, expressed in hectares (ha), for each segment.

The total number of potential redds in each segment was obtained by dividing the total habitat area suitable for spawning in each segment by the area required for a redd. Burner (1951) suggested a conservative estimate of redds an area could support may be obtained by multiplying the average area of a redd (5.1 m^2 for fall and summer chinook) by four to allow for spacial requirements between spawning pairs. We used this approach to obtain a spawning area estimate of 20.4 m^2 required for each spawning pair. This was similar to Swan's (1989) estimate of 21.7 m^2 for each redd observed in concentrated fall chinook spawning areas at Vernita Bar on the Columbia River. Swan's estimate was based on transect interval observations with the assumption that the distribution of redds within the site were representative of the average redds/transect.

During our freeze-core study (Chapter 4), we observed moderate armoring of the spawning substrate which typically occurs in rivers below dams. Therefore, the estimate for potential redds in the LMCR is based on armoring not being a factor. We reviewed literature sources to assess spawning substrate enhancement methods that may be appropriate for the LMCR.

Results

We calculated 95,489 as the total number of chinook salmon redds the LMCR could potentially support assuming full seeding (Table 11.1). The Bedrock Creek and Potlatch River study segments possessed substantial areas of substrate suitable for spawning. These two segments accounted for 86% of the total available spawning area. As mentioned earlier, most islanded reaches occur in these segments. Based on one pair of spawners per redd, the LMCR could potentially support approximately 190,978 spawning chinook salmon.

The degree of armoring occurring in the LMCR spawning substrate may be substantial. During our freeze-core study (Chapter 4), we observed some spawning areas that were compacted and difficult to drive the freeze probes in.

Table 11.1. Estimated redd numbers at each study segment on the lower mainstem Clearwater River, Idaho based on a total river discharge of 113 cms (4,000 cfs).

River segment	Segment length (km)	Total spawning area (ha)	Total no. redds (estimated)
Big Canyon	21.8	27.4	13,431
Bedrock Creek	16.0	57.8	28,333
Potlatch River	19.5	109.6	53,725
		Total	95,489

Discussion

The total number of redds calculated for the LMCR is probably liberal, since PHABSIM tends to overestimate the spawning values for chinook salmon (Shirvell, 1990). This total redd estimate did not consider other factors not included in PHABSIM analysis. Velocity, depth, and substrate may not be the only parameters regulating spawning. It has long been known that many salmonids prefer to spawn in transitional zones where downwelling hydraulics occur between pools and riffles (Stuart 1953). However, during aerial redd surveys (Chapter 2), we observed almost half of all fall chinook redds not in association with a pool-riffle interchange, although total sample size was low. These redds were located in homogeneous main channel runs with moderate water velocities. Also, this redd estimate does not consider all biological or behavioral aspects of production potential.

Swan (1989) reported an estimated fall chinook adult escapement of over 76,000 fish to the Hanford Reach on the Columbia River during 1986. Along this 47.3 km stretch, spawning area utilization was estimated to be only 22% of availability (Swan 1989). Based on McNeil substrate samples, Vernita Bar of the Hanford Reach contained a higher percentage of medium cobble than what we found on the LMCR (Chapter 4). Chapman et al. (1986) reported 32-35% of particles were greater than 76 mm compared to 20-30% found on the LMCR. However, we sampled the best spawning areas on the LMCR. If we had sampled spawning areas randomly, the percentage of medium cobbles may have been similar to Vernita Bar. If hydraulic conditions are similar to the Columbia River at Vernita Bar, fall chinook should have no problems constructing redds in the LMCR substrate, provided armoring is not a problem.

Our shear velocity study (Appendix F) suggested that spawning substrate moves at a fairly low flow within the islanded sections. However, in the main channel areas, substrate does not seem to mobilize until a relatively high flow is reached, which may be a result of the armoring. There has been a number of techniques used to clean spawning substrate, however these studies concentrated mostly on removing excess fines within the gravels. Andrew (1981) suggested the use of heavy equipment with a bucket attachment or a rotary drum screener as a means to clean spawning areas. Chapman et al. (1983) used a bulldozer with a front-mounted rake designed for cleaning gravel in a spawning channel to scarify a spawning substrate site at Vernita Bar on the Columbia River. This technique satisfactorily loosened the substrate, however, it did not adequately cleanse the substrate of fines (Chapman et al. 1983). Although percent fines should not be a limiting factor for incubating chinook salmon on the LMCR (Chapter 5), this technique may prove useful to loosen and break the armoring in key spawning areas.

Bailey and Rimbach (1991) report the use of various instream structures in the Umatilla River Basin to enhance spawning habitat quality and quantity. Similarly, Espinosa and Lee (1991) report the use of log weirs or woody debris to collect and enhance spawning habitat in smaller tributary streams of the LMCR. This technique may benefit spawning chinook salmon by breaking up higher velocity areas on the LMCR, but may not be technically feasible because of the LMCR's large size and high water velocities.

Conclusions

We made a somewhat liberal estimate of the number of redds the LMCR could potentially support. It is apparent, however, that other physical and biological factors will effect the total number of spawners the LMCR can support besides adequate spawning substrate size. The fact that fall chinook are currently using both island riffles and main channel areas on the LMCR suggests that both habitat types can support spawning. A possible spawning substrate enhancement strategy may be to break up the armor layer by mechanically loosening the substrate particles. Log structures and woody debris to enhance spawning conditions are probably less feasible due to the high water velocities on the LMCR. However, concentrating spawning substrate enhancement in key side channels of islanded areas may be feasible and prove beneficial for chinook salmon spawning.

CHAPTER 12

TEMPERATURE ANALYSIS

Abstract-We developed a stream temperature model to predict temperature conditions in the lower mainstem Clearwater River (LMCR) for several Dworshak Dam discharge and temperature release alternatives. The Stream Network Temperature Model (SNTEMP) was used to identify the potential for improving temperature conditions for salmonid fish by modifying flow and temperature releases from Dworshak Dam. After calibration procedures were completed, the model was used to predict average temperatures in the LMCR on a longitudinal basis under different reservoir discharge and temperature release alternatives. We modeled temperature releases during hot climatic conditions in July and August to assess the potential for improving habitat conditions for rearing rainbow/steelhead trout ***Oncorhynchus mykiss*** and chinook salmon 0. ***tshawytscha.*** We also modeled temperatures in November and December to determine if low temperatures could be increased for advancing chinook salmon incubation timing. Results of temperature modeling indicate that Dworshak Reservoir can be used to dramatically improve temperature conditions for salmonid fish in the summer and advance incubation timing only slightly. A 57 cms (2,000 cfs) release of 7.2 °C water from the dam would benefit fish by reducing summer water temperatures to more optimal for rearing salmonids. These same benefits could be obtained by a 113 cms (4,000 cfs) release of 12.8 °C water (the approximate temperature released under existing conditions). A 113 cms (4,000 cfs) release of 10 °C water may not be possible during all of November and December to effectively advance chinook salmon incubation timing.

Introduction

The Stream Network Temperature Model (SNTEMP), developed and supported by the National Ecology Research Center (NERC), was used to model temperatures on the lower mainstem Clearwater River LMCR under a number of Dworshak Reservoir release alternatives. SNTEMP is a physical process model used to predict average daily water temperatures using meteorological, stream geometry, and hydrological input data (Theurer et al. 1984; Bartholow 1989). SNTEMP consists of several component programs, the most important being a heat flux model and a heat transport model. The heat flux model predicts the energy balance between water and the surrounding environment and is based upon influx of solar radiation and radiant heat exchange between the water, atmosphere, surrounding terrain, and streambed. The heat transport model predicts mean daily water temperatures as a function of distance and time of travel, and requires hydrological and stream geometry information. Minimum and maximum daily temperatures are also predicted by the heat transport model and are calculated from a regression model which is applied to average daily temperature estimates. The heat transport model is based upon steady flow conditions and is not suitable for changing flow conditions within a daily time frame. In addition to heat flux and heat transport models, SNTEMP also includes a solar model, shade model, meteorological model, and temperature and hydrology regression model. The solar, shade, and meteorological models provide input data required by the heat flux program. The regression model provides simulated hydrology and headwater temperature data to the heat transport program when required due to lack of field data. Data required by SNTEMP includes baseline water temperatures at headwaters and reservoir structures, meteorological values, daily mean discharge information for specified locations, and stream geometry data for specified stream reaches. We used SNTEMP in our LMCR study to: 1) characterize the river's temperature regime; and 2) identify the potential for improving conditions for existing and potential anadromous salmonid populations.

Methods

We calibrated the SNTEMP model to realistically predict temperatures in the LMCR under a wide range of flow and meteorological conditions (Appendix E). Appropriate global calibration coefficients were developed to minimize daily and mean modeling errors for the two time periods modeled: June 1 to October 31, and November 1 to December 31. Summer water temperature modeling was conducted in order to identify combined river flow and meteorological conditions that result in critical water temperatures for salmonids. Average daily temperatures can exceed 22 °C and maximum daily temperatures can exceed 23 °C in the LMCR (Chapter 1). These temperatures, although below critical lethal values for juvenile rainbow/steelhead trout ***Oncorhynchus mykiss*** (Raleigh et al. 1984) and juvenile chinook salmon 0. ***tshawytscha*** (Raleigh et al. 1986), substantially exceed those temperatures required for optimal growth and health. Early winter temperature modeling was conducted to identify the potential for advancing incubation timing of fall chinook in the LMCR. Fall chinook salmon emerged approximately 3 weeks later on the LMCR than on the Snake River which was mainly due to colder November water temperatures in the LMCR (Chapter 3). Later emergence of fall chinook and hence smolt timing in the LMCR may coincide with unfavorable summer temperatures and low flows, therefore earlier emergence timing may be advantageous.

The SNTEMP model was used to predict temperatures in the Potlatch, Bedrock, and Big Canyon segments (see Chapter 1, Figure 1.1) of the LMCR under a number of flow and reservoir temperature release alternatives. The SNTEMP model predicted average and maximum daily temperatures at a number of locations in the LMCR, including the upper end of the LMCR at the North Fork Clearwater River (NFCR) confluence, the Big Canyon study site, the Bedrock study site, the Potlatch study site, and the lower end of the LMCR at Lewiston. Due to the complexity and volume of model outputs, this report focuses on temperatures predicted at upper end of the LMCR at the NFCR confluence and the lower end of the LMCR at Lewiston. These locations effectively bracket the entire LMCR, and provide upper and lower limits of the predicted average daily water temperatures.

The temperature model was initially calibrated to simulate temperatures under baseline discharge and temperature release conditions at Dworshak Dam. Baseline conditions closely approximated existing discharge and temperature conditions from June 1 to September 30, 1989. Simulation of baseline conditions varied somewhat from actual conditions due to hydropeaking that occurred for a number of days (20) during this modeling period. Because SNTEMP is a steady state discharge model (Theurer et al. 1984), steady flow conditions in modeling runs were assumed in defining baseline temperature conditions. These baseline temperatures in turn were used as a benchmark from which to measure potential benefits derived from alternative flow releases.

For the June 1 to September 30 period, LMCR temperatures were simulated under reservoir releases of 57, 113, 170, and 227 cms (2,000, 4,000, 6,000, and 8,000 cfs). In addition, two release alternatives proposed by the U.S. Army Corps of Engineers was modeled: a 283 cms (10,000 cfs) release from August 7 to August 27, and a 708 cms (25,000 cfs) release from August 7 to 22. River water temperatures for each of these six flow regimes were modeled under three temperature release alternatives from Dworshak Dam: 1) baseline conditions (approximately 12.8 °C or 55 °F); 2) a 7.2 °C (45 °F) temperature release; and 3) a 10 °C (50 °F) temperature release.

For the November 1 to December 31 period, LMCR temperatures were modeled for: 1) 1989 baseline reservoir discharge conditions; 2) a 113 cms (4,000 cfs) reservoir release; and 3) a 170 cms (6,000 cfs) reservoir release. For each discharge alternative, river temperatures were simulated under selective reservoir temperature releases of 7.2 °C and 10 °C. Since Dworshak reservoir typically looses thermal stratification during late November or early

December, temperature releases of 10 °C may not be attainable during the entire early winter time period modeled.

Results

June 1 throush September 30

Under baseline conditions, average daily water temperatures at the confluence of the NFCR ranged from 10 °C in early June to 19.0 °C during the first week of August (Figure 12.1). During this same period, average daily water temperatures predicted in the LMCR at Lewiston ranged from 11.0 to 20.2 c. Water temperatures were between 10 and 15 °C throughout the entire length of the LMCR during the months of June and September. Average daily water temperatures in July and August were typically between 15 and 20 °C at Lewiston. Average daily water temperatures at the NFCR confluence were generally less than 17 °C during July and August. Average daily water temperatures at Lewiston exceeded 18 °C for 7 days in July and 4 days in August. Water temperatures in the LMCR at Lewiston were generally 1 °C warmer than the NFCR confluence during most of June and September, and from 1 to 2.5 °C during July and August (Figure 12.1).

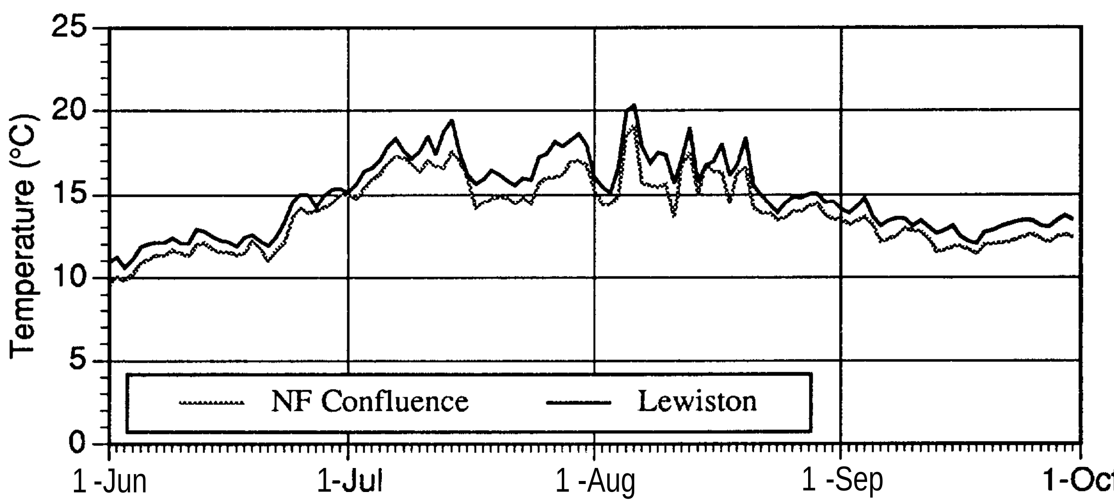


Figure 12.1. Clearwater River temperatures under baseline Dworshak Reservoir release discharge and temperature conditions, June 1 to September 30, 1989.

Under a 57 cms (2,000 cfs) Dworshak Dam release alternative at baseline release temperatures (approximately 12.8 °C) from June through September, predicted temperatures at both the NFCR confluence and at Lewiston are generally higher than those observed under 1989 baseline conditions (Figure 12.2). Flows released from Dworshak Dam were higher than 57 cms (2,000 cfs) during all of June, during the last two weeks of July, and during all of September. Flow releases greater than 57 cms (2,000 cfs) occurred intermittently in August. Temperature reductions in the LMCR from June through September only occur during periods when reservoir discharges are greater than 57 cms (2,000 cfs).

A 57 cms (2,000 cfs) Dworshak Dam release at 7.2 °C would lower water temperature at the NFCR confluence from 1 to 2 °C in July, and from 1 to 3 °C in August (Figure 12.2). Temperatures at the NFCR confluence would typically be less than 17 °C in July and 15 °C in August under this release alternative. Mean daily temperatures at Lewiston would be reduced by 1 to 1.5 °C in July, and by 1 to 2 °C in August under this release alternative. This would have a significant impact on LMCR maximum water temperatures, which would not be expected to exceed 19 °C during the summer.

A 57 cms (2,000 cfs) Dworshak Dam release at 10 °C would provide slight cooling benefits when compared to the 1989 baseline release temperatures of approximately 12.8 °C (Figure 12.2). Temperatures would not substantially differ from that provided by a 12.8 °C release during June and September. During July, water temperatures at the NFCR confluence would be reduced by about 0.5 °C, and between 0.5 to 1.0 °C in August. Water temperatures at Lewiston would be reduced up to 1.0 °C during July and August.

A 113 cms (4,000 cfs) Dworshak Dam release at baseline release temperatures would considerably lower high water temperatures in the LMCR during July and August (Figure 12.3). Reductions in seasonal peak water temperature would be substantially greater under this alternative than that predicted for a 57 cms (2,000 cfs) release. Water temperatures at both the NFCR confluence and at Lewiston would be less variable under the 113 cms (4,000 cfs) release alternative than baseline flow conditions. With a 113 cms (4,000 cfs) discharge alternative at baseline release temperatures, average daily water temperatures would not exceed 17.0 °C at the NFCR confluence and not exceed 18.5 °C at Lewiston. Temperatures in the LMCR would not be notably affected by a 113 cms (4,000 cfs) release in June due to the overriding influence of high inflows from the upper mainstem Clearwater River during this month. Temperatures in September would increase in relation to existing conditions

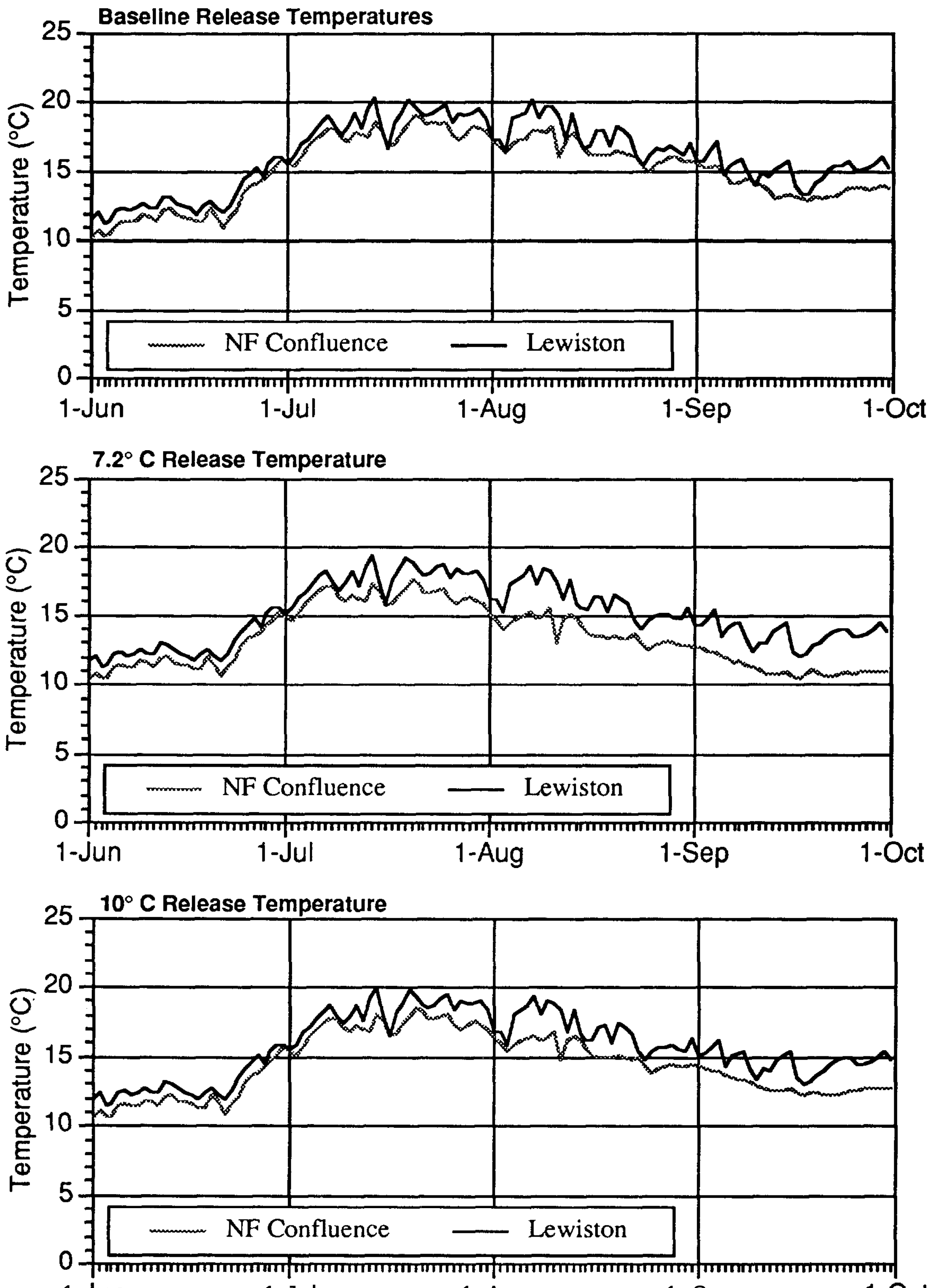


Figure 12.2. Clearwater River water temperatures under Dworshak Reservoir release of 2,000 cfs, June 1 to September 30, 1989.

