Juvenile Salmonid Use of Lateral Stream Habitats Middle Green River, Washington 2000 Data Report

-FINAL-

Prepared for:

U.S. Army Corps of Engineers, Seattle District
4735 E. Marginal Way
Seattle, Washington 98124-2255

Prepared by:

R2 Resource Consultants, Inc.
15250 NE 95th St.
Redmond, Washington 98052-2518

July 19, 2001

Juvenile Salmonid Use of Lateral Stream Habitats Middle Green River, Washington 2000 Data Report

-FINAL-

Prepared for:

U.S. Army Corps of Engineers, Seattle District
4735 E. Marginal Way
Seattle, Washington 98124-2255

Prepared by:

Eric D. Jeanes
Phil J. Hilgert
R2 Resource Consultants, Inc.
15250 NE 95th St.
Redmond, Washington 98052-2518

July 19, 2001

1242.01

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The Green River, Washington, supports a wide array of fish species, each with a slightly different life history strategy. Populations of sockeye (*Oncorhynchus nerka*), coho (*O. kisutch*), chinook (*O. tshawytscha*), and chum (*O. keta*) salmon, cutthroat (*O. clarki*) and steelhead (*O. mykiss*) trout are present in the system in varying numbers; pink salmon (*O. gorbuscha*) are occasionally found, but not in large numbers. Historically, bull trout (*Salvelinus confluentus*) have been reported to occur in the Green River. Pacific (*Lampetra tridentatus*) and river *(L. ayresi*) lamprey are also present in the Green River, but little information is available on their present status.

The variety of juvenile rearing strategies expressed by Green River salmonids play a significant role in their response to changing environments. The construction of Howard Hanson Dam interrupted the natural hydrology of the Green River and changed fish habitat below the dam. Dams are often considered the key factor in the demise of many Pacific salmon stocks. Fish inhabiting the Green River today have survived in spite of hydrology and habitat changes. The Green River is one of the few rivers in the Greater Seattle Metropolitan Region that contain healthy populations of anadromous salmonids, albeit at lower levels of production than historically observed. Understanding the respective life history characteristics of Green River salmonids will help water managers identify and implement strategies to minimize the effects of flow changes on aquatic species.

This study was funded by the U.S. Army Corps of Engineers, Seattle District, and Tacoma Public Utilities, Tacoma, Washington. The objectives of this study were to: monitor the emergence of juvenile salmonids in the middle Green River; measure the growth of juvenile salmonids in lateral habitat; determine the relative abundance of middle Green River juvenile salmonids; and identify the species distribution of