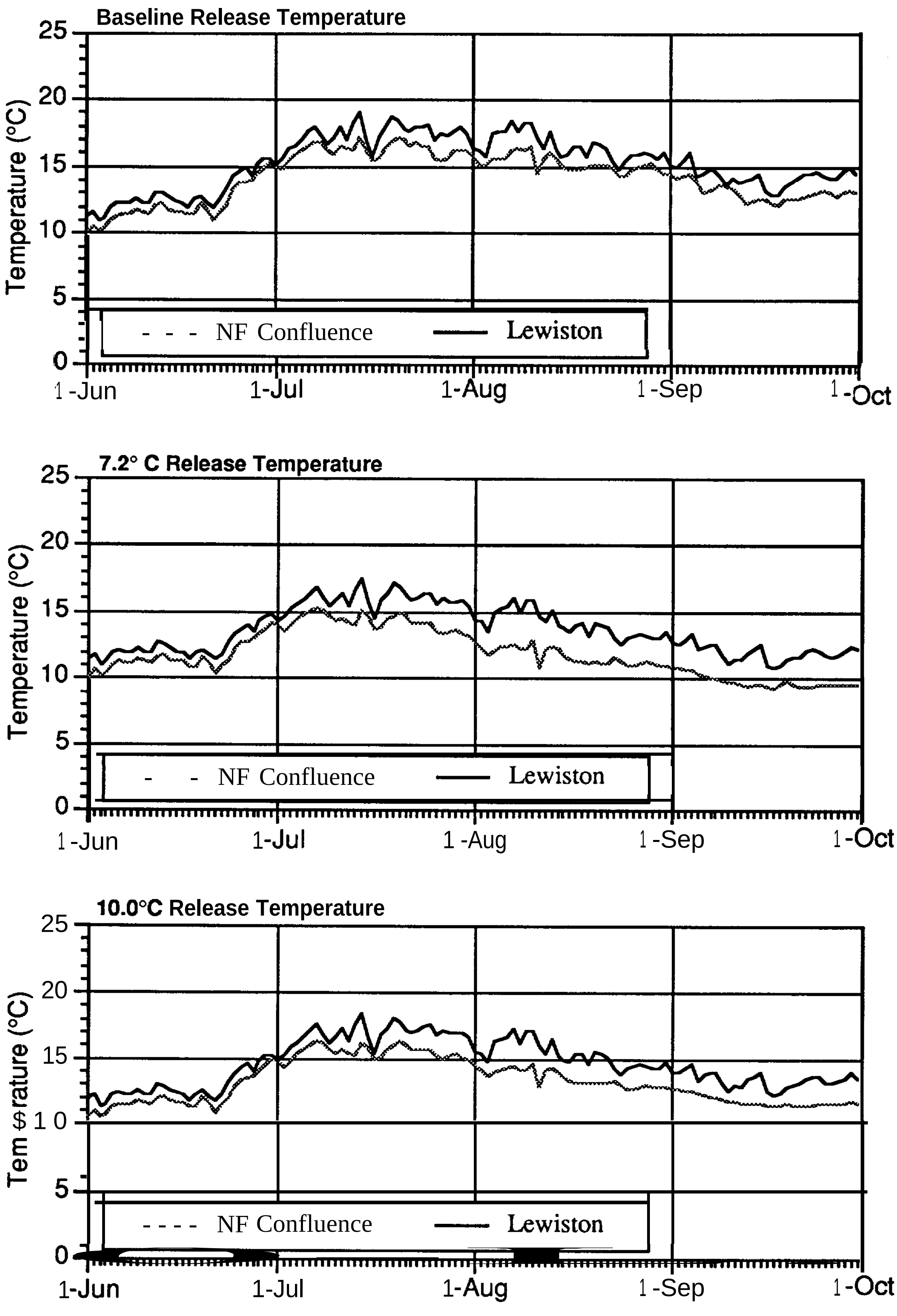


Figure 12.3. Clearwater River water temperatures under Dworshak Reservoir release of 4,000 cfs, June 1 to September 30, 1989.

at both locations by about 2 °C (Figure 12.3).

A 113 cms (4,000 cfs) Dworshak Dam release at 7.2 °C would substantially lower water temperatures throughout the entire LMCR during July and August compared to existing conditions (Figure 12.3). Under this alternative, temperatures in July would range from 12 to 15 °C at the NFCR confluence, and from 15 to 17 °C at Lewiston. In August, temperatures would range from 11 to 13 °C at the NFCR confluence, and from 13 to 16 °C at Lewiston. A 113 cms (4,000 cfs) release at 10 °C would provide temperature reductions similar to those predicted under a 7.2 °C release except at the NFCR confluence. Temperatures at the NFCR confluence would be from 1 to 2 °C higher in July and August under at a 10 °C release (Figure 12.2). Temperatures in July under a 10 °C release at 113 cms (4,000 cfs) would range from 15 to 16 °C at the NFCR confluence, and from 15 to 18 °C at Lewiston. Temperatures in August under this alternative would range from 11 to 13 °C at the NFCR confluence, and from 13 to 16 °C at Lewiston.

Reservoir releases of 170 cms (6,000 cfs) (Figure 12.4) and 227 cms (8,000 cfs) (Figure 12.5) would reduce average daily temperatures beyond that attained by a 113 cms (4,000 cfs) release. Increasing flows would greatly reduce variation in temperature as well. Under baseline release temperature (12.8 °C) and a 170 cms (6,000 cfs) release, temperatures in July and August would vary between 12 and 15 °C at the NFCR confluence, and vary between 13 and 17 °C at Lewiston. A 7.2 °C reservoir release at 170 cms (6,000 cfs) would result in temperatures between 10 and 13 °C at the NFCR confluence, and 12 and 16 °C at Lewiston (Figure 12.4). A 10 °C release would provide values intermediate to those obtained from the baseline and 7.2 °C release temperatures. A 227 cms (8,000 cfs) release would result in temperatures at the NFCR confluence and Lewiston only slightly lower (< 0.5 °C) than those attained from the 170 cms (6,000 cfs) release (Figure 12.5).

Under a U.S. Army Corps of Engineers alternative to release 283 cms (10,000 cfs) at a baseline release of 12.8 °C from August 7 to 27, temperatures in the LMCR would drop rapidly from baseline conditions but only during this relatively short period. High temperatures would persist in the river during the rest of July and August not within the specified release period (Figure 12.6). Temperatures would drop to 14 °C at the NFCR confluence and 15 C at Lewiston during the 20-day period in August. A 283 (10,000 cfs) release at 7.2 °C would reduce water temperatures to 9 °C at the NFCR confluence and 11 °C at Lewiston. Under a 10 °C release, temperatures of 12 °C would be expected at the NFCR confluence and 13 °C at Lewiston (Figure 12.6).

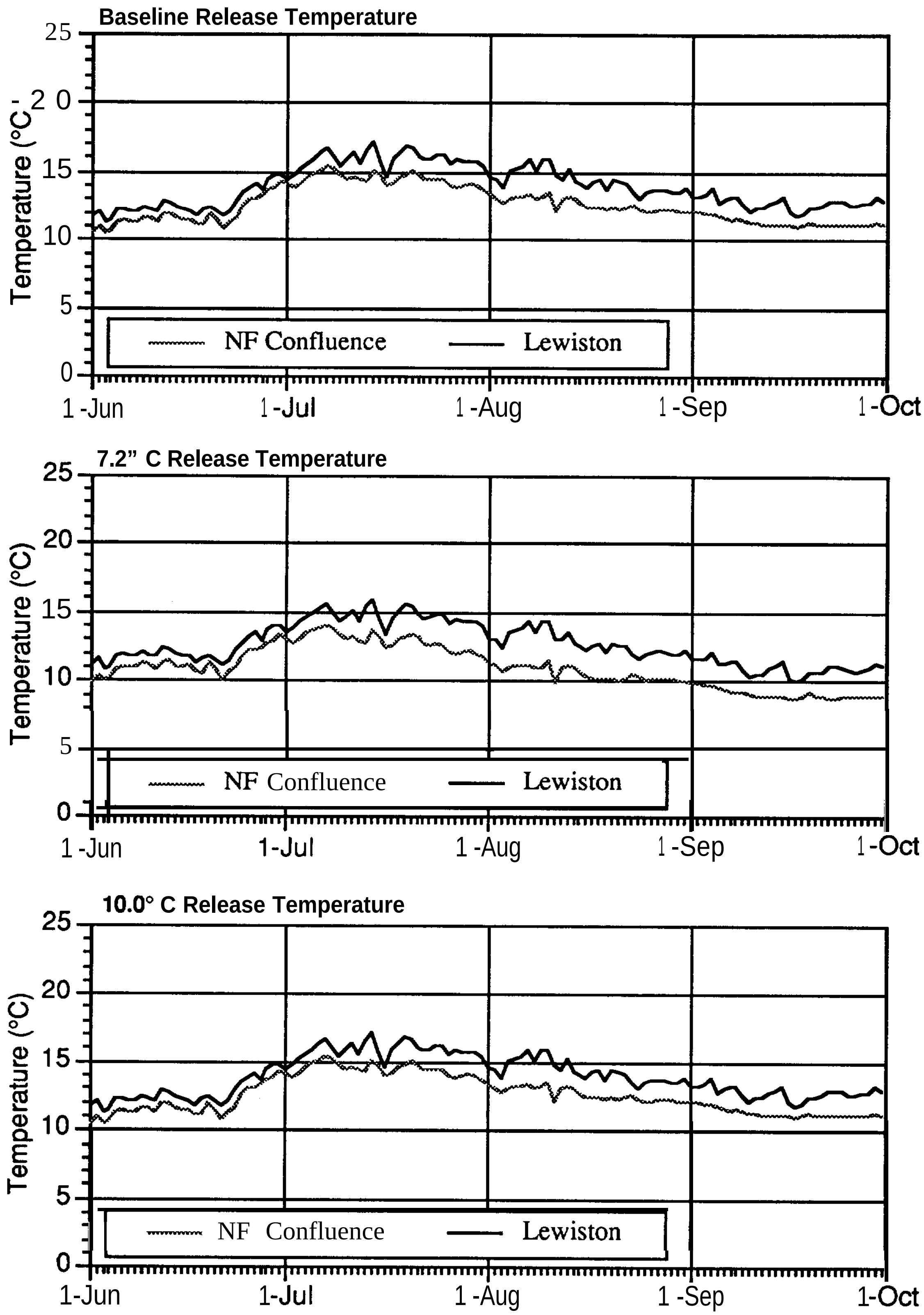


Figure 12.4. Clear-water River water temperatures under Dworshak Reservoir release of 6,000 cfs, June 1 to September 30, 1989.

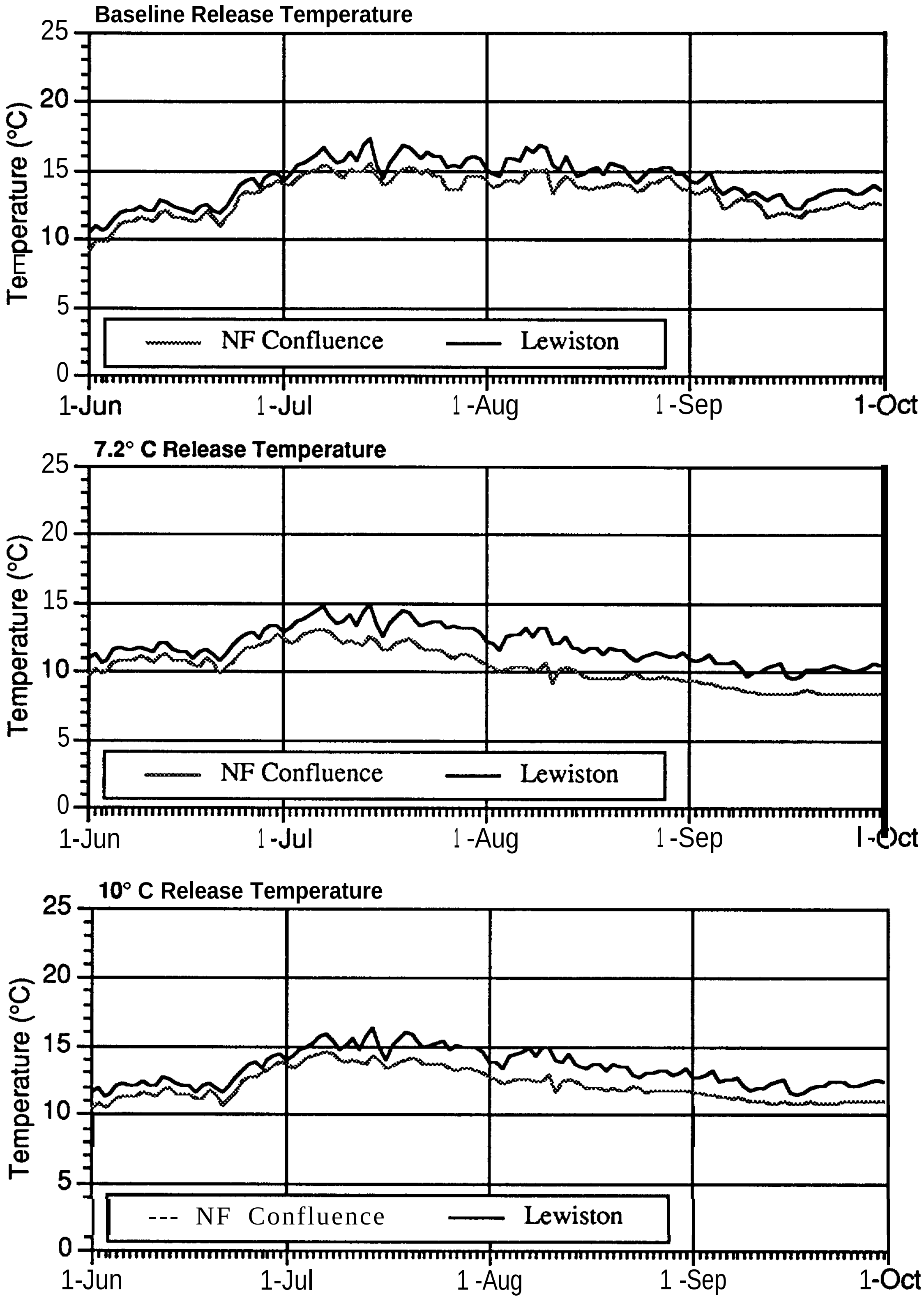


Figure 12.5. Clearwater River water temperatures under Dworshak Reservoir release of 8,000 cfs, June 1 to September 30, 1989.

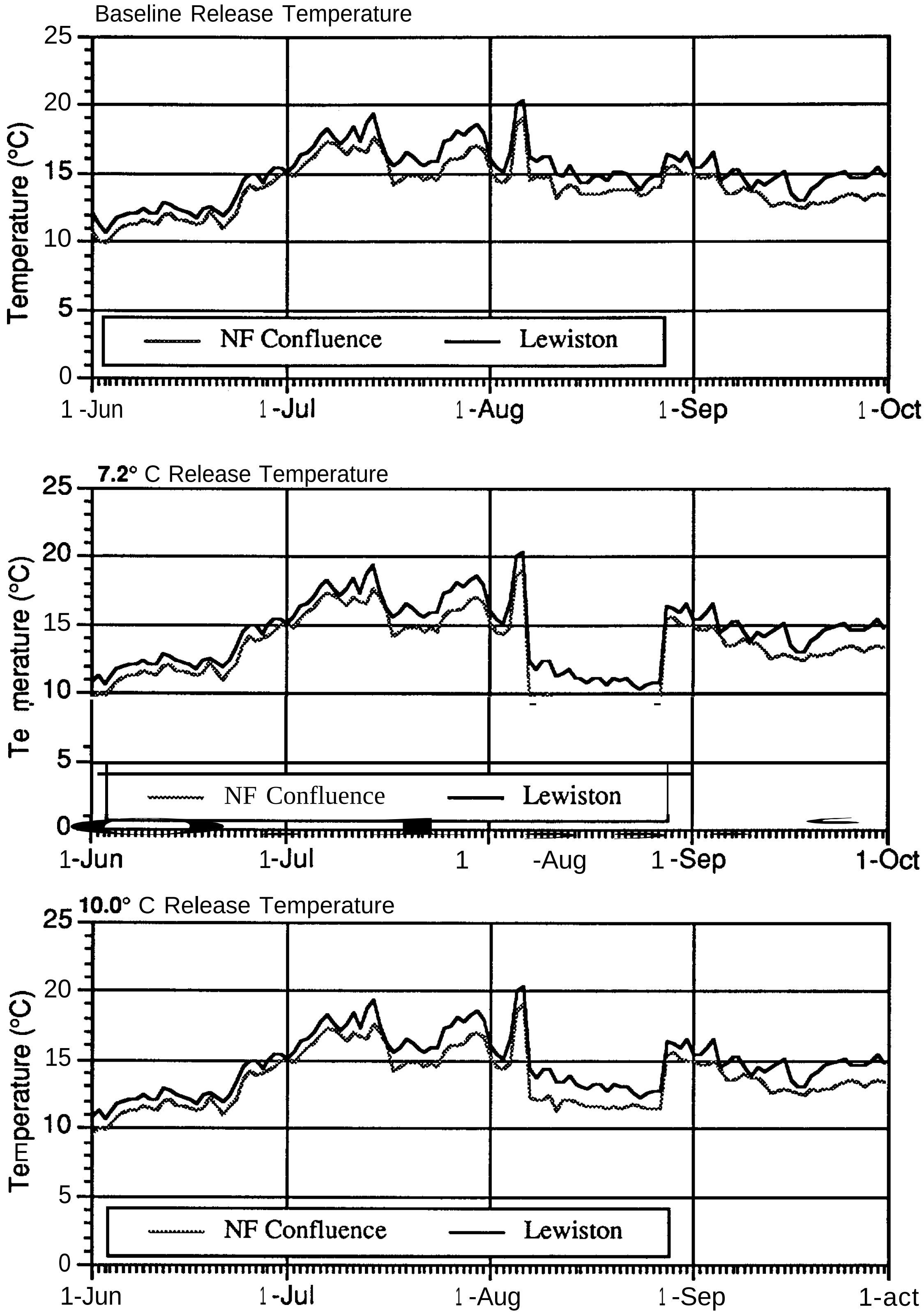


Figure 12.6. Clearwater River temperatures under U.S. Army Corps of Engineers Alternative 24: Dworshak Reservoir release of 10,000 cfs from August 7 to August 27, 1989.

The Corps alternative to release 708 cms (25,000 cfs) would create even greater temperature extremes in the LMCR (Figure 12.7). Under a baseline release temperature, average daily water temperatures at the NFCR confluence would be expected to drop as much as 5 °C, resulting in average daily temperatures of about 13 °C. Temperatures could drop by about 10 °C during the initiation of this alternative discharge at a reservoir release of 7.2 °C. Temperatures would drop to 8 °C at the NFCR confluence and to 9 °C at Lewiston under a 708 cms (25,000 cfs) reservoir release at 7.2 °C (Figure 12.7).

November 1 through December 31

Under 1989 baseline discharge and temperature release conditions, temperatures at the NFCR confluence ranged from 5 to 8 °C in November, and from 3 °C to 5 °C in December (Figure 12.8). Under these same conditions, water temperatures at Lewiston ranged from 4 to 9 °C in November, and from 3 to 6 °C in December (Figure 12.8). Water temperatures did not change from the upper to the lower section of the LMCR, except during relatively warm conditions when temperature increased by as much as 1 °C. During relatively cold conditions, water temperature declined by as much as 0.5 °C in the lower river.

The release of 10 °C water from the Dworshak Reservoir under baseline release discharges would result in river temperatures at the NFCR confluence which are up to 1 °C higher than those observed under existing conditions (Figure 12.8). Temperatures at Lewiston would not increase as much because of down-river cooling due to cold climatic conditions during these months.

A release alternative of 113 cms (4,000 cfs) at 7.2 °C, would provide temperatures at the NFCR confluence between 5 to 7 °C in November, and from 4 to 5 °C in December (Figure 12.9). Water temperatures at Lewiston would range from 5 to 8 °C in November, and from 4 to 6 °C in December. This discharge release substantially reduced temperature variation in both the upper and lower river during this time period over 1989 baseline conditions (Figure 12.8). A 10 °C release at 113 cms (4,000 cfs) would further raise temperatures throughout the entire LMCR over baseline conditions (Figure 12.9). Temperatures at the NFCR confluence would range from 7 to 9 °C in November, and from 5 to 8 °C in December. Temperatures at the Lewiston would range from 6 to 9 °C in November, and from 6 to 7 °C in December. As noted earlier in this chapter, temperature releases of 10 °C would not be possible after the reservoir becomes thermally uniform.

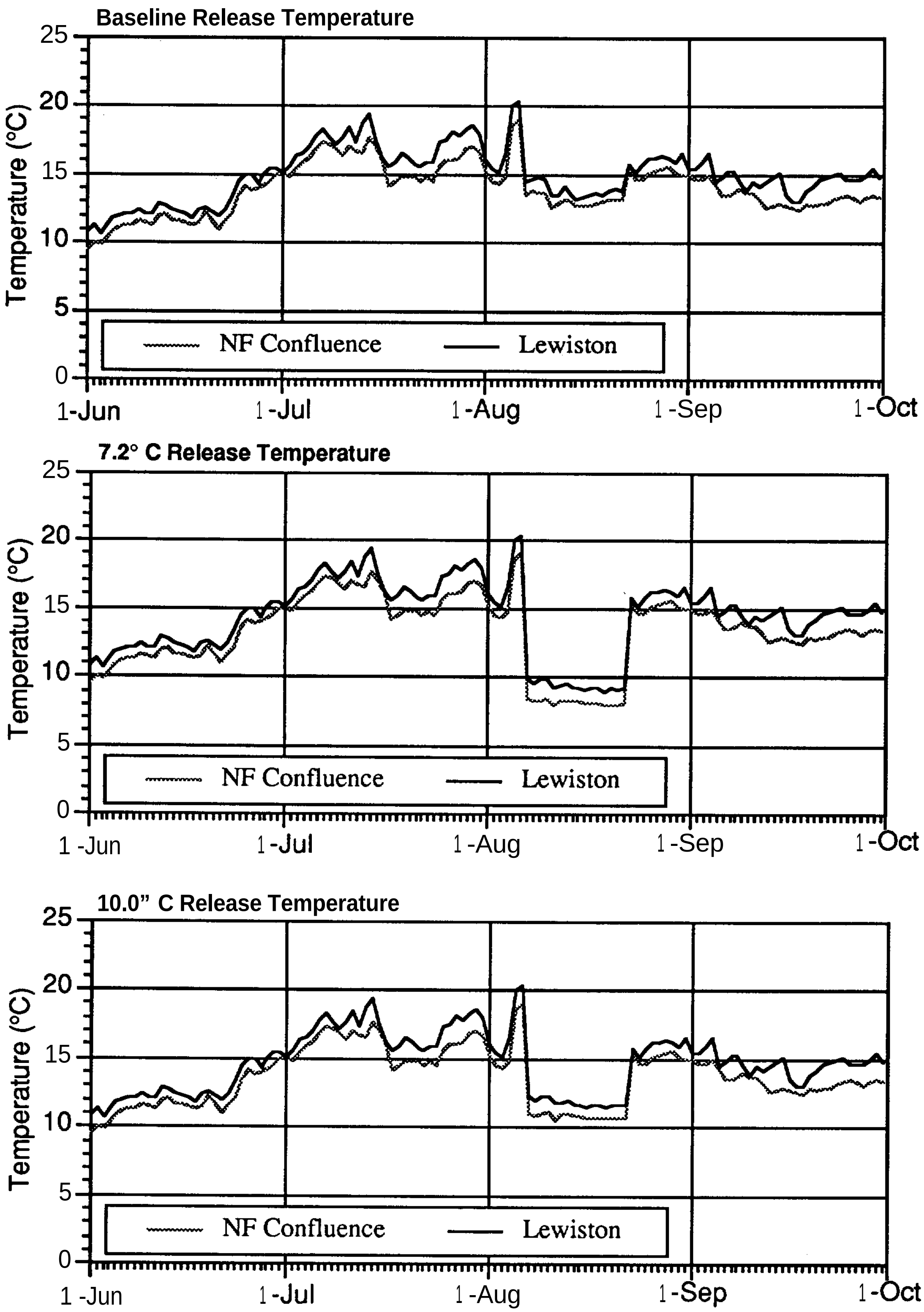


Figure 12.7. Clearwater River temperatures under U.S. Army Corps of Engineers Alternative 26: Dworshak Reservoir release of 25,000 cfs from August 7 to 22, 1989.

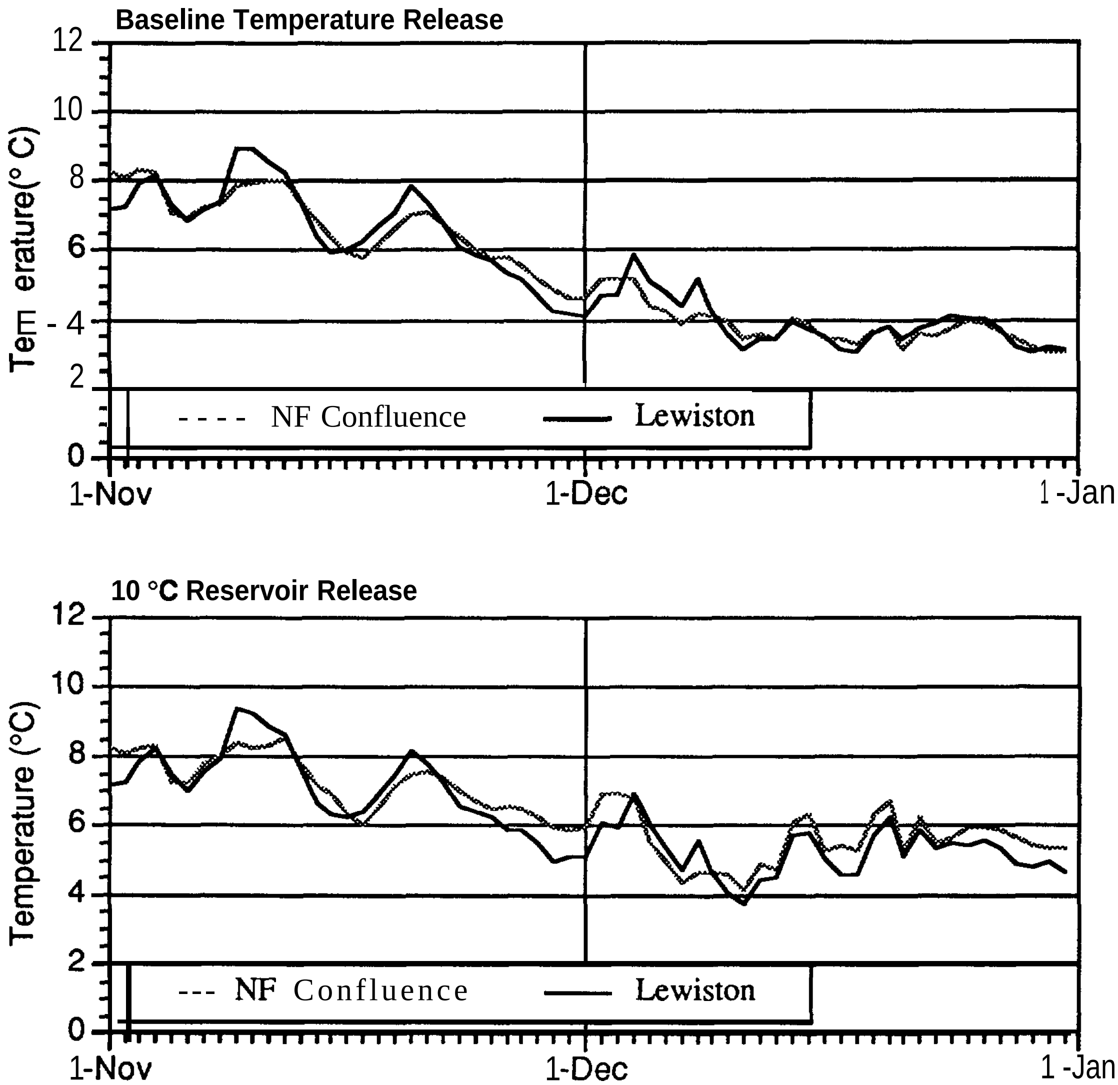


Figure 12.8. Clearwater River temperatures under baseline Dworshak Reservoir releases, Nov. 1 to Dec. 31, 1989.

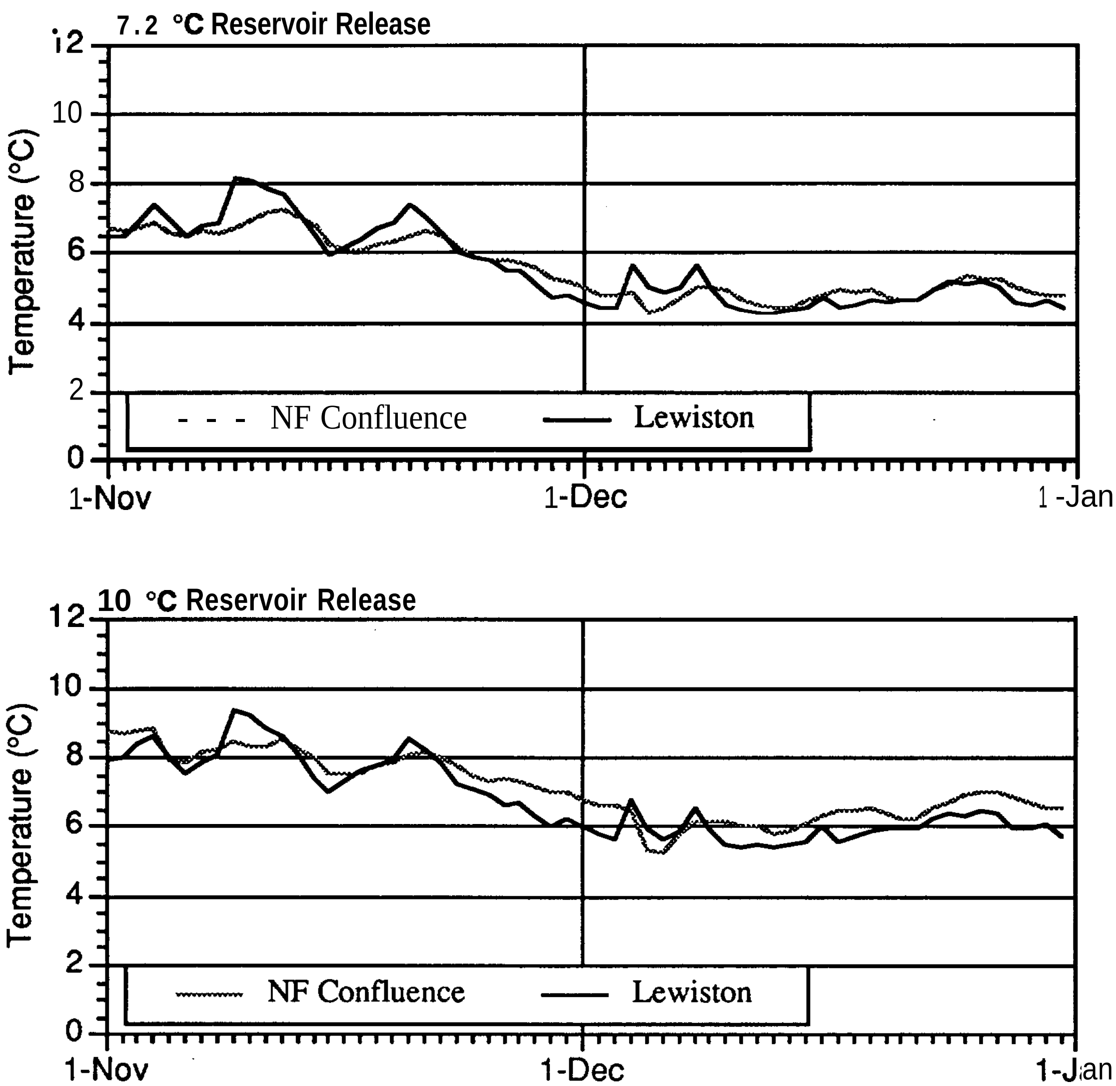


Figure 12.9. Clearwater River temperatures under Dworshak Reservoir release of 4000 cfs, Nov. 1 to Dec. 31, 1989.

Increasing discharge to 170 cms (6,000 cfs) would further reduce variation in temperatures (Figure 12.10). At this discharge, temperatures between 6 to 8 C and 4 to 6 °C could be maintained in the LMCR during November and December, respectively. By increasing release temperatures to 10 °C, temperatures in the LMCR between 7 and 9 °C would be expected in November, and between 6 and 8 °C in December.

Discussion

Under baseline conditions existing from June 1 to September 30, 1989, water temperatures in the LMCR mainly varied according to three factors: 1) meteorological conditions; 2) flow releases from Dworshak Dam: and 3) inflow temperature from the upper mainstem Clearwater River. Meteorological conditions varied considerably during this period, with relatively cool conditions occurring in June, and very hot conditions occurring in August. Releases from Dworshak Dam varied, with high releases of 255 cms (9,000 cfs) throughout most of September, and low releases of less than 42 cms (1,500 cfs) during several days in August. Temperatures in the upper mainstem Clearwater River were considerably higher than those in the LMCR during the summer, ranging in average daily temperatures from 11.0 °C in early June to 23.5 °C in mid-August. The highest temperatures in the LMCR were observed when hot climatic conditions coincided with low Dworshak Dam releases.

During the summer, lower Dworshak Dam releases can result in increased temperatures in the LMCR for two reasons: 1) warmer upper mainstem Clearwater River flows constitute a larger proportion of water in the LMCR under low reservoir releases; and 2) decreased travel time of water in the LMCR during low flows provide greater heat transfer potential from the warmer air during hot summer conditions.

Under a Dworshak Dam release alternative of 57 cms (2,000 cfs) at baseline conditions (12.8 °C), water temperature during most of the summer would exceed those that existed during extreme low flow condition in 1989. Temperature increases result from flow releases which are lower than those that occurred during 1989. This alternative would only slightly lower peak summer temperature in the LMCR and would provide minimal benefits to salmonids. The selective release of cooler waters from Dworshak Dam could provide considerably greater temperature benefits to salmonids in the LMCR under the 57 cms (2,000 cfs) release scenario, but only if these releases were substantially colder than 12.8 °C.

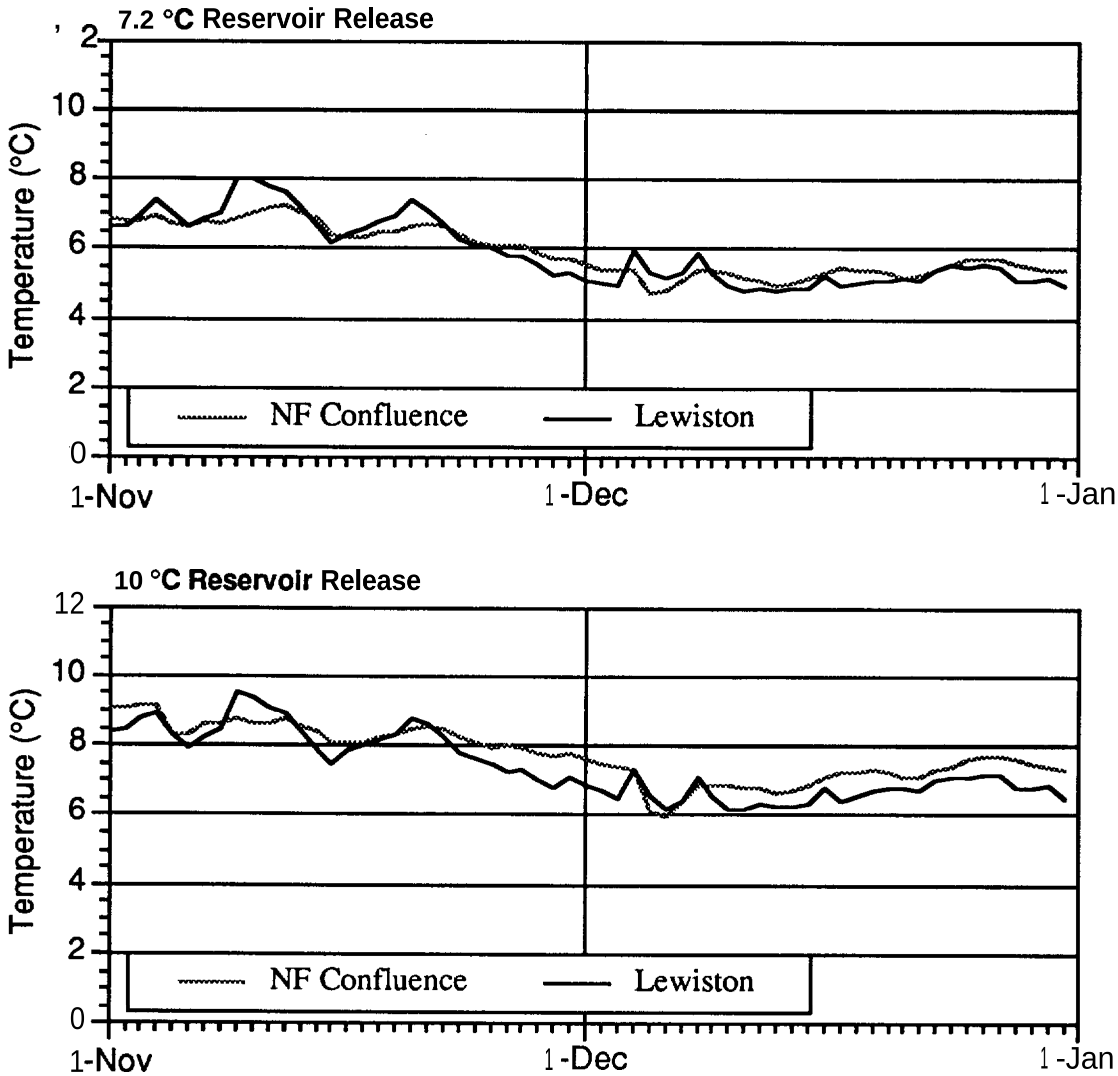


Figure 12.10. Clearwater River temperatures under Dworshak Reservoir Release of 6000 cfs, Nov. 1 - Dec. 31, 1989.

A 7.2 °C Dworshak Dam release at 1989 baseline discharges would mainly improve habitat conditions in the upper reaches of the LMCR, as average daily water temperatures would generally not exceed 18 °C. Because of rapid downriver heating of water during low flows during the summer, the lower end of the LMCR at Lewiston would not receive the same cooling effects, however, average daily water temperatures would not be expected to exceed 19 °C during July and August.

A 113 cms (4,000 cfs) Dworshak Dam release at 12.8 °C would considerably reduce highest summer water temperatures in the LMCR during July and August. Average daily water temperatures in July and August would be expected to range between 15 and 18 °C in the entire LMCR. Benefits to rearing salmonids are primarily attained by reduced peak water temperatures during hot summer days. These cooler river temperatures would fall within the range preferred by rearing salmonids, unlike those that occurred during 1989.

A 113 cms (4,000 cfs) Dworshak Dam release at 7.2 °C would substantially reduce water temperatures throughout the entire LMCR during July and August. Average daily water temperatures in July and August would not exceed 15 °C in the upper reaches of the LMCR and not exceed 17 °C in the lower reaches of the LMCR. At this same discharge at a 10 °C release, temperatures would range from 15 to 16 °C in the upper river and 15 to 18 °C in the lower river. Under both temperature release alternatives, LMCR temperatures would be more optimal for rearing salmonids.

A release of 170 cms (6,000 cfs) and 227 cms (8,000 cfs) would reduce average daily temperatures beyond that attained by a 113 cms (4,000 cfs) release. These relatively high reservoir flow releases would greatly reduce daily variation in river temperature and be even more in the range of optimal temperatures for rearing salmonids.

Under the proposed U.S. Army Corps of Engineers alternative to release 283 cms (10,000 cfs) from August 7 to 27, temperatures in the LMCR would drop rapidly from 1989 baseline conditions. Under this alternative, sudden reductions in water temperature of up to 10 °C would occur in the LMCR. Thermal shock to fish would be possible under these conditions and could adversely result in reduced growth rates. Temperatures would remain high in the LMCR during hot summer days before and after the proposed release period. Consequently, the relatively short period of this alternative would not benefit salmonids to the extent provided by a more continuous and reduced discharge alternative. The proposed release of 708 cms (25,000 cfs) from August 7 to 22 would pose even greater temperature problems to salmonids in addition to reducing habitat area for fry and juveniles (Chapter 10).

For the period of November 1 to December 31, all release temperatures and discharges modeled may not be possible during this entire period, depending on Dworshak Reservoir pool levels and temperatures. Water temperatures in Dworshak Reservoir typically become vertically uniform during late November to December. Early seasonal mixing of thermally stratified waters in the reservoir would limit benefits in advancing the incubation timing of fall chinook. Benefits to incubating fall chinook for all alternatives modeled are discussed in Chapter 3.

Conclusions

Results of temperature modeling indicate that Dworshak Reservoir can be used to improve temperature conditions for salmonids in the LMCR. High water temperatures presently occurring during low flow periods during the summer in the LMCR can be effectively reduced by releasing higher flows or by selecting lower release temperatures from Dworshak Dam. A 57 cms (2,000 cfs) release of 7.2 °C water from the dam would substantially benefit salmonids by reducing summer water temperatures to more optimal levels for growth. At the present time, however, a 7.2 °C release would reduce steelhead trout growth at Dworshak National Fish Hatchery which takes water directly from the North Fork Clear-water River (William Miller, USFWS personal communication). Considerable benefits to rearing salmonids on the LMCR could be obtained by a 113 cms (4,000 cfs) release of 10 °C or 12.8 °C water. A release of higher discharges at these temperature alternatives would provide only slightly increased benefits to salmonids. As warm as possible temperature releases in November and December may advance fall chinook emergence in the LMCR and thus smolt timing to more favorable early summer flow and temperature conditions.

CHAPTER 13

CONCLUSIONS AND RECOMMENDATIONS

The success of augmenting chinook salmon ***Oncorhynchus tshawytscha*** natural reproduction in the lower 61 km of the lower **mainstem** Clearwater River (LMCR) will depend on a number of variables which are outlined in this study. We studied chinook salmon spawning, incubation, and rearing potential of the LMCR and modeled habitat conditions for all life stages and considered alternative discharge and temperature release strategies from Dworshak Dam. We also considered **rainbow/steelhead** trout 0. ***mykiss*** habitat conditions in these alternative releases.

The physical habitat for either summer or fall chinook salmon spawning in the **LMCR** was found to be excellent in both quality and quantity. Armoring of the main channel caused by controlled flow releases at Dworshak Dam may decrease the usability of spawning substrate in certain areas. Analysis of critical shear stress values using Shields criterion indicated that most spawning substrate particles would not move until relatively high discharges in the LMCR are reached (Appendix F). High spring discharges of 50,000 cfs and greater may promote spawning substrate movement and redd scouring thereby decreasing chinook salmon incubating success. However, incubating success of chinook salmon would be expected high based on the relatively low intrusion of fines into redds over incubation and favorable substrate temperature and oxygen conditions found in the LMCR.

Based on the incubation timing results, either upper Columbia River (UCR) summer or Snake River fall chinook salmon would be compatible stocks for the **LMCR.** Emergence at the beginning of May for UCR summer chinook and the third week in May for Snake River fall chinook would be more conducive to higher survival than mid-winter emergence of South Fork Salmon River summers. Both the UCR summer and the Snake River fall chinook outmigrate as subyearlings, however the UCR summers may have an advantage of earlier emergence timing. The Snake River fall chinook may smolt and outmigrate during unfavorable low flow and temperature conditions in July and August. However, given alternative flow and temperature releases from Dworshak Dam, incubation and outmigrating conditions may be improved in the **LMCR.** Additional research is needed on growth rates and outmigration timing of fall chinook salmon in the LMCR.

Because limited fall chinook spawning has been documented in the LMCR in recent years and because declining numbers in Idaho has caused this stock to be proposed as threatened or endangered by the Federal Endangered Species Act of 1973, the Snake River fall chinook salmon should be considered a prime candidate for natural reproduction development in the LMCR.

Habitat Area (HA) values versus flow relationships developed for the Potlatch, Bedrock, and Big Canyon segments of the LMCR were evaluated to identify the optimal flow and temperature regime for target species and life stages. Optimal flows were defined as those resulting in the greatest HA value achieved in the HA versus discharge relationships. Optimal flows for maximum habitat were designated irrespective of flow availability or Dworshak Dam operating criteria. Optimal discharges were identified on a month-to-month basis for target species and life stages currently present in the river, or potentially present as a result of enhancement or supplementation efforts. Chinook salmon spawning had a maximum HA value of 207 ha at 85 cms (3,000 cfs); chinook salmon and steelhead trout holding had a maximum HA value of 236 ha at 453 cms (16,000 cfs); chinook salmon juveniles had a maximum HA value of 58 ha at 85 cms (3,000 cfs); chinook salmon fry had a maximum HA value of 2.5 ha at 85 cms (3,000 cfs); rainbow/steelhead trout juveniles had a maximum HA value of 76 ha at 85 cms (3,000 cfs); and rainbow/steelhead trout fry had a maximum HA value of 26 ha at 85 cms (3,000 cfs).

Flow recommendations based upon the above criteria alone would be inadequate for four reasons. First, life stages of chinook salmon and steelhead trout life stages have different maximum habitat discharge values but would occupy the LMCR at similar times (see Chapter 10, Figure 10.24). For example, spring chinook staging occurs during the same months as steelhead trout fry and juvenile rearing. Also, steelhead trout staging occurs at the same time as steelhead trout fry and juvenile rearing, spring chinook salmon fry rearing, and fall chinook salmon spawning. Consequently, flow recommendations are more effectively developed on a month-to-month basis to optimize habitat for all target species and their critical life stages. Second, flows recommendations must be based upon important biological criteria not analyzed in this study, including incubation flows for chinook salmon from November to April, and smolt outmigration flows for salmon and steelhead trout in May and June. Third, flows should not affect other ongoing fisheries such as the growth of steelhead trout at Dworshak National Fish Hatchery which receives water directly below Dworshak Dam from the North Fork Clearwater River. Finally, flows should be attainable with respect to the operation of Dworshak Dam, and with regard to patterns of unregulated inflow from the upper mainstem Clearwater River tributaries.

Potential Dworshak Dam release alternatives for fish habitat enhancement were evaluated using a reservoir release model. This model was developed to assess the feasibility of flow release alternatives for Dworshak Dam. A computer program was written to calculate the total reservoir storage volume required on both a monthly and yearly basis to meet alternative instream flows in the LMCR. This program first read daily discharge records from the upper mainstem river (Orofino gaging station) to determine if natural inflows from the upper river were sufficient to meet minimum instream flow requirements in the lower river. Given that flows were insufficient to meet an instream flow target in the LMCR, the volume of water from Dworshak Reservoir needed to make up the difference was calculated. This volume of water was converted into units of acre-feet, and accrued on a monthly and yearly basis. This analysis was carried out on the 25 year period of record available from the Orofino gaging station which started measuring flows in 1965.

Minimum instream flows from 28 cms to 283 cms (1,000 to 10,000 cfs) were evaluated using this approach. The feasibility of alternative flow releases was determined on a yearly basis, and was based upon 700,000 acre-ft of storage available in Dworshak Reservoir at the end of each summer. This volume of water is presently released from the reservoir during the month of September to lower reservoir pool elevations for required flood protection. Alternative flow releases to meet minimum instream flows in the LMCR were regarded as attainable if total volumes of water released for this purpose during the months of July, August, and September did not exceed 700,000 acre-ft.

The reservoir release model indicated that a 198 cms (7,000 cfs) minimum flow for July 1 to September 30 would provide the approximate break-even point above which the 700,000 acre-ft storage in Dworshak Reservoir could not sustain (Figure 13.1). Further analysis indicated that this level of storage could provide minimum flows of 28 to 142 cms (1,000 cfs to 5,000 cfs) for all 25 years for which the model was run (Figure 13.2). A 170 cms (6,000 cfs) discharge could be attained from this amount of reservoir storage in only 21 of 25 years. The number of years which could sustain high minimum discharges dropped progressively to 255 cms (9,000 cfs), which only 1 year in 25 could be provided for by reservoir storage.

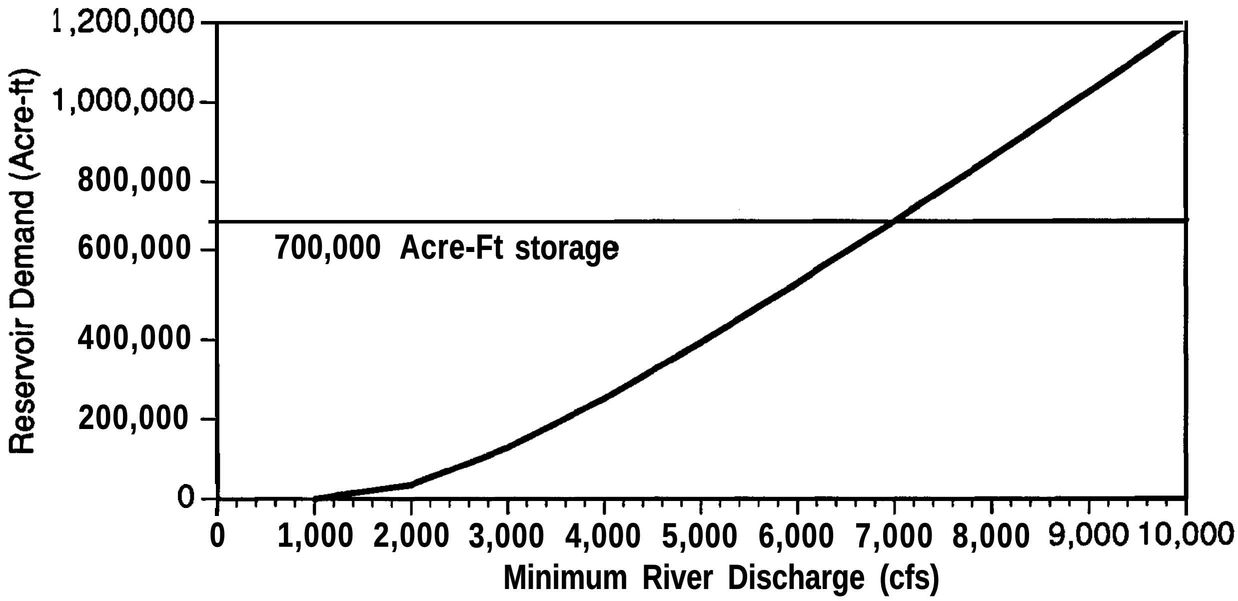


Figure 13.1. Average Dworshak reservoir storage required to meet minimum flows in the lower mainstem Clearwater River from July 1 to September 30, 1965-l 989.

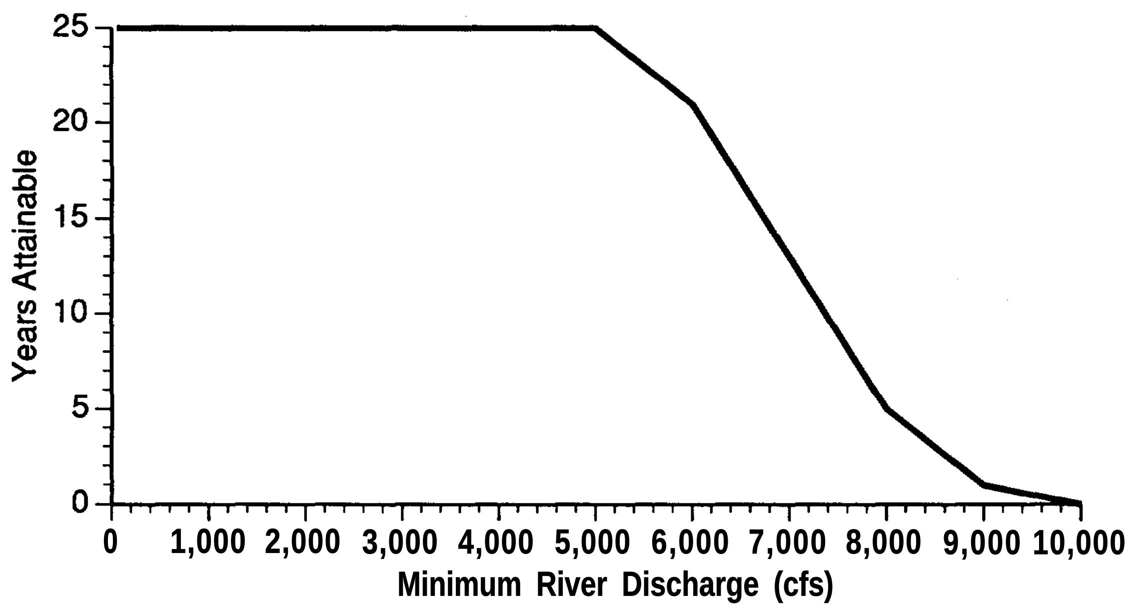


Figure 13.2. Number of years in which July 1 to September 30 minimum flows are attainable from 700,000 acre-ft storage in Dworshak Reservoir (based on discharge records from 1965 to 1989).

In consideration of Dworshak Dam and Dworshak National Fish Hatchery operations and unregulated inflow patterns from the upper mainstem Clearwater River, the following LMCR total steady-state discharges at the Spalding Gaging Station and Dworshak Reservoir temperature releases would provide optimal habitat for critical target species and their life stages in the LMCR:

1) 142 cms (5,000 cfs) from July 1 through August 31 for spring chinook salmon adult holding and juvenile rearing, fall chinook rearing, and rainbow/steelhead trout rearing;

2) A Dworshak Reservoir release of 10 °C (50 °F) water from July 1 through September 15 for rearing salmonids. A 7.2 °C (45 °C) release would be optimal provided a Dworshak Reservoir water supply is available to Dworshak National Fish Hatchery:

3) 142 cms (5,000 cfs) from September 1 through October 31 for rainbow/steelhead trout rearing and adult steelhead trout and fall chinook holding;

4) 142 cms (5,000 cfs) from November 1 through December 15 for fall chinook spawning and rainbow/steelhead trout rearing and adult steelhead trout holding;

5) A Dworshak Reservoir release of the warmest water possible from November 1 through December 31 for fall chinook salmon incubation:

6) flows from December 15 through April 31 be maintained at maximum sustained flows that existed during fall chinook spawning (November 1 through December 15) for fall chinook incubation; and

7) higher flows that naturally occur in the LMCR during May and June would be required for steelhead trout and spring chinook salmon smolt outmigration.

LITERATURE CITED

Adams, J.N. and R.L. Beschta. 1980. Gravel bed composition in Oregon coastal streams. Canadian Journal of Fish and Aquatic Sciences 37:1514-1521.

Andrew, F.J. 1981. Gravel cleaning to increase salmon production in rivers and spawning channels, Pages 15-31 in Proceedings from the conference on salmon spawning gravel: a renewable resource in the Pacific Northwest. Washington State University, Washington Water Research Center Report 39, Pullman.

Asherin, D.S. and M.L. Orme. 1978. Inventory of riparian habitats and associated wildlife along the Dworshak Reservoir and lower Clearwater River. A report to the U.S. Army Corps of Engineers North Pacific Division by the University of Idaho Cooperative Wildlife Research Unit, Moscow.

Bailey, T.D., and G.P. Rimbach. 1991. Umatilla Basin habitat improvement project. Oregon Department of Fish and Wildlife annual report to the Bonneville Power Administration, Project No. 87-100-02, Contract No. DE-AI79-87BP35769.

Bartholow, J.M. 1989. Water temperature investigations: field and analytical methods. U.S. Fish and Wildlife Service, National Ecology Research Center, Fort Collins, CO.

Bennett, D.H., T.S. Curry, and T.J. Dresser. 1991. Monitoring fish community activity at disposal and reference sites in Lower Granite Reservoir, Washington-Year 3. A quarterly report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.

Bjornn T.C. and D.W. Riser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 in Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19:83-138.

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Information Paper 12. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-82/26.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Instream flow information paper 21. U.S. Fish and Wildlife Service Biological Report 86(7).

Brusven M.A. and C. MacPhee. 1976. The effect of river fluctuations resulting from hydropeaking on selected aquatic invertebrates and fish. OWRT Technical Completion Report. Project No. A-035-IDA. University of Idaho, Moscow.

Buettner E.W., and V.L. Nelson. 1990. Smolt monitoring at the head of Lower Granite Reservoir and Lower Granite Dam. Idaho Department of Fish and Game annual report to the Bonneville Power Administration, Project No. 83-323, Contract No. DE-BI79-83BP11631.

Burger, C.V., D.B. Wangaard, R.L. Wilmot, and A.N. Palmisano. 1982. Salmon investigations in the Kenai River, Alaska, 1979-1981. U.S. Fish and Wildlife Service National Fisheries Resource Center, Seattle, WA.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildlife Service, Fishery Bulletin 61. 52:97-110.

Burton, T.A., G.W. Harvey, and M. McHenry. 1990. Protocols for assessment of dissolved oxygen, fine sediment and salmonid embryo survival in an artificial redd. Idaho Department of Health and Welfare, Division of Environmental Quality, Boise.

Chambers, J.S., G.H. Allen, and R.T. Pressey. 1956. Research relating to study of spawning grounds in natural areas. Annual report to U.S. Army Corps of Engineers by Washington Department of Fisheries, Olympia, WA.

Chapman, D.W., D.E. Weitkamp, T.L. Welsh, and T.H. Schadt. 1983. Effects of minimum flow regimes on fall chinook spawning at Vernita Bar 1978-82. Report to Grant County Public Utility District, Ephrata, WA. by Don Chapman Consultants, Inc., and Parametrix, Inc.

Chapman, D.W., D.E. Weitkamp, T.L. Welsh, M.B. Dell, and T.H. Schadt. 1986. Effects of flow on the distribution of chinook salmon redds. Transactions of the American Fisheries Society 115:537-547.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117:1-21.

Chapman, D., A. Giorgi, M. Hill, A. Maule, S. McCutcheon, D. Park, W. Platts, K. Pratt, J. Seeb, L. Seeb, and F. Utter. 1991. Status of Snake River chinook salmon. Don Chapman Consultants, Inc. for the Pacific Northwest Utilities Conference Committee.

Cheslak, E.F. and J.C. Garcia. 1988. An evaluation of the effects of various smoothing and curve-fitting techniques on the Accuracy of suitability functions. Pages 259-283 in Bovee, K.D. and J.R. Zubby. Proceedings of a Workshop on the Development and Evaluation of Habitat Suitability Criteria. U.S. Fish and Wildlife Service, National Ecology Center, Fort Collins, CO. Biological Report 88 (11).

Combs, B.D. 1965. Effect of temperature on the development of salmon eggs. Progressive Fish-Culturist 27(3)134-137.

Connor, W.P. 1989. Mainstem Clearwater River Study: Assessment for salmonid spawning, incubation, and rearing. Nez Perce Tribe Department of Fisheries 1988 annual report to the U.S. Department of Energy, Bonneville Power Administration, Contract No. DE-AI79-BP37474, Project No. 88-15.

Connor, W.P., B.D. Arnsberg, E. Connor, and C.M. Prewitt. 1990. Mainstem Clearwater River: Assessment for salmonid spawning, incubation, and rearing. Nez Perce Tribe Department of Fisheries 1989 annual report to the U.S. Department of Energy, Bonneville Power Administration, Contract No. De-A179-87BP37474, Project No. 88-15.

Crance, J.H. and J. Shoemaker. 1986. Eighteen minute slide-tape on development and use of suitability index curves for use in instream flow studies. U.S. Fish and Wildlife Service, National Ecology Center. NEC-86/21.

Espinosa F.A., and K.M. Lee. 1991. Natural propagation and habitat improvement Idaho: Lolo Creek and upper Lochsa Clearwater National Forest. Clearwater National Forest annual report to the Bonneville Power Administration, Project No. 84-6, Contract No. DE-A179-86BP62665.

Everest, F.H., C.E. McLemore, and J.F. Ward. 1980. An improved cryogenic gravel sampler. U.S. Forest Service Research note PNW-350, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Everest, F.H., F.B. Lotspeich, and W.R. Meehan. 1982. New perspectives on sampling, analysis, and interpretation of spawning gravel quality in N.B. Armantrout, editor, Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division American Fisheries Society, Portland, Oregon 99:325-333.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cederholm. 1987. Fine sediment and salmonid production: a paradox. Pages 98-142 in E. Salo and T. Cundy, editors. Streamside Management: Forestry and Fishery Interactions: Proceedings of a Symposium. University of Washington, College of Forest Resources, Contribution 57, Seattle.

Fish Passage Center. 1989. Bi-weekly report #89-19. FPC 825 N.E. 20th Avenue, Suite 336, Portland, Oregon 97232-295.

Fulton, L.A. 1968. Spawning areas and abundance of chinook salmon in the Columbia River Basin: past and present. Special Scientific Report, U.S. Fish and Wildlife Service No. 571.

Hampton, M. 1988. Development of habitat preference criteria for anadromous salmonids of the Trinity River. U.S. Fish and Wildlife Service, Division of Ecological Services, Sacramento, California.

Hart, P.J.B., and T.J. Pitcher. 1969. Field trials of fish marking using a jet inoculator. Journal of Fish Biology 1:383-385.

Heming, T.A. 1982. Effects of temperature on utilization of yolk by chinook salmon ***Oncorhynchus tshawytscha* eggs** and alevins. Canadian Journal of Fish and Aquatic Sciences 39(1):184-190.

Horner, N. and T.C. Bjornn. 1981. Status of upper Columbia and Snake River summer chinook salmon in relation to the Endangered Species Act. Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow.

Irving, J.S. and T.C. Bjornn. 1980. Status of Snake River fall chinook salmon in relation to the Endangered Species Act. Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow.

Johnson, R.A. and R.F. Brice. Effects of transportation of green eggs, and of water temperature during incubation, on the mortality of chinook salmon. Progressive Fish-Culturist 15(3)104-108.

Jones, M.L., and H.R. Seitz. 1980. Sediment transport in the Snake and Clearwater Rivers in the vicinity of Lewiston, Idaho. U.S. Geological Survey, Water-Resources Investigation, Open-File Report 80-690.

Keifer, R.B. and K.A. Forster. 1991. Idaho habitat and natural production monitoring. Idaho Department of Fish and Game annual report to the U.S. Department of Energy, Bonneville Power Administration, Contract No. DE-BI79-84BP13381, Project No. 83-7.

Kronemann, L.A. and K. Lawrence. 1988. Wildlife protection, mitigation, and enhancement planning-Dworshak Reservoir. A report to the U.S. Department of Energy Bonneville Power Administration by the Nez Perce Tribe Department of Wildlife Resources. Contract No. DE-AI79-87BP35333.

Lotspeich, F.B., and F.H. Everest. 1981. A new method for reporting and interpreting textural composition of spawning gravel. U.S. Forest Service Research Note PNW-369.

McNeil, W.J. 1962. Variations in the dissolved oxygen content of intragravel water in four spawning streams of southeastern Alaska. U.S. Fish and Wildlife Service Special Scientific Report-Fisheries 402.

McNeil, W.J. and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report-Fisheries 469.

Meehan, W.R. and D.N. Swanston. 1977. Effects of gravel morphology on fine sediment accumulation and survival of incubating salmon eggs. U.S. Forest Service Research Paper PNW-220.

Milhous, R.T. 1984. The use of one velocity calibration set with IFG4. PHABSIM Technical note No. 4. U.S. Fish and Wildlife Service, National Ecology Research Center. Fort Collins, Colorado.

Milhous, R.T., T. Wegner, and T. Waddle. 1984. User's guide to the Physical Habitat Simulations System (PHABSIM). Instream Flow Information Paper No. 11. U.S. Fish and Wildlife Service Biological Services Program. Revision FWS/OBS-81/43.

Milhous, R.T., M.A. Updike, and D.M. Schneider. 1989. Computer reference manual for the Physical Habitat Simulation System (PHABSIM)-Version II. U.S. Fish and Wildlife Service, National Ecology Research Center. Fort Collins, Colorado.

Morhardt, J.E. 1983. Instream flow methodologies. Electric Power Research Institute, EPRI EA-4819.

Murphy, P.K. 1986. Water quality status report for lower Clearwater River Tributaries, Nez Perce Reservation, Idaho Water Year 1986. Submitted to The Bureau of Indian Affairs, Department of Fisheries Resource Management, Nez Perce Tribe, Lapwai, Idaho.

Olson, P.A. and R.F. Foster. Temperature tolerance of eggs and young of Columbia River chinook salmon. Transactions of the American Fisheries Society 85:203-207.

Ott, L. 1984. An introduction to statistical methods and data analysis. PWS Publishers, Boston, Massachusetts.

Parkhurst, Z.E. 1950. Survey of the Columbia River and its tributaries. Special Scientific Report No. 39, Part 6. U.S. Fish and Wildlife Service, Washington, D.C.

Petrosky, C.E. and T.B. Holubetz. 1987. Idaho habitat evaluation for off-site mitigation record. Idaho Department of Fish and Game 1986 annual report to the U.S. Department of Energy, Bonneville Power Administration, Contract No. DE-A179-84BP13381, Project 83-7.

Petrosky, C.E. and T.B. Holubetz. 1988. Idaho habitat evaluation for off-site mitigation record. Idaho Department of Fish and Game 1987 annual report to the U.S. Department of energy, Bonneville Power Administration, Contract No. DE-A179-84BP13381, Project 83-7.

Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104:461-466.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Foeler, and J.R. Leonard. 1989. Fish hatchery management. U.S. Fish and Wildlife Service ISBN 0-913235-03-2.

Platts, W.S., M.A. Shirazi, and D.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environmental Protection Agency, Ecological Research Series EPA-600/3-79-043.

Platts, W.S. and V.E. Penton. 1980. A new freezing technique for sampling salmonid redds. U.S. Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-248.

Platts, W.S., W.F. Magahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service General Technical Report INT-138.

Prentice, E.F., T.A. Flagg, C.S. McCutcheon, and D.F. Brastow. 1990. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. American Fisheries Society Symposium 7:323-334.

Prentice, E.F., T.A. Flagg, C.S. McCutcheon, D.F. Brastow, and D.C. Cross. 1990. Equipment, methods and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7:335-340.

Raleigh, R.F., T. Hickman, R.C. Soloman, and P.C. Nelson. 1984. Habitat suitability information: rainbow trout. U.S. Fish and Wildlife Service FWS/OBS-82/10.60.

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: chinook salmon. U.S. Fish and Wildlife Service, National Ecology Center. Fort Collins, Colorado.

Richards, K. 1982. Rivers: form and process in alluvial channels. Methuen and Co., London.

Schill, D.J. and J.S. Griffith. 1984. Use of underwater observations to estimate cutthroat trout abundance in Yellowstone River. North American Journal of Fisheries Management 4:479-487.

Shirazi, M.A. and W.K. Seim. 1979. A stream systems evaluation--an emphasis on spawning habitat for salmonids. U.S. Environmental Protection Agency EPA-600/3-79-109.

Shrivell, C.S. 1990. Ability of PHABSIM to predict chinook salmon spawning habitat. Regulated Rivers 3:277-289.

Slauson, W.L. 1988. Constructing suitability curves from data. Pages 225-255 in K.D. Bovee and J.R. Zubby. Proceedings of a workshop on the development and evaluation of habitat suitability criteria. U.S. Fish and Wildlife Service National Ecology Research Center, Fort Collins, Colorado. Biological Report 88 (11).

Stowell, R., A. Espinosa, T.C. Bjornn, W.S. Platts, D.C. Burns, and J.S. Irving. 1983. Guide for predicting salmonid response to sediment yields in Idaho Batholith watersheds. U.S. Forest Service, Northern and Intermountain Regions, Ogden, Utah.

Stuart, T.A. 1953. Spawning migration, reproduction, and young stages of lock trout (*Salmo trutta* L.). Scottish Home Department, Freshwater and Salmon Fisheries Research 5, Edinburgh.

Sturges, H.A. 1926. The choice of class interval. Journal of the American Statistical Association 21(53):65-66.

Swan, G.A. 1989. Chinook salmon spawning surveys in deep waters of a large, regulated river. Regulated Rivers: Research and Management 4:355-370.

Swan, G.A., B.H. Monk, J.G. Williams, and B.P. Sandford. . 1990. Fish guidance efficiency of submersible traveling screens at Lower Granite Dam-1989. Coastal Zone and Estuarine Studies Division annual report to the U.S. Army Corps of Engineers, Interagency agreement DACW68-84-H-0034.

Tappel, P.D. and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3:123-135.

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish and Wildlife Service FWS/OBS-84/15.

Thurow, R. and J. King. 1991. Effects of fine sediment on fish populations. Proceedings of the Fifth Annual Federal Interagency Sedimentation Conference. Las Vagas, Nevada.

Uremovich, B.L., S.P. Cramer, C.F. Willis, and C.O. Junge. 1980. Passage of juvenile salmonids through the ice-trash sluiceway and squawfish predation at Bonneville Dam, 1980. Oregon Department of Fish and Wildlife, Annual Progress Report to the U.S. Army Corps of Engineers, Contract No. DACW57-78-C-0058.

U.S. Army Corps of Engineers. 1975. Final environmental impact statement-Dworshak Reservoir, North Fork Clearwater River, Idaho. Walla Walla District.

U.S. Army Corps of Engineers. 1986. Water Control Manual for Dworshak Dam and Reservoir, North Fork Clearwater River, Idaho. Walla Walla District.

U.S. Geological Survey. 1989. Water resources data, Idaho, water year 1989. USGS Water-Data Report ID-89-l.

Vigg, S. 1988. Functional response of northern squawfish predation to salmonid prey density in McNary tailrace in Predation by resident fish on juvenile salmonids in John Day Reservoir, 1983-1986. Vol I - Final Report of Research to the Bonneville Power Administration, T. P. Poe editor, Contract Nos. DE-AI79-82BP34796 and DE-AI79-82BP35097.

Wampler, P.I. 1986. Development of habitat preference criteria for holding adult spring chinook salmon. U.S. Fish and Wildlife Service, Olympia, WA.

Young, M.K. and W.A. Hubert. 1989. Substrate alteration by spawning brook trout in a Southeastern Wyoming stream. Transactions of the American Fisheries Society. 118:379-385.

APPENDIX A

DIRECT OBSERVATION

Table A.1. Description of habitat types used to classify and identify the typical hydraulic and morphologic characteristics of the lower mainstem Clearwater River, Idaho.

Habitat types	Description
Run	Smooth hydraulics, low gradient, no channel scour, depth between 2 and 5 meters
Rapid run	Standing waves, higher gradient, no channel scour, depth between 2 and 5 meters
Rapid riffle	Turbulent hydraulics, higher gradient, depth less than 2 meters
Pool	Smooth hydraulics, scoured channel, depth between 5 and 7 meters
Eddy	Swirling hydraulics, scour, depth greater than 7 meters
Side channel	Secondary channel in islanded areas
Intermittent side channel	Secondary channel in islanded areas which dry up periodically

APPENDIX A (continued)

Table A.2. Habitat type area for study sites within the Potlatch, Bedrock Creek, and Big Canyon segments of the lower mainstem Clearwater River, Idaho.

Site[a]	Habitat type	Area (HA)	Site area (HA)
PL	Run	49.8	91.0
PL	Side channel riffle	17.4	
PL	Deep run	16.4	
PL	Intermittent side channel	7.4	
BDR	Deep run	31.8	90.8
BDR	Run	17.6	
BDR	Inside bend run	11.6	
BDR	Outside bend run	10.4	
BDR	Side channel riffle	7.7	
BDR	Rapid run	5.8	
BDR	Rapid riffle	3.2	
BDR	Intermittent side channel	2.7	
BGC	Rapid riffle	23.0	60.2
BGC	Inside bend pool	14.2	
BGC	Pool	13.4	
BGC	Outside bend pool	9.6	
NF	Rapid riffle	14.6	27.7
NF	Pool	10.9	
NF	Rapid run	2.2	

[a] Habitat area calculated by combining upper and lower Potlatch River site area.

Table A.3. Lane assignments, length, and total combined lengths by site and habitat type for the Potlatch River, Bedrock Creek, and North Fork segments, lower mainstem Clearwater River, Idaho.

Site	Habitat type	Percent of habitat composition at the site	Lane length (m)	Total combined length (m)
PL	Run	55	366	669
PL	Side channel riffle	19	128	
PL	Deep run	18	121	
PL	Intermittent side channel	8	54	
BDR	Deep run	35	234	667
BDR	Run	19	129	
BDR	Inside bend run	13	85	
BDR	Outside bend run	11	76	
BDR	Side channel riffle	8	57	
BDR	Rapid run	6	42	
BDR	Rapid riffle	4	24	
BDR	Intermittent side channel	3	20	
BGC	Rapid riffle	38	168	440
BGC	Inside bend pool	24	104	
BGC	Pool	22	98	
BGC	Outside bend pool	16	70	
NF	Rapid riffle	52	106	186
NF	Pool	39	80	
NF	Rapid run	8		

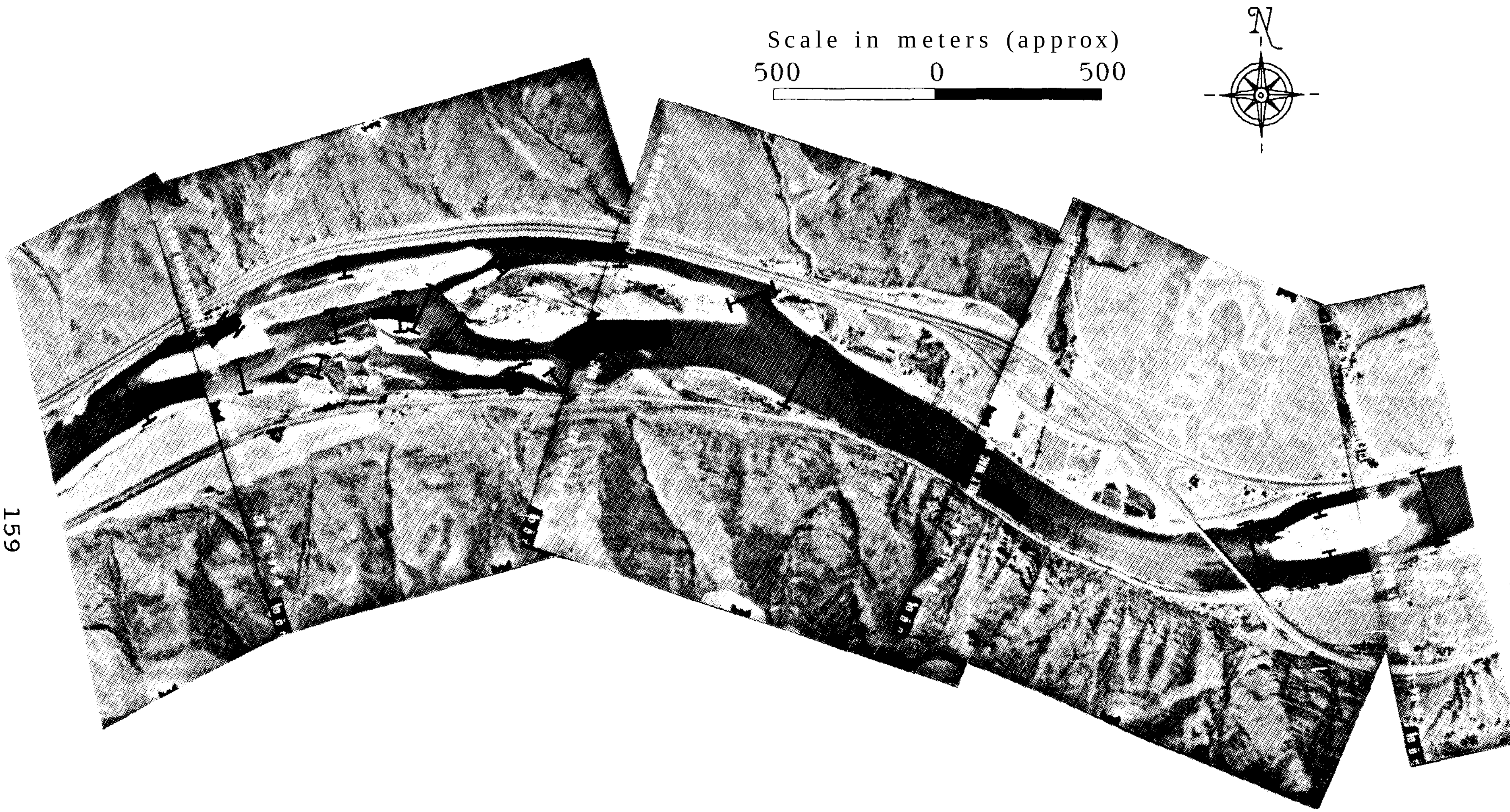


Figure A.1. Assignment of direct observation lanes (■) in relation to hydraulic cross-sections (├─┤) within the Potlatch River Site of the Potlatch River Segment, lower mainstem Clearwater River (LMCR) project area.

Figure A.2. Assignment of direct observation lanes (■) in relation to hydraulic cross-sections (⊢—⊣) within the Bedrock Creek Site of the Bedrock Creel; Segment, lower mainstem Clearwater River (LMCR) project area.

Figure A.3. Assignment of direct observation lanes (■) in relation to hydraulic cross-sections (├──┤) within the Big Canyon Creek Section of the North Fork Creek Segment, lower mainstem Clearwater River (LMCR) project area.

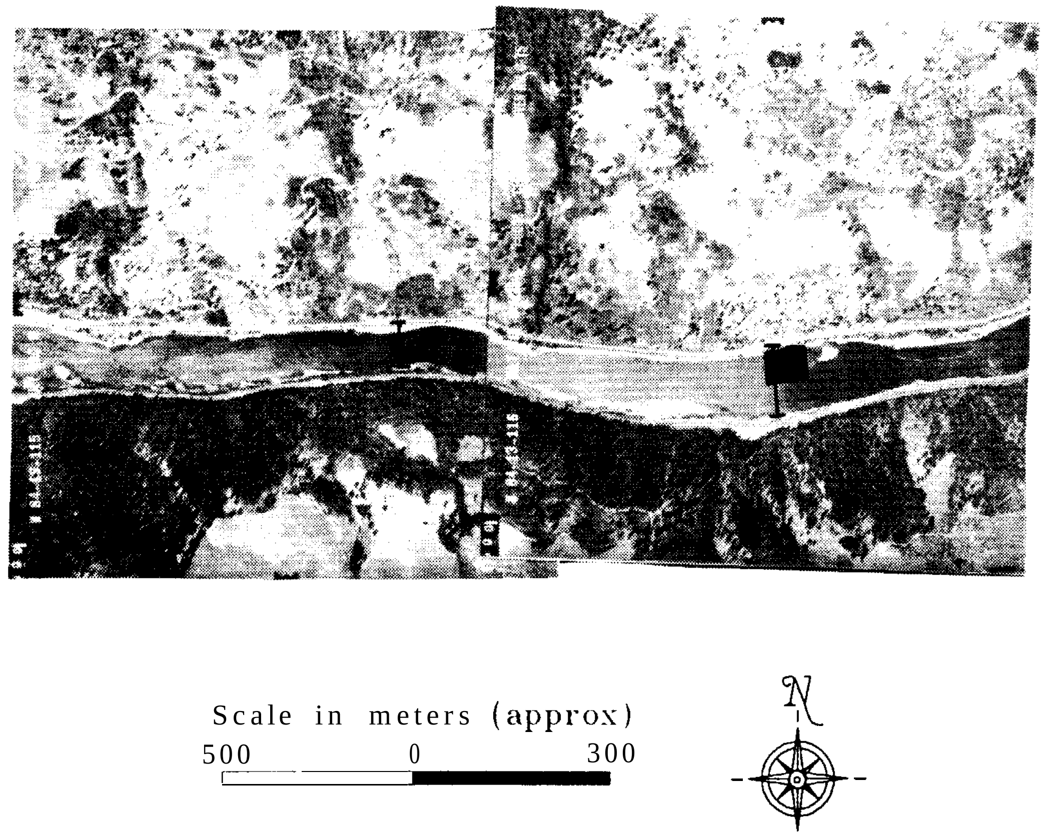


Figure A.4. Assignment of direct observation lanes (■) in relation to hydraulic cross-sections (├─┤) within the North Fork Site of the North Fork Creek Segment, lower mainstem Clearwater River (LMCR) project area.

APPENDIX B

HYDRAULIC MODEL CALIBRATION

Final calibration procedures for the lower mainstem Clearwater River (LMCR) IFG4 hydraulic model involved three steps. First, the initial IFG4 data set (Data Set 1) described in the 1989 Annual Report (Connor et al. 1990) was revised to produce an intermediate calibration data set (Data Set 2) which incorporated corrections in water surface elevations and discharges. Second, the modeling procedure used in IFG4 to describe the stage-discharge relationship at each transect was reviewed. Since the default log-linear relationship provided a bad fit for the stage-discharge relationship, a linear interpolation procedure was developed for this purpose. Finally, edge roughness problems were identified by reviewing output from the Data Set 2. Roughness values were modified on a cell by cell basis to provide a more realistic simulation of velocities in overbank areas at higher flows. Modifications to the stage-discharge model and in cell roughness values were incorporated in a final set of IFG4 calibration data files (Data Set 3).

This deck was then reviewed to determine if water surface elevation and velocity distribution predictions were realistic over the entire range of discharges measured on the LMCR. A final production data deck was then produced by turning off the diagnostic output options on Data Set 3, and by specifying a range of simulation discharges to be modeled. A BASIC computer program was written to provide the water surface elevations, based upon a linear interpolation technique, for each simulation discharge.

<u>Calibration Data Set 1</u>

Data Set 1 contained uncalibrated IFG4 data files which were used to check for data entry errors. It also provided hydraulic geometry information used to predict flow apportionment among islands using Manning's equation. IFG4 data files were first checked for data entry errors using the program CK14. Output from this program provides a convenient method for checking distance, depth, substrate, and velocity input values contained in IFG4 data files. Data file input values were compared to those entered in field notebooks (distance, substrate), as well as those calculated by a spreadsheet program prior to file assembly (elevation, reach gradient, stage of zero flow, mean column velocity). This program also checks for file format errors, an important consideration because IFG4 data files have a very rigid FORTRAN file structure which is very susceptible to mistakes in data entry.

APPENDIX B (continued)

After checking and correcting data entry and file format errors, the IFG4 data files were run through the hydraulic review program, REV14. This program was initially used to provide hydraulic geometry measures at islanded transect sites which would latter be used to calculate partial discharges using Manning's equation. Hydraulic geometry variables obtained from REV14 output included Manning's N (calculated from the REV14 "conveyance factor") and the hydraulic radius for each of 6 water surface elevations measured on the LMCR.

Data Set 1 files were finally run through IFG4 to identify input data errors not recognized by the CK14 and REV14 programs. Two major data errors were identified with IFG4: out-of-sequence transect verticals; and water surface elevations exceeding headpin and tailpin elevation (transect end) measurements. Out-of-sequence transect verticals were corrected by sorting raw data files, and then generating new IFG4 data files with I4TEXT. Bed elevations were extrapolated beyond the headpin and tailpin location along a transect when water surface elevations exceeded headpin and tailpin elevations. A spreadsheet program was used to extrapolate bed elevations when required. A linear extrapolation formula, based upon the slope of the previous transect bed elevations, was used for this purpose, and is defined as follows:

Elev3 = Elev2 + ((Dist3 - Dist2) * (Elev2 - Elevl) / (Dist2 - Distl))

where:
- Elev3 = extrapolated bed elevation past transect end
- Dist3 = transect distance where bed elevation is extrapolated
- Elev2 = last measured bed elevation along a transect
- Dist2 = transect distance at Elev2
- Elevl = measured bed elevation immediately preceding Elev2
- Distl = transect distance at Elevl

Extrapolated bed elevations were added to transect spreadsheet files when necessary. Input data for problematic transects in IFG4 Data Set 1 were then replaced with modified transect data. Once corrected for data input and bed elevation errors, the revised IFG4 Data Set 1 was renamed IFG4 Data Set 2.

APPENDIX B (continued)

Calibration Data Set 2

Two major calibration problems where identified in running Data Set 2 through the hydraulic review program REV14, and through the hydraulic simulation program IFG4. The first problem involved flow apportionment among multiple channels at islanded study sites in the Bedrock and Potlatch segments. This problem was identified early in the review process from unusually high conveyance factor values calculated in REV14 for low flows. More importantly, velocities predicted at low discharges, approximately 100 cms (3,530 cfs), by IFG4 for certain island side channel transects were unrealistically high. Predicted velocity values exceeding 3 m/s (10 ft/sec) at low calibration discharges indicated a severe overestimation of side channel discharge. The most likely cause of discharge overestimation was the failure of the Manning's equation method to predict partial channel discharges for total river discharges less than 340 cms (12,000 cfs). Failure of this method was attributed to rapid and unpredictable changes in channel gradient at low flows at islanded transect sites. Channel gradient, or slope, is one of three input variable used in Manning's equation to predict discharge. Changes in channel slope were caused by localized deviations in the longitudinal profile of the channel corresponding to water surface elevation changes between riffles and pools. At discharges higher than 340 cms (12,000 cfs), channel gradient along a given reach approached a uniform condition, and was no longer influenced by localized changes in channel elevation.

The second problem involved the interpolation of water surface elevations at instream flow transect locations. Water surface elevations for transects were calculated from water surface elevation measurements obtained at rebar placed at water's edge upstream and downstream from each transect. This method was based upon channel gradient calculations obtained from rebar placed along the river at each of 6 calibration discharges. This problem was most pronounced for transects located a relatively large distance (> 300 m) from adjacent water surface elevation rebar. Errors in interpolating water surface elevations were attributed to local breaks in the water surface slope between rebar locations, and were most evident at steep riffles. The linear interpolation method assumes a uniform water surface slope between adjacent upstream and downstream rebar locations.

The interpolation error for each transect was calculated by subtracting a known water surface elevation measured at the transect from the water surface elevation predicted by interpolation at the same discharge. This known water surface elevation was obtained from survey measurements obtained during the velocity calibration discharge (approximately 340 cms or 12,000 cfs).

Interpolation error values were then added to each of six water surface elevations previously calculated at each transect to obtain corrected values. Transect water surface elevations in Data Set 2 files were replaced with corrected values using a text editor. These adjusted water surface elevation values were also employed in both Data Set 3 and the Production Data Set.

An additional interpolation problem was revealed at a few transects after running IFG4 Data Set 2 through the REV14 and IFG4. Unusually high channel conveyance factor values and unrealistically high velocities were predicted at these transects at low flows, indicating that water surface elevations had been underestimated. This error was observed at three transect sites: Lower Potlatch Transect 13 and 16, and Bedrock Transect 6. These problem transects were all located within riffles which were located a substantial distance (> 500 m) from adjoining water surface elevation rebar. Errors at these transects were apparently the result of high bed elevations occurring between rebar locations. A water surface elevation modeling program, MANSQ, was used to provide better estimations of water surface elevations at these three transects for low flow conditions. MANSQ provides water surface elevations estimates for specified discharges using Manning's equation. These improved water surface elevation estimates were then placed in Calibration Data Set 2 with a text editor, and used in all subsequent data sets.

Data Set 2 represents an intermediate set of files which were used to identify the best combination of hydraulic modeling options to be incorporated in IFG4 modeling runs. We assumed that the best combination of options would be that which most realistically predicted water surface elevations and velocities at transect sites for discharges ranging from 85 to 1,416 cms (3,000 to 50,000 cfs). This range of discharges represents the range of values in the LMCR from which calibration stage measurements were obtained.

Calibration Data Set 2 employed IFG4 input-output (IOC) settings which specified the use of a log-linear stage-discharge regression to predict water surface elevations for simulation discharges (Table B.l). The use

Table B. 1. IFG4 Input-Output settings employed in Calibration Data Set 2 for lower mainstem Cleat-water River.

OPTION	STATE	RESULT
1		
2	1	WSL and velocity calculation details printed in IFG4 output
	1	Calibration details printed in IFG4 output
3	0	Line printer graphics not printed (REV14 used instead for this purpose)
4	0	Additional line printer graphics not printed (REV14 used instead)
5	1	Stage-discharge relationship determined from discharges provided on CAL lines, and not from transect discharge calculations. Log-linear regression relationship used to predict stage for QARD discharges.
6	0	Option turned off; applies to multiple velocity calibration sets only
7	0	Use stage of zero flow provided in input deck
8	0	Turned off, since Option 5 = 1.
9	0	Option turned off; applies to multiple velocity calibration sets only
10	0	Option turned off; applies to multiple velocity calibration sets only
11	0	Adjust simulated velocities with velocity adjustment factor (VAF)
12	0	N (roughness) calculated for dry cells when not provided in input deck
13	1	Print VAF summary plot
	0	Option turned off; applies to multiple velocity calibration sets only
14/15	0	BMAX or BMIN not used to limit N (roughness) values
16	0	Roughness not adjusted according to depth
	0	TAPE4 written in HABTAT format
19	0	Option not implemented by NERC
20	01	Print CALQ table in IFG4 output
		Width multiplier not applied to transect verticals (river width < 1000 ft)
21	0	Option not yet implemented by NERC
22	0	IFG4 run aborted if velocity -discharge regression exponent exceeds 3.0
23	0	Option turned off; applies to multiple velocity calibration sets only

of this regression relationship is specified setting option 5 to 1, and option 8 to 0. Input-output options in this data set also specified for lengthy line printer output containing water surface elevation and velocity calculations, as well as other calibration details. output of velocity adjustment factor (VAF) plots and discharge calibration (CALQ) tables was specified in IOC settings.

Calculated roughness (N) values were not modified in this data set, since an initial review of calculated roughness values should precede the modification of these values. Roughness values should be modified when cell velocity predictions are unrealistically high or low. This frequently occurs along the edges of the channel, especially for transect verticals which are dry during calibration velocity measurements. Underestimation of channel margin velocities often results in a severe overestimation of velocities in the center of the channel.

Review of hydraulic geometry calculations in REV14 output, and velocity predictions in IFG4 output, indicated that data input errors had been corrected in Data Set 2. Notably, values for width, depth, hydraulic radius, and conveyance factor changed in a predictable manner over the full range of calibration discharges. More importantly, velocity predictions in IFG4 modeling runs were realistic over the entire range of calibration discharges. However, inspection of REV14 output did indicate unusually high edge roughness values for many transects at discharges exceeding the velocity calibration discharge of 323 cms (11,400 cfs).

Stage-discharge calibration details in IFG4 output revealed an important modeling problem. Specifically, the log-linear regression provided a relatively poor fit to the stage-discharge curve. Predicted discharge values from specified water surface elevations overestimated or underestimated discharges by as much as 25 percent from observed values. This relationship was also reviewed with a microcomputer statistics program, which also suggested a relatively poor fit of the regression log-linear model to observed stage-discharge data. A poor fit was indicated by unusually low regression R-square values. Stage-discharge regression plots produced by this statistics program disclosed that the log-linear model poorly estimated stage values at low and high discharges for some transects, and at intermediate discharges for other transects.

Data Set 3

Data Set 3 was the final calibration set used to model hydraulic conditions for Clearwater River study sites. The hydraulic modeling options applied to Data Set 3 were the same as Data Set 2 with two important exceptions. First, a linear interpolation method employing measured data was used instead of the default log-linear model to predict water surface elevations from simulation discharges. Second, roughness values were entered into the IFG4 data files on a cell by cell basis when appropriate to provide a more realistic estimate of channel velocities.

Water surface elevations were estimated for simulation discharges using a linear interpolation method based upon measured stage-discharge pairs. A computer program was written for this purpose, and was very similar to that used to predict partial discharges from total river discharges at islanded sites. The program first reads stage-discharge pairs measured at calibration discharges on the river. Discharges for which water surface elevations are required are then read from this same file. Water surface elevations are then calculated for specified discharges, and are based upon linear interpolation between measured stage-discharge pairs. Predicted water surface elevations are then written to an output file. This program employs the following linear interpolation formula:

WSL = STG1 + ((STG2 - STG1) * (QARD - Q1) / (Q2 - Q1))

Where:
- WSL = water surface elevation to be calculated
- QARD = simulation discharge provided on QARD line
- STG1 = stage measurement less than WSE
- Q1 = discharge corresponding to STG1
- STG2 = stage elevation greater than WSE
- Q2 = discharge corresponding to STG2

Water surface elevations provided from this program were then entered into Data Set 3 files using WSL lines. For each simulation discharge entered on a QARD line in IFG4 data files, a corresponding water surface elevation value was entered on a WSL line. QARD and WSL lines were added to each Data Set 3 file using the PHABSIM file modification program WSEI4D. Water surface elevations provided on WSL lines were used for hydraulic calculations by setting Option 5 to 0, and option 8 to 1 (Table B.2). This combination of options specifies the use of given water surface elevations, instead of those predicted from a log-linear stage-discharge regression, in all hydraulic calculations.

In its default setting, IFG4 carries the value of the last wetted cell in a transect over to all dry cells for simulation discharges exceeding the velocity calibration discharge. If the last wetted cell has a high value, unrealistically low velocity predictions will occur at channel margins. To provide a more realistic simulation of velocities at higher discharges, roughness values were entered into IFG4 data files for cells which were dry, or which had an unusually high or low calculated roughness value. The roughness value entered for a given cell was calculated by averaging the values calculated by IFG4 for the previous four wetted cells. For estimating roughness values for dry cells, we assumed that an average of channel roughness values provided a better simulation of channel

Table B.2. IFG4 Input-Output settings employed in Calibration Data Set 3 for lower mainstem Clearwater River.

OPTION	STATE	RESULT
1	1	WSL and velocity calculation details printed in IFG4 output
2	1	Calibration details printed in IFG4 output
3	0	Line printer graphics not printed (REV14 used instead for this purpose)
4	0	Additional line printer graphics not printed (REV14 used instead)
5	0	Log-linear regression relationship not used to predict stage for QARD discharges.
6	0	Option turned off; applies to multiple velocity calibration sets only
7	0	Use stage of zero flow provided in input deck
8	1	Use water surface elevations provided on WSL lines for each QARD discharge. Default log-linear stage-discharge regression calculations overridden.
9	0	Option turned off; applies to multiple velocity calibration sets only
10	0	Option turned off; applies to multiple velocity calibration sets only
11	0	Adjust simulated velocities with velocity adjustment factor (VAF)
12	2	N (roughness) supplied in IFG4 in data deck for certain cells on NS lines
13	1	Print VAF summary plot
14	0	Option turned off; applies to multiple velocity calibration sets only
15	0	BMAX or BMIN not used to limit N (roughness) values
16	0	Roughness not adjusted according to depth
17	0	TARE4 written in HABTAT format
18	0	Option not implemented by NERC
19	1	Print CALQ table in lFG4 output
20	0	Width multiplier not applied to transect verticals (river width < 1000 ft)
	0	Option not yet implemented by NERC
22	0	IFG4 run aborted if velocity -discharge regression exponent exceeds 3.0
23	0	Option turned off; applies to multiple velocity calibration sets only

margin velocities than that provided by a single wetted cell. This approach was substantiated by the observation that the last wetted cell usually had a relatively low velocity, and corresponding high roughness value, compared to adjacent wetted cells. Entered roughness values were used in hydraulic calculations by setting input-output option 12 to 2 (Table B.2).

Production Data Set

Production IFG4 data files were created by modifying Calibration Data Set 3. Simulation discharges ranging from 85 to 1,416 cms (3,000 to 50,000 cfs) were entered on QARD lines in IFG4 data files for single channel reaches. From 3,000 cfs to 10,000 cfs, simulations discharges were entered in increments of 1,000 cfs. For discharges exceeding 10,000 cfs, simulations discharges were entered in increments of 2,000 cfs. A smaller increment was used for lower discharges to better define the hydraulic response of study transects to low flow conditions. For side channel data files developed for islanded sites, partial discharges were entered on QARD lines instead of total river discharges.

The same hydraulic modeling options used in Data Set 3 were applied to the Production Data Set. However, options providing for output of length calibration details were turned off in the production run. Input-output options employed in final production IFG4 runs are listed in Table B.3. As with Data Set 3, water surface elevations for simulation discharges were estimated with a linear interpolation method. Water surface elevations were entered on WSL lines of IFG4 data files.

Transect and Reach Weighting

Transect reach length and weighting values employed in production data files were based upon a combination of several methods, but fundamentally followed the "habitat mapping" method (Bovee 1986). The habitat mapping method is based upon first identifying habitat types (i.e. riffles, runs, pools) within a given river or stream segment, and then measuring the length or area of river provided by each habitat type within the segment. The latter is usually accomplished by measuring habitat lengths with a map wheel, or habitat areas with a planimeter from aerial photographs. Aerial photographs of the LMCR (scale 1:10,000) were acquired for this purpose. The lengths or areas measured were then summed to determine the proportion of stream or river provided by each habitat type. Resulting habitat type proportion values were then assigned to transects in IFG4 data files representing the same habitat type. IFG4 data files require two input parameters which are used to calculate the weighting assigned to each transect: downstream length and upstream weighting. With the habitat mapping method, all transects are assigned an upstream weighting value of 1. The downstream length assigned to each transect is based upon the proportion of habitat represented by the transect in the stream or river segment.

Table B.3. IFG4 Input-Output settings employed in Production Data Set for lower mainstem Clear-water River.

OPTION	STATE	RESULT
1	0	WSL and velocity calculation details not printed in IFG4 output
2	0	Calibration details not printed in IFG4 output
3	0	Line printer graphics not printed (REV14 used instead for this purpose)
4	0	Additional line printer graphics not printed (REVI4 used instead)
5	0	Log-linear regression relationship not used to predict stage for QARD discharges.
6	0	Option turned off; applies to multiple velocity calibration sets only
7	0	Use stage of zero flow provided in input deck
8	1	Use water surface elevations provided on WSL lines for each QARD discharge. Default log-linear stage-discharge regression calculations overridden.
9	0	Option turned off; applies to multiple velocity calibration sets only
	0	Option turned off; applies to multiple velocity calibration sets only
10/11	0	Adjust simulated velocities with velocity adjustment factor (VAF)
12	2	N (roughness) supplied in IFG4 in data deck for certain cells on NS lines
13	0	VAF summary plot not printed
14	0	Option turned off; applies to multiple velocity calibration sets only
15	0	BMAX or BMIN not used to limit N (roughness) values
16	0	Roughness not adjusted according to depth
	0	TAPE4 written in HABTAT format
17/18	0	Option not implemented by NERC
19	0	CALQ table not printed in IFG4 output
20	0	Width multiplier not applied to transect verticals (river width c 1000 ft)
	0	Option not yet implemented by NERC
21/22	0	IFG4 run aborted if velocity -discharge regression exponent exceeds 3.0
23	0	Option turned off; applies to multiple velocity calibration sets only

The length value assigned to the transect is based upon a total segment length which has been scaled by convention to 1,000 ft. For example, if riffles account for 33 percent of the habitat in a segment, than a single transect crossing a riffle would be assigned a length of 333 ft (i.e. 33 percent of 1,000 ft). If more than one transect represents a given habitat type, then the total length assigned to the habitat type is divided equally among the transects (e.g. three riffle transects in this example would each be assigned a value of 111 ft to total 333 ft).

The habitat mapping approach was originally developed to more accurately represent the habitat of an entire stream or river segment (Morhardt 1983). However, this approach becomes much more complex when applied to multiple channel situations. The habitat mapping approach works well in single channel situations because all transects in a segment can be included in the same IFG4 data file. The habitat mapping approach cannot be directly applied to multiple channel situations (Bovee 1986). This is a consequence of transect weighting values which cannot be held in correct proportion to one another when multiple channel conditions require the use of two or more IFG4 data files in a segment.

In order to apply the habitat mapping approach to multiple channel situations, we developed a stratified mapping procedure which involved two levels of habitat delineation. The first level of mapping applied to individual channels within a multiple channel complex. Each channel was essentially regarded as an entire stream or segment in this situation: transects located within each channel were assigned length values based upon the proportion of habitat types measured only within that channel. This level of habitat mapping was used to determine transect weighting values within islanded channels in the Potlatch and Bedrock study sites (Table B.4). This procedure resulted in the development of a separate habitat mapped IFG4 hydraulic model input file for each channel located within these study sites. A conventional habitat mapping procedure was applied to the Big Canyon site because it possessed a single channel.

The second level of habitat mapping determined the proportion of habitat represented by each channel within the entire IFIM site. The area of each channel in the Potlatch and Bedrock sites was first measured with a planimeter to determine the proportion of habitat provided by the channel within the respective site. Channel weighting factors were then calculated by dividing the area of each channel by the total area provided by the IFIM study site. Resulting channel weighting factors for the Potlatch and Bedrock sites (Table B.5) were not used until habitat simulation modeling had been completed. Habitat weighted usable area (WUA) values obtained from habitat simulation model runs for each channel were multiplied by these channel weighting factors. This procedure resulted in habitat values which were correctly weighted by the proportion of habitat provided by each channel within a multiple channel IFIM study site. Site habitat values were finally calculated by adding the weighted habitat values obtained from all channels within the site.

Table 8.4. Transect weightings for islanded reaches of lower mainstem Cleat-water River study sites based on the habitat mapping approach.

Reach	Transect	Area (sq in)	Weight	Assigned Length (ft)
LPMC	1	0.50	0.500	500
		0.50	0.500	500
	TOT A::	1 .00	1 .000	1,000
LPRC1	15	1.69	0.690	690
	16	0.76	0.310	310
	TOTAL	2.45	1 .000	1.000
LPCC1	2	0.69	0.408	408
	3	1 .00	0.592	592
	TOTAL	1.69	1 .000	1,000
LPCC2	4	0.33	0.333	333
	5	0.33	0.333	333
	6	0.33	0.333	333
	TOTAL	0.99	1 .000	1,000
LPCC3	7	1 .00	1 .000	1,000
LPRC2	12	0.42	0.365	365
		0.73	0.635	635
	TOT::	1.15	1 .000	1,000
LPLC	10	0.61	0.370	370
	11	1.04	0.630	630
	TOTAL	1.65	1 .000	1,000
UPMC	1	1.40	0.386	386
	3	2.23	0.614	614
	TOTAL	3.63	1 .000	1,000
UPRC	4	1 .00	1 .00	1,000
UPLC	2	1.00	1.00	1,000
BRMC	2	18.08	0.815	815
	3	2.24	0.101	101
	7	1.87	0.084	84
	TOTAL	22.19	1 .000	1,000
BRRC	4	1.55	0.245	245
	5	1.55	0.245	245
	6	3.23	0.510	510
	TOTAL	6.33	1 .000	1,000
BRLC	8	1.60	0.620	620
	9	0.98	0.380	380
	TOTAL	2.58	1 .000	1,000

APPENDIX B (continued)

Table B.5. Weighted usable area curve weighting values applied to islanded sites on the lower mainstem Clearwater River.

Potlatch Site weightings

Reach	Area (sq in)	WUA Curve Area Wt
LPMC	23.15	0.57
LPCC1	1.71	0.04
LPCC2	1.84	0.05
LPCC3	1.66	0.04
LPRC1	2.46	0.06
LPRC2	2.10	0.05
LPLC	1.90	0.05
UPMC	3.63	0.09
UPRC	0.85	0.02
UPLC	1.38	0.03
Total	40.68	1.00

Bedrock Site weightings

Reach	Area (sq in)	WUA Curve Area Wt
BRMC	22.19	0.67
BRRC	6.90	0.21
BRLC	4.13	0.12
Total	33.22	1.00

APPENDIX C

SUITABILITY CURVE DEVELOPMENT

Utilization curves were first calculated from fish microhabitat measurements obtained from the LMCR, Wenatchee River, and South Fork Salmon River. Utilization curves were developed using the histogram approach (Bovee 1986; Slauson 1988). With this approach, microhabitat measurements are used to construct frequency distributions of microhabitat suitability. Observations are combined into intervals or "bins" having increasing value. The bin width used in histogram construction can have an important effect on the shape of the resulting utilization curve (Bovee 1986; Slauson 1988; Cheslak and Garcia 1988). A too narrow bin width can result in an erratic or "noisy" curve which is hard to define and has multiple peaks and troughs, while a too broad bin width can result in a over-homogenized curve which portrays a broad, unrealistic response of fish to a given microhabitat variable.

The effect of varying bin widths for each microhabitat variable on every species was evaluated using a frequency distribution computer program. To eliminate bias in bin width selection, Sturges Rule (Sturges 1926 cited in Cheslak and Garcia 1988) was used to determine proper bin widths for histogram construction. Sturges Rule consists of a relatively simple equation which defines the optimal bin width (class interval) by range of a given variable, and by the number of observations made for that variable. Optimal bin widths of 15 cm/sec (0.5 ft/sec) were employed for velocity. Bin widths between 15 and 30 cm (0.5 and 1.0 ft) were used for depth, depending upon the life stage.

To develop preference curves from utilization curves developed by this study, availability curves were calculated for the LMCR, Wenatchee River, and South Fork Salmon River. Availability curves on all three rivers were 'constructed using a habitat mapping approach (Bovee 1986), which was based upon transect measurements of habitat availability. With the habitat mapping approach, each transect is assigned a weighting factor which is defined by the proportion of habitat types (e.g. riffles, runs, pools) mapped out in the river using aerial photographs, ground surveys, or other methods. Weighting factors for transects on the Clearwater and Wenatchee Rivers were obtained from 1:10,000 scale aerial photographs, while those for the South Fork Salmon River were obtained from ground measurements. For the Clearwater River availability data, only transects located within or adjacent to observation reaches were used. All Wenatchee River and South Fork Salmon River transects were used to provide availability data since all were located within the observation reaches of these rivers.

The hydraulic simulation program IFG4 was used to simulate the velocities and depth availability data on the Clearwater and Wenatchee Rivers. It was not possible to conduct both utilization and availability measurements in these rivers at the same time because of logistical constraints. Simulation discharges used in IFG4 simulations corresponded to river discharges under which microhabitat observations were obtained in the Clearwater and Wenatchee Rivers. Predicted velocities, depths, and substrate values generated by IFG4 model runs were imported into a statistical package for development of availability frequency histograms. Transect measurements for the South Fork Salmon River were imported directly into the statistical package, since utilization data on this river were obtained at the same time as availability data.

Depth, velocity, and substrate frequency histograms were defined using optimal bin widths selected during utilization curve construction. These frequency distributions were generated on an individual transect basis. Transect frequency distributions for each variable were then entered into a microcomputer spreadsheet program. This program was then used to combine the transect frequency distributions according to weighting factors defined for the transects by the habitat mapping procedure. Resulting spreadsheet calculations provided a total availability curve for each river.

Utilization and availability curves were finally used to construct preference curves for target species and life stages. Velocity, depth, and substrate preference curves were calculated using the following relationship (Bovee 1986):

$$P_i = U_i / A_i$$

where: P_i = unnormalized index of preference at x_i,
U_i = relative frequency of fish observations at x_i
A_i = relative frequency of x_i availability during the observation period
x_i = the interval of the variable (x).

Resulting preference curves were then smoothed using a 3-point running mean technique to reduce random error associated with utilization and availability measurements (Cheslak and Garcia 1988). This technique was preferred over other methods since it did not "force" the data to assume a theoretical distribution or non-linear function. Running mean calculations were not applied to the lower end of preference curves, since this tended to unrealistically extend these curves. Following smoothing, preference curves were scaled from 0 to 1 by dividing each value of the curve by the maximum observed value (Bovee 1986).

Composite preference curves were developed for both chinook salmon spawners and juveniles. Composite curves were constructed by combining preference curves produced from this study with selected preference curves obtained from the literature. This was done for two reasons. First, chinook spawning curves developed in this study were collected on rivers other than the LMCR for reasons mentioned earlier. Curves developed on the Wenatchee and South Fork Salmon Rivers, however well obtained, were not acquired under the range of velocity, substrate, and depth conditions existing in the LMCR. Second, chinook salmon juvenile preference curves for the LMCR were developed from a relatively small number of observations (65). Because of a limited number of observations due to underseeding of fish in the river, it was concluded that the chinook juvenile curves did not realistically portray the full range of environmental conditions which the fish potentially use. In order to broaden the chinook salmon spawning preference curves into "big river" curves more appropriate for use on the LMCR, literature curve values were reviewed to find those suitable for extending the curves developed in this study. Spawning preference curves from the Wenatchee and South Fork Salmon Rivers were combined with Type III fall chinook salmon curves developed by Hampton (1988) on the Trinity River, California. Although Hampton's curves were obtained on a much smaller river than the Clearwater River, curves obtained from the relatively large fish measured during this study were broad, especially for substrate use. Because of this, they were concluded to be very applicable to large river situations. Comparable preference measurements for large rivers were not found in our search of published literature. Composite curves were developed by using the maximum suitability value from the Wenatchee, South Fork Salmon, and Trinity River curves for each interval of a given variable.

Studies of spawning by Chambers et al. (1955) and Swan (1989) in the Columbia River, Washington indicated that fall chinook salmon could spawn at depths considerably deeper (> 15 m) than indicated by preference curves we developed, or for that matter any curves in the literature. For this reason, we extended the depth preference curves for spawning chinook salmon to reflect known spawning of these fish in deep water.

Suitability curves for adult chinook salmon holding habitat were also identified as necessary for the LMCR instream flow study. Holding habitat is important to both adult chinook salmon and steelhead trout because both species migrate into the LMCR and hold in deeper waters for several months before spawning. Given that holding habitat is so important, it is unfortunate that relatively little information exists with respect to holding or staging habitat requirements. Two studies were identified which have resulted in suitability curves for chinook salmon holding: summer chinook salmon holding curves obtained by Burger et al. (1982) on the Kenai River, Alaska; and spring chinook salmon holding curves obtained by Wampler (1986) on the Wind River, Washington. Holding criteria produced in both studies were in the form of utilization (Type II) curves. Curves from both studies were combined into a composite set of curves before being applied to the LMCR. We decided to modify the Wind River curves (Wampler 1986) curves using a running mean smoothing technique prior to combining them with Kenai River curves (Burger et al. 1982) because they seem to have been developed using a too narrow bin width and consequently had an erratic frequency distribution.

Holding criteria were not identified from any published source for adult steelhead trout. We decided to apply the holding curves developed for chinook salmon for this purpose, as steelhead and chinook salmon are known to generally seek out the same types of holding habitat conditions (i.e. deeper runs and pools) in the LMCR.

APPENDIX D

HABITAT MODELING PROCEDURE

HABTAT models fish habitat quantity by calculating the wetted area of river provided by a specified discharge. Wetted area information is provided to HABTAT by a hydraulic simulation model such as IFG4. More specifically, HABTAT evaluates instream flow transect data at a number of cells, with cell area defined in terms of width by transect verticals, length by transect reach length, and weighting criteria provided in the hydraulic model input data file. To define habitat quality, HABTAT evaluates each cell according to microhabitat suitability criteria.

Mean column velocities are most commonly used in habitat simulation modeling, and were used for the majority of habitat simulation conducted with HABTAT for the LMCR. There are several reasons for this, but the most important is that most hydraulic simulation models (including IFG4) only predict mean column velocities (Milhous et al. 1989). Consequently, most published suitability criteria for velocity are in the form of mean column velocity. Certain species or life stages of fish, however, are consistently located at a certain position in the water column. One obvious example is spawning salmon, which are typically located about 15 cm above the bottom of the streambed. Mean column velocities can be used in some cases to model habitat of fish which consistently select a certain position in the water column, but only when the velocity conditions which fish prefer are highly correlated to mean column velocities.

Several problems can occur when mean column velocity suitability curves are obtained from one stream and applied to another. One problem results from using mean column velocities from a relatively shallow river and applying them to a deeper river. This problem is a result of bottom velocities decreasing with respect to mean column velocities in deeper water, a condition typical of most rivers. Consequently, suitability measurements of mean column velocities for spawning salmon obtained from shallow rivers tend to underestimate spawning habitat suitable in deeper rivers. This is because bottom velocities in a deeper river are lower than that of a shallow river for the same mean column velocity values. This was the case for the LMCR, as habitat suitability data for spawning chinook salmon was obtained from the Wenatchee and South Fork Salmon Rivers (Chapter 9). Both of these rivers were considerably shallower than the LMCR.

Given this situation, it was preferable to use bottom velocity criteria (i.e. "nose velocities") rather than mean column velocity criteria when modeling spawning habitat on the LMCR. HABTAT is capable of calculating bottom or "nose" velocities from the mean column velocities acquired from the habitat simulation model. A logarithmic velocity distribution equation was used in HABTAT model runs of chinook salmon spawning habitat for the LMCR. This equation predicts velocities at a given position in the water column based upon mean column velocity, depth, and the D65 (65th percentile diameter) of the bed material (Milhous et al. 1989). Use of this procedure in conjunction with nose velocity utilization curves rather than mean column velocity curves resulted in more realistic simulations of chinook salmon spawning habitat for the LMCR.

This problem did not pertain to curves developed for chinook salmon juveniles and rainbow/steelhead trout juveniles and fry, since suitability criteria for these fish were obtained from utilization measurements in the LMCR. Mean column velocity criteria were consequently applied to these species and life stages in habitat simulation modeling.

HABTAT calculates habitat quality on a cell by cell basis through the use of a joint suitability function (Bovee 1982; Milhous et al. 1984). This function is defined by:

$$SI = S_v \times S_d \times S_{ci}$$

where: SI = suitability index
S_v = velocity suitability
S_d = depth suitability
S_{ci} = channel index (i.e. substrate, cover)

Because all microhabitat suitability criteria are scaled from 0 to 1, resulting joint suitability index values also range from 0 to 1. HABTAT combines habitat quantity and quality though the concept of weighted usable area (WUA). WUA is calculated by the following relationship:

$$WUA = \Sigma\ C_i \times SI_i$$

where: C_i = wetted area provided the ith cell
SI_i = joint suitability index ith cell.

WUA is typically expressed in units of sq-ft of habitat per 1,000 ft of river, and is the primary output of PHABSIM habitat models, including HABTAT (Milhous et al. 1989). WUA values are typically calculated to site or representative reach basis for a range of discharge conditions. Results of HABTAT habitat simulations model are usually presented in the form of a WUA versus discharge curve.

WUA versus discharge relationships were calculated by HABTAT for the Potlatch, Bedrock, and Big Canyon study sites. Input files to HABTAT simulation runs included the hydraulic simulation data from the 14 IFG4 model files developed for the LMCR, and preference curve files developed for several life stages of chinook salmon and rainbow/ steelhead trout. A total of 14 WUA versus discharge relationships were produced for the LMCR: 10 for the Potlatch site, 3 for the Bedrock Site, and 1 for the Big Canyon Site. As mentioned earlier in this report, a number of WUA versus discharge files were required for the Potlatch and Bedrock sites because of multiple channels located within these sites. The WUA values at each of these sites were combined using a computer spreadsheet to produce a single WUA versus discharge relationship for each site. These composite WUA values were calculated from the weighted sum of channel WUA values for each site. Weighting factors developed for this purpose are described in the Appendix B.

While WUA provides a combined value of habitat quantity and quality for a given study site or reach, aquatic habitat using PHABSIM is ultimately expressed in terms of habitat area (HA). HA describes the total habitat available provided in a river segment at a given discharge. HA is the product of weighted usable area per unit length of river for a study site and the total length of the river or river segment represented by the study site (Bovee 1982). HA can be expressed by the following relationship:

HA = WUA x L

where: HA = total segment habitat area (e.g. hectares)
WUA = site weighted usable area (sq-ft per 1000 ft)
L = length of river or river segment (e.g. km)

Comparison of HA values is preferable to that of WUA values, since river segments usually have unequal lengths. Consequently, some segments can potentially provide far more habitat than others from modeled flows.

HA values can be further refined by multiplying them by macrohabitat preference factors which apply to the entire river segment (Bovee 1982). Macrohabitat preference factors include water temperature and other water quality variables which can reduce or eliminate the habitat provided by a given river discharge. Water temperature was identified as a potentially important flow related macrohabitat factor influencing the habitat quality of salmon and trout on the LMCR. Relatively high water temperatures (> 20 °C) were observed on the LMCR during hot summer conditions in 1989 and 1990. High water temperatures had a high negative correlation to discharge.

This relationship between discharge and maximum daily water temperatures of the LMCR was analyzed using a computer regression program from thermograph data collected at the U.S. Highway 95 Bridge (river km 16.7) and from discharge records obtained at the Spalding gage site (river km 18.7). Data collected from June 1 to September 30, 1989 was used for this purpose. This regression relationship (Figure D.l) was specifically defined for hot climatic conditions by limiting analysis to days in which average air temperatures exceeded 25 °C. The relationship between water temperature and discharge for these conditions had a very high significance level (< 0.0001) and a high goodness-of-fit value (R-square = 0.88).

The resulting water temperature versus flow relationship was used to define the temperature suitability of the LMCR under hot summer conditions. Development of a suitability relationship with discharge for fish habitat involved three steps. First, relationships between water temperature and flow in the LMCR was defined using the regression procedure. Second, water temperature suitability curves (Figure D.2) were obtained from published literature values for chinook salmon juveniles (Raleigh et al. 1986), and for rainbow trout fry and juveniles (Raleigh et al. 1984). Finally, suitability index values for discharge were developed by predicting a water temperature for a given discharge from the regression relationship, and then looking up the suitability index value for that temperature from the suitability curves. This procedure was developed for suitability index versus flow relationships for discharges ranging from 85 to 510 cms (3,000 to 18,000 cfs) (Table D.l). All discharges above 510 cms (18,000 cfs) had a temperature suitability index of 1.0.

The temperature suitability index values for each discharge were then multiplied by the habitat area (HA) values for each segment. This procedure resulted in the production of a set of summer month HA versus discharge relationships for chinook salmon juveniles, and rainbow/ steelhead trout juveniles and fry. These temperature modified HA versus discharge curves were applied to the

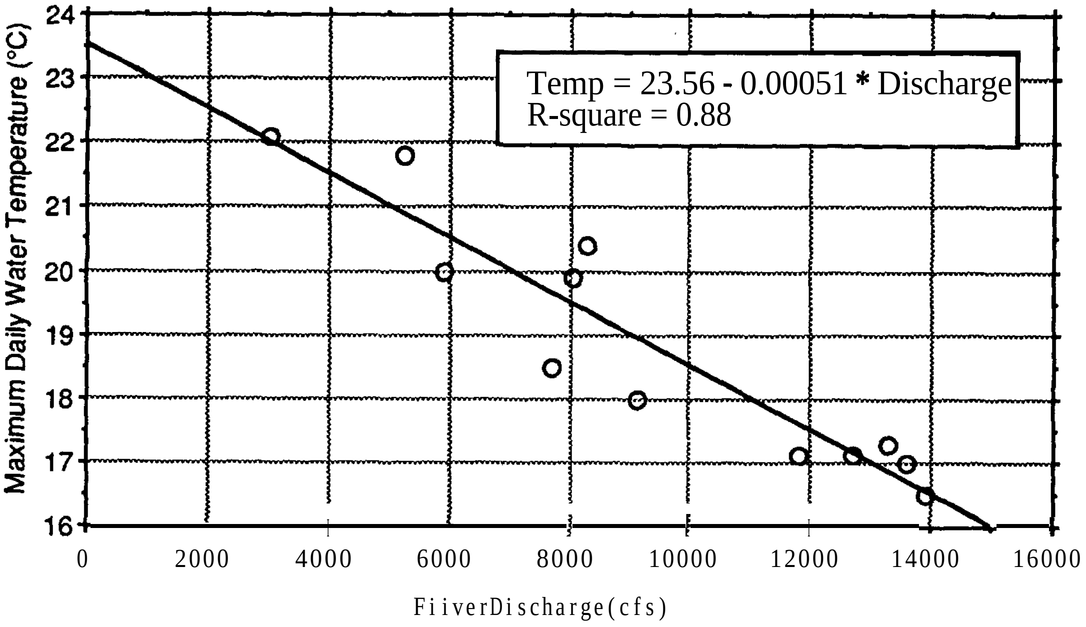


Figure D. 1. Maximum daily water temperature versus discharge regression for lower mainstem Cleat-water River: hot climatic conditions (average air temperature greater than 25 °C).

Table D.I. Temperature suitability index versus flow relationships developed for the lower mainstem Clearwater River for hot climatic conditions.

Discharge (cfs)	Discharge (cms)	Predicted Water Temp. (°C)	SUITABILITY INDEX Chinook Salmon Juveniles	Rainbow Trout Fry	Rainbow Trout Juveniles
3,000	85	21.6	0.38	0.60	0.73
4,000	113	21.1	0.43	0.67	0.78
5,000	142	20.7	0.47	0.73	0.82
6,000	170	20.3	0.51	0.80	0.87
7,000	198	19.8	0.55	0.87	0.91
8,000	227	19.4	0.60	0.93	0.98
9,000	255	19.0	0.66	1.00	1.00
10,000	283	18.5	0.70	1.00	1.00
11,000	312	18.1	0.74	1.00	1.00
12,000	340	17.7	0.79	1.00	1.00
13,000	368	17.2	0.83	1.00	1.00
14,000	396	16.8	0.87	1.00	1.00
15,000	425	16.4	0.94	1.00	1.00
16,000	453	16.0	0.98	1.00	1.00
17,000	481	15.5	1.00	1.00	1.00
18,000	510	15.1	1.00	1.00	1.00

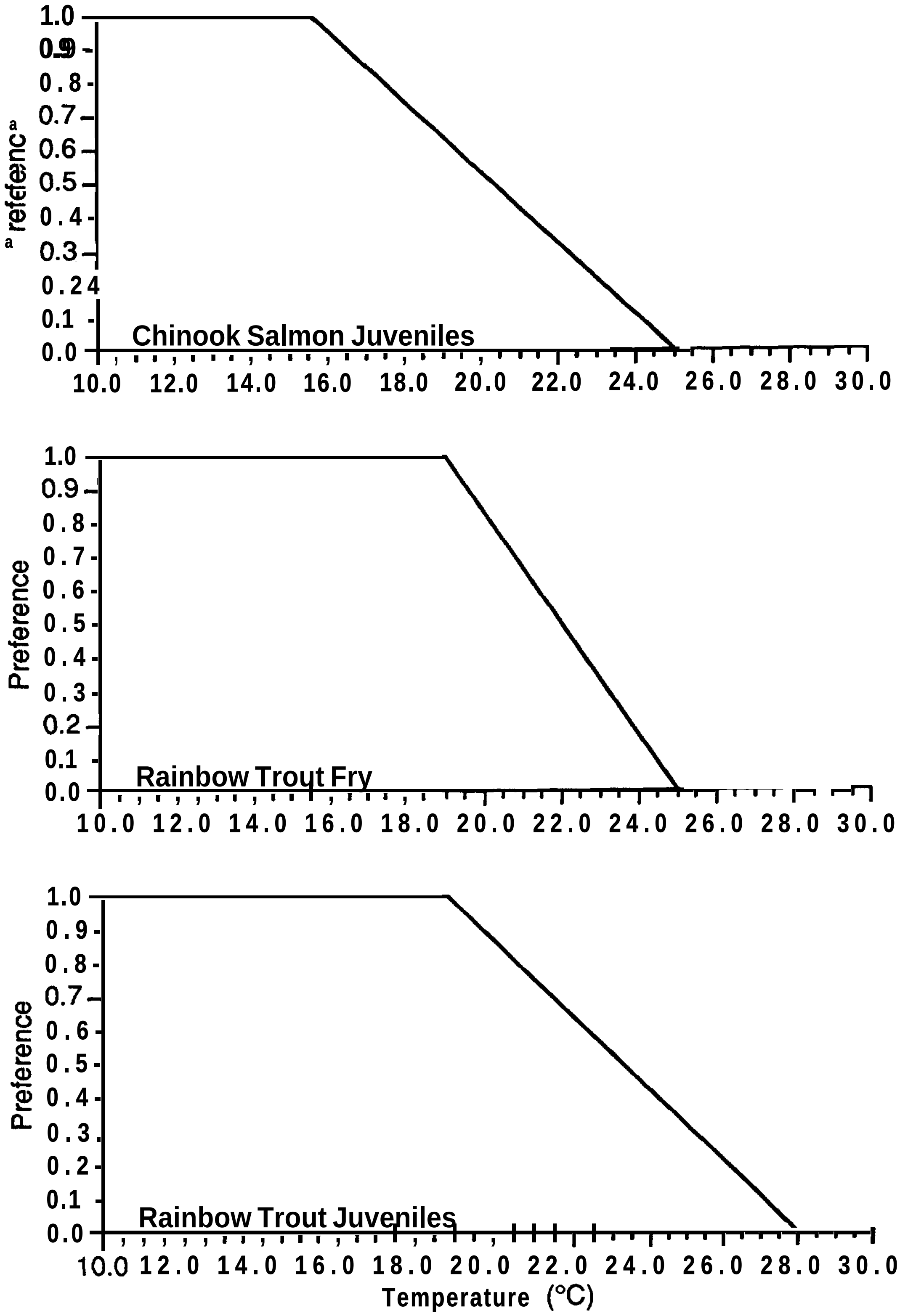


Figure D.2. **Temperature suitability criteria for chinook salmon juveniles, and rainbow trout fry and juveniles (Source: Raleigh et al. 1986).**

months of July and August when hot temperatures typically coincide with low flows on the LMCR. Although hot conditions do not typically occur during all days during these months, we decided to apply the temperature modified criteria to the entire month. This is because high water temperatures occurring for relatively short durations of time could behaviorally and physiologically affect fish for much longer periods of time.

APPENDIX E

RIVER TEMPERATURE MODELING PROCEDURE

SNTEMP is a network model which is able to integrate and predict water temperatures over a large number of tributary and mainstem reaches. A relatively simple network was employed on the lower mainstem Clear-water River (LMCR) (Figure E.l). The LMCR temperature model network consisted of a 6.4 km reach of the upper mainstem river above the North Fork confluence, a 0.8 km reach of the North Fork Clear-water River between Dworshak Reservoir and the mainstem river, and a 65.4 km reach of the LMCR located below the North Fork confluence. The upper end of the network is located at river km 71.8 at Orofino, Idaho, while the lower end of the network is located at the confluence of the mainstem river with the Snake River at Lewiston, Idaho (river km 0.0). The confluence of the upper mainstem Clearwater River and the North Fork Clearwater River was located at river km 65.4.

SNTEMP utilizes a node designation system which was used to describe the temperature model network (Figure E.l). The "headwater" (H) node, representing the starting point of the network was located in the upper mainstem river at the Orofino USGS gaging station. Temperature data for the upper mainstem river were obtained using a Ryan TempMentor recording thermograph at this location and discharge data obtained from the gaging station. Dworshak Reservoir is represented in this network as a "structural" (S) node located on the North Fork Clearwater River (NFCR). A recording thermograph was located approximately 2 km downstream from Dworshak Dam at Ahsahka Bridge and was used to provide stream temperature data for water released from the reservoir. Hydrology data for the NFCR were obtained from reservoir flow release records provided by the U.S. Army Corps of Engineers. The junction of the NFCR with the LMCR is represented by "tributary" (T), "branch" (B), and "junction" (J) nodes, which provide the discharge information required by SNTEMP for thermal mixing calculations. The "end" (E) node of the network is located at the LMCR confluence with the Snake River (river km 0.0).

Channel geometry and river discharge information was required to account for changes in channel shape and tributary inflow to the LMCR between Orofino and Lewiston. This information was provided to SNTEMP at stream geometry "change" nodes (C). The LMCR below Orofino was divided into three consecutive segments to coincide with the IFIM habitat model. The first segment, Big Canyon, begins at the J node located at the confluence of the NFCR with the LMCR and ends at the C node located at Bedrock Creek (Figure E.1). The

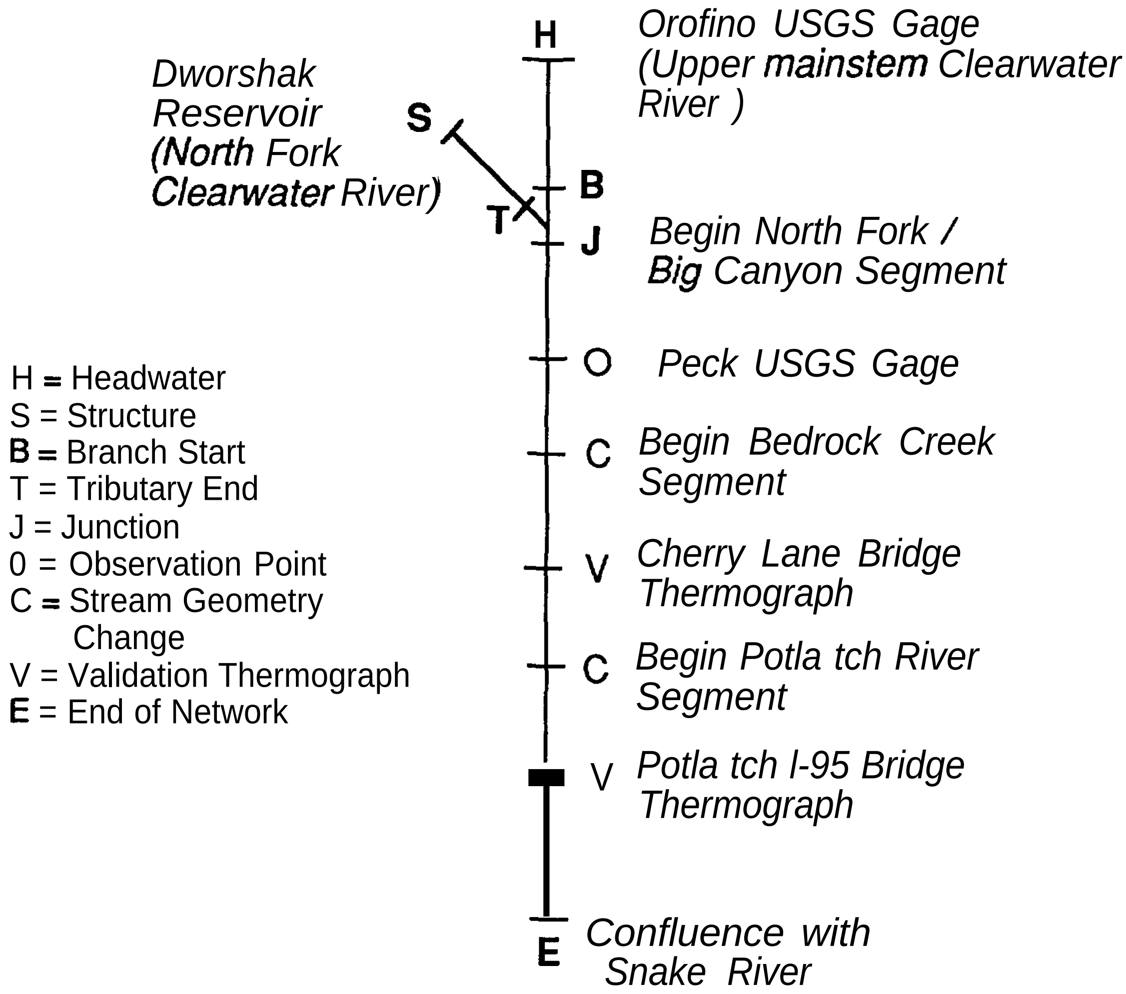


Figure E.1. Schematic diagram of stream temperature modeling network applied to LMCR.

second segment, Bedrock, extends from Bedrock Creek to the C node located at Potlatch River. The third segment, Potlatch, extends from Potlatch River to the LMCR confluence with the Snake River.

Segment designations were based upon differences in channel morphology, hydrology, and topography. Segment specific discharge, stream geometry, and topographic shade information is provided to the model at each C node. Discharge data for the Big Canyon Segment was obtained from the Peck gaging station (river km 60.2). Discharge data for the Potlatch Segment was obtained from the USGS Spalding gaging station (river km 18.7). Discharge for the Bedrock Segment (river km 33.3) was synthesized by a watershed area based interpolation of discharges observed at the Peck and Spalding gages.

Due to the lack of significant tributary inflow in the LMCR during the period modeled, additional tributary nodes or hydrology were not required. Tributary discharge was incorporated into the temperature model through lateral inflow calculations based on increases in discharge between the Peck and Spalding gages.

Thermographs placed at the Cherrylane Bridge (river km 33.3; Bedrock Segment) and the I-95 Bridge (river km 16.7; Potlatch Segment) served as "validation" (V) nodes since temperatures recorded at these locations were used for model validation purposes. SNTEMP validation nodes represent locations where predicted temperatures are compared to observed temperatures. In addition to validation node, an "observation" (0) node was located at the Peck gaging station. An observation node provides an additional location where water temperatures are to be predicted, but which is not used for validation purposes.

Time Period for Model

Temperature modeling was conducted for two time periods: summer (June to September) and early winter (November to December). The summer time period is of concern because of relatively high water temperatures which currently occur during hot climatic conditions. Average daily water temperatures in the LMCR can exceed 20 °C during the summer which is above the range of temperatures preferred by rearing salmonids (Connor 1989). Early winter water temperatures are also a concern because they affect development rates of incubating chinook salmon. Temperature modeling was conducted using a daily time step during both the summer and early winter periods. A daily time step was appropriate for the LMCR because the travel time of water from Dworshak Dam to Lewiston is less than a day. For travel times greater than one day, a longer time step would be more appropriate to use with SNTEMP (Bartholow 1989).

The 1989 water year was used as the basis for modeling temperatures on the LMCR since thermograph data was also collected during this time. We assumed in using this model that the range of water temperature, flow, and climatic conditions occurring during this time were adequate representatives of typical conditions.

Data Acquisition and Reduction

River distance, elevation, and latitude data were measured using 1:100,000 USGS quadrangle maps obtained for the LMCR (Orofino and Potlatch Quadrants). A map-wheel was employed for distance measurements. Benchmark river distance and elevation measurements for the Spalding, Peck, Orofino, and Dworshak Reservoir gaging stations were also obtained from published gaging records. These were used to provide accurate points of reference from which other measurements were based. Latitude measurements were converted from degrees to radians using the formula:

$$\text{radians} = \text{degrees} * \pi / 180$$

Distance and elevation data were converted to metric units. Resulting distance, elevation, and latitude data was used in SNTEMP input data files.

Hourly water temperature data for the NFCR below Dworshak Reservoir and the upper mainstem river at Orofino were obtained from Ryan Tempmentor thermographs. Hourly temperatures were converted into daily average temperatures for use with SNTEMP.

Daily average discharge data for 1988-89 water year were obtained from published USGS gaging data (USGS 1989) for the Orofino, Peck, and Spalding gaging stations. Flow release records for Dworshak Reservoir were obtained from the U.S. Army Corps of Engineers, Walla Walla District.

Meteorology variables used in the LMCR temperature model included air temperature, humidity, percent sunshine, and wind velocity. Air temperature is the most important meteorological input variable in SNTEMP (Bartholow 1989). Daily air temperature, humidity, percent sunshine, and wind velocity data for the time period modeled were acquired from values published by the National Climate Data Center (Athens, Georgia) for the nearest Local Climatic Data (LCD) station located at the municipal airport in Lewiston, Idaho. Hourly and meteorological data values were converted into average daily values for use with SNTEMP.

Stream geometry variables required by SNTEMP include channel width and Manning's N channel roughness coefficient. For temperature modeling purposes, channel width is expressed as a log-log regression relationship with discharge. Width-discharge relationships were obtained from IFIM transects located on the LMCR. Transect width measurements were weighted according to the habitat mapping approach, described in (Chapter 8), for each of six discharge calibration measurements obtained from IFIM transects. Widths and discharges were converted to metric units prior to regression analysis. Manning's N roughness coefficient was obtained from hydraulic simulation modeling conducted on the LMCR. An appropriate Manning's N value can be obtained from the channel "conveyance factor" provided at each transect by the hydraulic simulation model, but should not be confused with the cell roughness factors used to simulate the distribution of velocities for a cross-section.

Topographic data required for the shade model were obtained from the quadrangle maps used for distance, elevation, and latitude measurements. The measurements were confirmed from several field observations. Topographic variables required for the shade model include the azimuth of the river, and the slope of the terrain adjacent to each bank. Azimuth was measured with a protractor and then converted into radians. Terrain slope (i.e. altitude) adjacent to each bank was calculated by dividing elevation gain, measured from the river to the top of the terrain slope, by the distance from the river to the same point. The following formula can be used to convert terrain slope measurements into radians as required by SNTEMP:

$$\text{Slope (radians)} = \text{Arctangent } (\Delta \text{ elevation} / \text{distance})$$

Model Calibration

The LMCR temperature model was calibrated by comparing predicted and observed temperature values at the Cherrylane Bridge and I-95 Bridge thermograph sites. Model calibration was initially conducted by running uncalibrated data decks with SNTEMP and inspecting validation statistics provided in output files. Modeling error (i.e. the difference between predicted and observed temperatures) was evaluated on a daily basis for each of the time periods modeled to determine if the model was consistently under-predicting or over-predicting water temperatures.

Daily modeling errors were evaluated using a regression procedure. We used a regression computer program to determine whether daily errors in temperature were significantly correlated with discharge or any of the meteorological input variables. Initial screening of model results indicated that the largest modeling errors occurred during days of unsteady discharge on the LMCR, a consequence of hydropeaking operations at Dworshak Dam. Unsteady flow conditions were easy to identify from large differences in daily discharge values between the Spalding and Peck gaging stations. Because SNTEMP assumes steady flow conditions (Bartholow 1989), hydropeaking proved to be the most important source of error during model calibration. To insure proper calibration of the model, days of unsteady flow were removed from the input data files.

This correlation analysis indicated that two meteorological variables, air temperature and sky cover, were significantly correlated to temperature model errors. Sky cover was correlated with model error, having a high significance level (< 0.0001) and an R-square value of 0.23. Air temperature had a lower level of significance (< 0.01) and lower R-square value of 0.10. The correlation of both variables to model error suggested that differences in cloud cover and air temperature existed between the LMCR and the location of the nearest meteorological observation station in Lewiston. The differences could be related to topography, since the LMCR is located within a canyon area.

Global air temperature and sky cover calibration factors were subsequently used in the model to partially correct for this source of error. A global calibration factor is one that is applied to the entire network, while a local calibration factor is one that is applied to only a specified reach. SNTEMP calibration factors are applied using a linear regression procedure using the formula:

$$\hat{y} = a_0 + a_1 y$$

where: $\hat{y}$ = the modified input variable
Y = the original input variable
a_0 = the calibration constant
a_1 = the calibration coefficient

APPENDIX E (continued)

Appropriate calibration constants and coefficients were determined by an iterative process and were applied to a subset of days in the calibration data file. Model validation was achieved by observing the effects of these changes on remaining days. Final calibration of the LMCR SNTEMP model resulted in a mean error of 0.02 °C with a maximum daily error in the period modeled of 0.86 °C. Considering the length of river modeled, these values indicated that SNTEMP was very accurate in predicting temperatures on the LMCR over a wide range of discharge and meteorological conditions.

APPENDIX F

SPAWNING SUBSTRATE MOVEMENT ANALYSIS

Introduction

In order to properly assess the natural reproduction potential of chinook salmon in the lower mainstem Clearwater River (LMCR), it was necessary to determine if habitat conditions were suitable for both spawning and incubation. The suitability of spawning was evaluated using IFIM hydraulic and habitat modeling procedures (Chapter 11). Suitable incubation flows for fall chinook salmon were identified as those which were equal to or greater than those occurring during the November to mid-December spawning period (Chapter 13). We recognized that peak flows, which typically occur between April through June on the LMCR, could potentially result in the scour of salmon redds and the subsequent loss of incubating eggs and alevins. Our main concern was to identify if flows during the chinook salmon incubation period (December through May) were sufficiently high enough to result in the mobilization and scour of spawning substrate particles.

The initiation of bedload transport in natural streams requires the exceedance of a threshold flow intensity which lifts substrate particles from the streambed, and which transport these particles downstream (Richards 1982). This critical threshold flow is that which has the minimum intensity capable of initiating movement, and is measured in terms of shear stress, velocity, or stream power. The critical flows required to initiate particle movement varies due to differences in particle size, channel roughness, and velocities from location in the stream channel. They are also difficult to estimate due to variable grain exposure and instantaneous variations in velocity which result from the turbulent flow characteristic of natural stream channels (Richards 1982).

Although critical flow is hard to measure, it can be approximated using a number of different methods. Shields mean bed shear stress criterion is often used to identify the critical bed shear which results in the initiation and transport of bed particles. This criterion defines critical shear stress (τ_{oc}) as a function of particle size and bed roughness condition (Richard 1982). Shields criterion (θ_c) is a dimensionless critical shear stress which is calculated from the following relationship:

$$\theta_c = \tau_{oc} / (\rho_s - \rho_w)\, gD$$

where: τ_{oc} = critical shear stress
ρ_s = density of bed material
ρ_w = density of water
g = gravitational acceleration
D = Diameter of bed material (D_{65})

Critical shear stress (τ_{oc}) is defined as that threshold shear stress (τ_o) value which initiates particle movement. Shear stress is expressed as:

$$\tau_o = \rho_w g d s$$

where: τ_o = mean bed shear stress
d = depth of water
s = water surface slope

Values of θ_c corresponding to initiation of particle movement vary according to bed roughness, the particle composition of the streambed, and particle sorting and consolidation. Shields criterion values of 0.01 are recommended for substrate particles which are extremely loose, perched on top of the streambed, and easily moved (Richard 1982). Values approaching 0.3 are recommended for well-packed gravel substrates which are difficult to detach from the stream bed. Criterion values of 0.06 are applicable to hydrodynamically rough beds which have intermediate levels of substrate particle packing.

Methods

Shields criterion values were calculated from hydraulic information obtained from instream flow study transect verticals located across spawning-sized substrate (50-150 mm) at the Bedrock and Lower Potlatch study sites (Connor et al. 1990). Criterion values were calculated at each transect vertical for river discharges ranging from 85 to 1,416 cms (3,000 to 50,000 cfs). The depth (d) of each vertical were calculated by subtracting the bed elevation from the water surface elevation for each flow modeled. The same water surface slope (s) was applied to all verticals of a transect for every modeled flow, and was obtained from water surface elevation measurements obtained during our instream flow study. The 65th percentile substrate size (D_{65}) was determined from gravel composition measurements obtained from freeze-core samples. A D_{65} value of 75 mm was employed in all shear stress calculations. The substrate density value (ρ_s) used for these calculations (2.65 g/cm^{-3}) was appropriate for the granitic cobbles and gravels which dominate the LMCR.

Shields criterion values were separately evaluated for main channel and island channel transects at the Bedrock and Lower Potlatch study sites. Only transects located across large areas of substrate suitable for spawning were used in this analysis. For the Bedrock study site, transects 2 and 3 were used to calculate Shields criterion values for substrate in the main channel, while transect 4,5 and 9 were used to calculate values for substrate in island channels. For the Lower Potlatch Site, transect 1 and 8 were used to calculate Shields criterion values for substrate in the main channel, transects 2,3,4,5,and 6 were used to calculate criterion values for substrate in the center channel of the Lower Potlatch island complex, and transects 12, 13, 15, and 16 were used to calculate values in the right channel of this island complex. Transect locations were given in Connor et al. (1990).

Two separate threshold criterion values were used to identify flows which potentially move spawning substrate in the LMCR. A value of 0.03 was used to identify flows which would result in the movement of the extremely loose, perched substrate particles which characterize the surface of a recently excavated spawning redd. Movement of these particles might lead to the loss of some eggs and embryos. A value of 0.06 was used to identify flows which would move the more consolidated or compacted substrate characteristic of a older spawning redd. These flows would be expected to result in more substantial redd scour and subsequent egg and embryo wash-out.

In addition to Shields criterion, flow competence was used to identify threshold discharges which move spawning substrate in the LMCR. Flow competence is defined as the maximum particle size transported, and is used to describe that flow critical for initiation of bed material movement (Richards 1982). We determined flow competence from sediment transport data collected by the U.S. Geological Survey over a wide range of discharges at the Spalding gaging station (Jones and Seitz, 1980). Flow competence was determined by identifying the maximum particle size recorded in bedload samples collected by the USGS from 1972 to 1979. Bedload samples were collected from Helley-Smith type samplers during discharge events ranging from approximately 10,000 to well over 100,000 cfs at the Spalding gaging station. The Spalding gaging station is located immediately upstream from the Potlatch Study Site. Measurements of bedload movement obtained at this gaging site should be very appropriate for defining relationships of bedload movement versus discharge for main channel sections of the Potlatch site.

Results

Loose, perched substrate particles in main channel sections of the Potlatch site are predicted to begin movement at approximately 5,000 cfs (Figure F.l). Approximately 40% of substrate particles by area of these loose particles would begin moving at 16,000 cfs, while 90% of spawning substrate by area would begin moving at 37,000 cfs. Spawning substrate particles in the center channel of the Potlatch site island complex would begin moving sooner than in the main channel (Figure F.1), mainly a result of steeper water surface slopes and corresponding higher shear stress values in the center channel. Fifty percent of loose, perched substrate particles are predicted to begin moving at 11,000 cfs in the center channel spawning habitat. Loose, perched particles in the right island channel of the Potlatch site would not be as susceptible to movement compared to particles in the main channel and center channel of the Potlatch Site (Figure F.l). Only 13% of these substrate particles by area in the right channel would begin moving at flows of 11,000 cfs, and only 32 percent of these particles would begin moving at 47,000 cfs. The reduced potential for movement of substrate particles in the right channel result from the relatively low water surface gradient and depths at this location.

The more compacted and consolidated spawning substrate particles in the main channel and right channel of the Potlatch site are not predicted to move during any flows up to 47,000 cfs (Figure F.l). Particles having these characteristics are only expected to move in the center channel of the Potlatch site, reaching maximum potential for particle motion at 36,000 cfs. The potential for substrate particle movement would decline beyond this flow because of an increasing backwater affect from a hydraulic control located immediately downstream.

Loose, perched substrate particles would be expected to begin moving in main channel sections of the Bedrock site at approximately 17,000 cfs (Figure F.2). Approximately 70% of loose, perched particles at this location would be expected to begin moving at flows of 36,000 cfs. Movement of loose, perched particles in the island right channel of the Bedrock site would begin at approximately 5,000 cfs, but only 40% of particles are predicted to initiate movement at flows of 47,000 cfs (Figure F.2). The right channel has a lower potential for particle movement when compared to the main

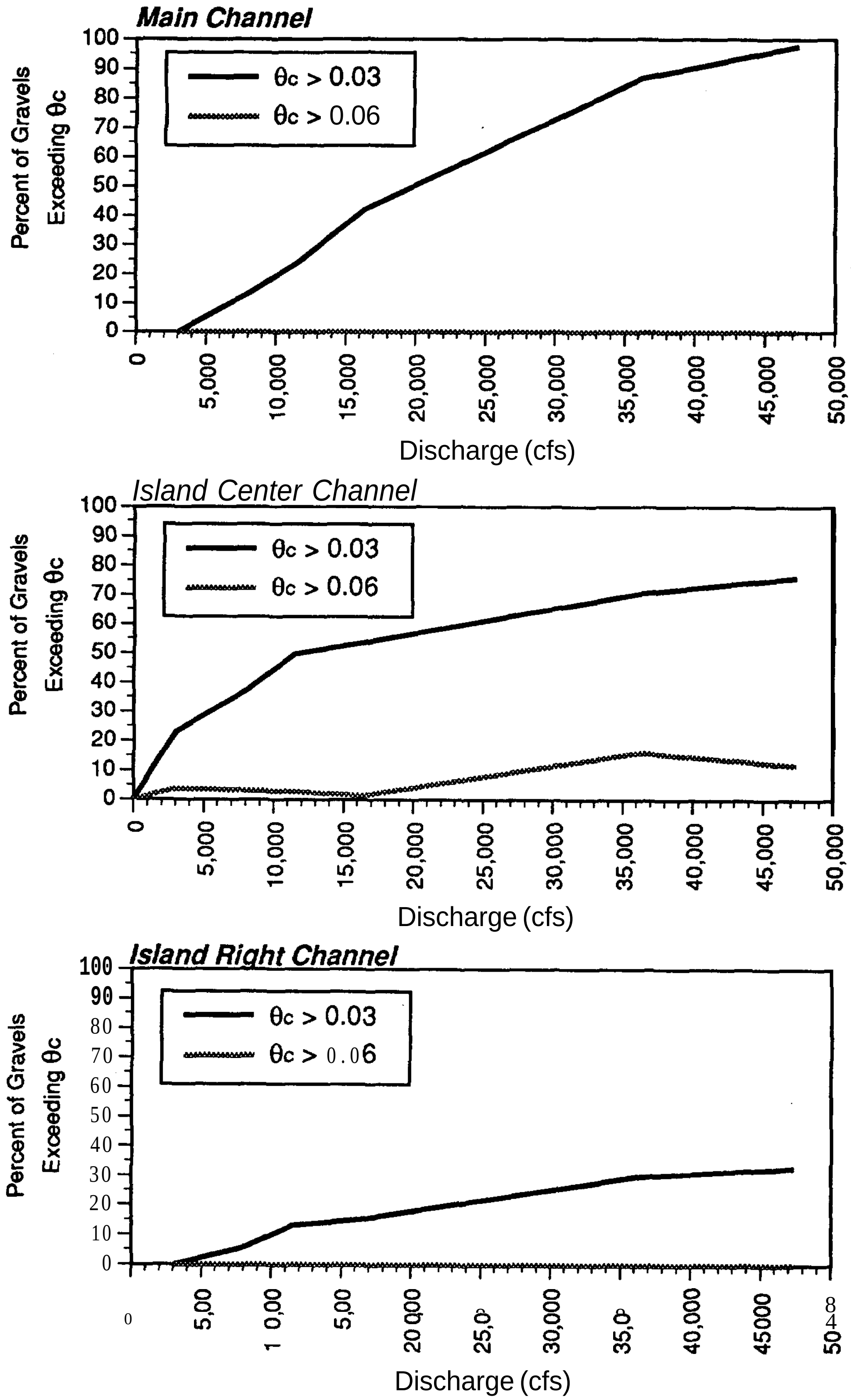


Figure F.l. Percent of spawning substrate by area at lower Potlatch site exceeding critical shear stress (θc) in relation to total river discharge.

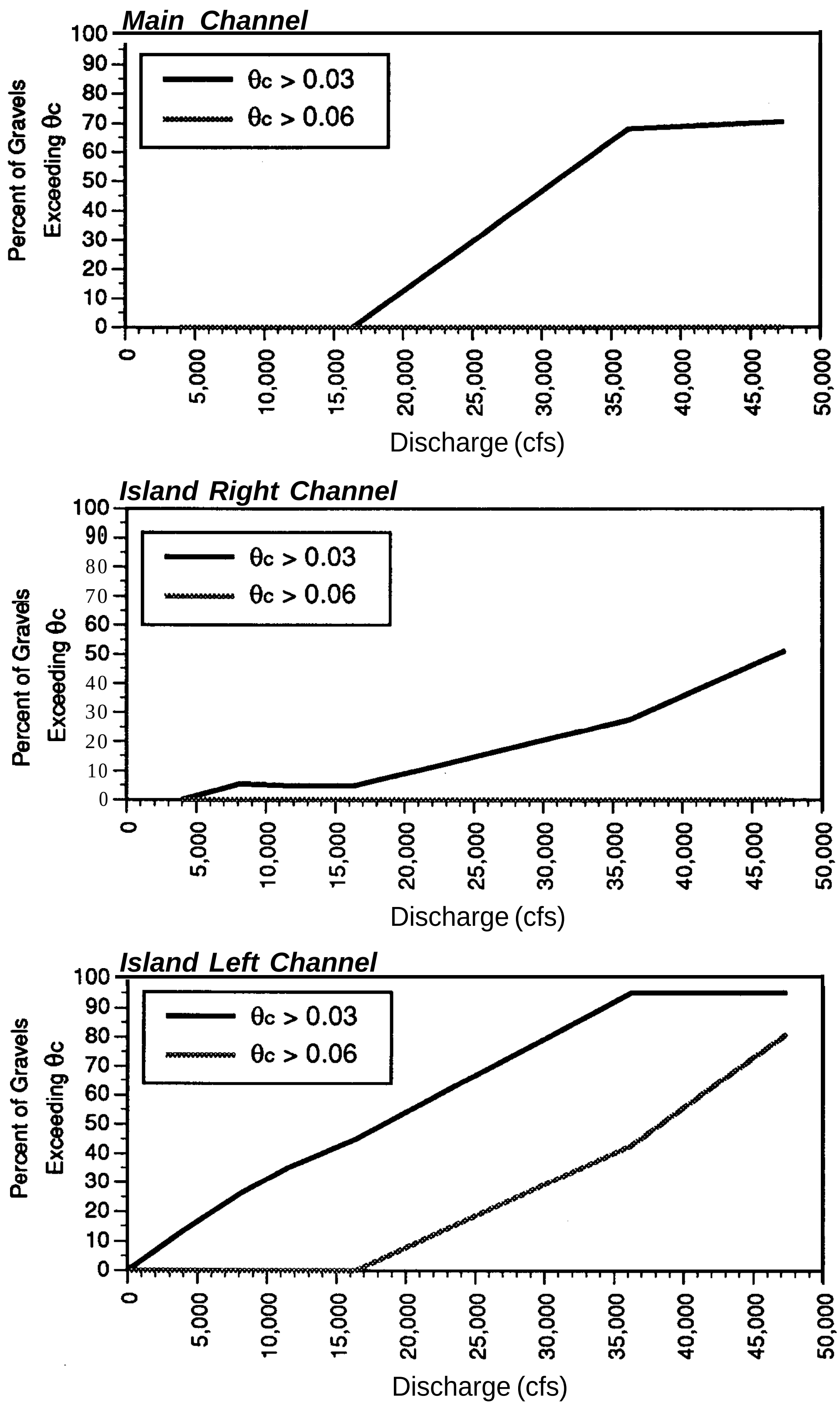


Figure F.2. Percent of spawning substrate by area at Bedrock site exceeding critical shear stress (θ_c) in relation to total river discharge.

channel because it has considerable reduced depths. Shear stress values increase proportionately with depth. The potential for movement of loose, perched particles is highest in the left island channel of the Bedrock site, a result of relatively high water surface slopes observed at this location. The spawning habitat at this location is characterized by relatively steep riffles, within which movement of loose perched particles is expected at low flow values (Figure F.2). About 95% of loose, perched particles would be expected to move at flows of 36,000 cfs **at** this location.

Movement of more compacted and deeper substrate particles is not predicted to occur during any of the flows modeled in the main channel and right island channel of the Bedrock Site (Figure F.2). However, initiation of movement of these particles are predicted in the left channel of this site at 16,000 cfs. Approximately 80% of these compacted particles would be expected to move at discharges of 47,000 cfs.

The relation between flow competency and discharge developed at the Spalding gaging site indicates that suitable fall chinook spawning substrate particles (50-150 mm) do not begin moving in the main channel of the river until flows of approximately 40,000 cfs are reached (Figure F.3). Variation in flow competency at discharge greater than 40,000 cfs are a likely result of changes in particle sorting and consolidation among bedload sampling dates.

Discussion

Analysis of critical shear stress values using Shields criterion indicates that loose, perched spawning substrate particles would begin moving at potential spawning sites in the LMCR at flows as low a 5,000 cfs. Potential movement of these particles would be greatest at islanded channels having relatively steep gradients, as indicated by criterion values calculated in the island center channel of the lower Potlatch Site, and the island left channel of the Bedrock Site. The potential for gravel movement would be lowest in islanded channels having low gradients and depths.

Movement of the more compacted, deeper substrate particles is not predicted by Shields criterion for flows less than 50,000 cfs, except in higher gradient islanded channels. Substrate movement and subsequent redd scour would substantially increase at river discharges of approximately 35,000 cfs. Analysis of flow competence at the Spalding gaging station indicates that spawning

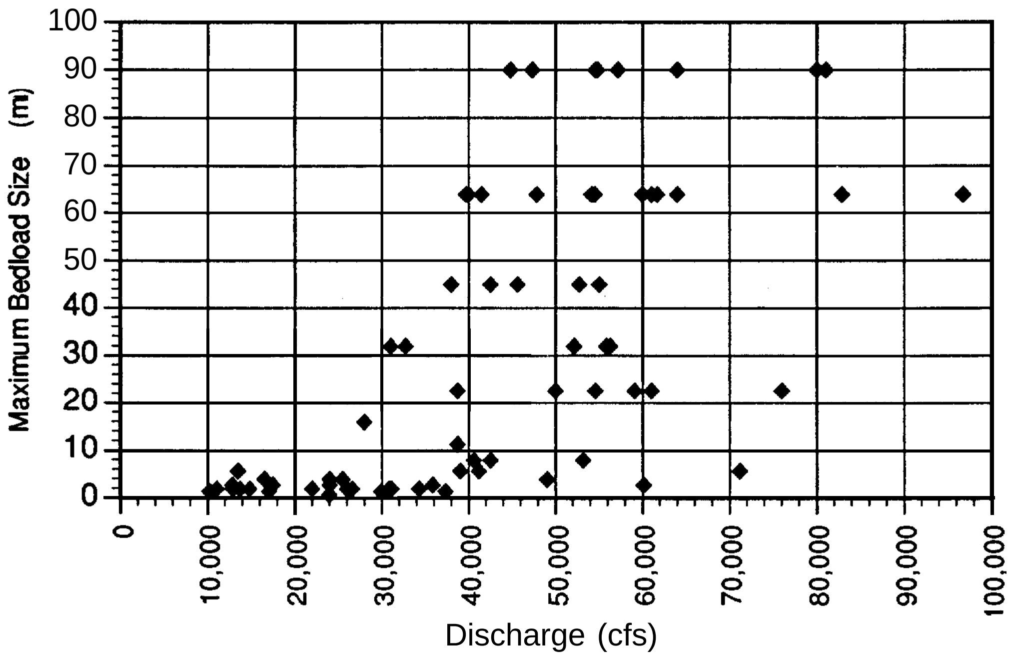


Figure F.3. Maximum size of bedload in tranport as a function of discharge; lower mainstem Cleat-water River at Spalding, Idaho (source: Jones and Seitz 1980).

substrate begins to move at approximately 40,000 cfs in the LMCR. Large gravels and small cobbles are effectively moved at flows observed from 40,000 to 100,000 cfs, with larger particles moved at higher flows.

With the exception of island channel locations having steeper gradients, the potential for redd scour in the LMCR would be extremely low for discharges less than 40,000 cfs. Shields criterion was not calculated for flows greater than 50,000 cfs because no hydraulic measurements were obtained at instream flow study transects for flows higher than this. However, evaluation of flow competence at the Spalding gage indicate that potential gravel scour would increase appreciably at discharges greater than 50,000 cfs. Flows of this magnitude do not typically occur except during the months of May and June in the LMCR (Chapter 10, Figure 10.23). Consequently, potential spawning redd scour would be likely to occur only during high flow events during these months.

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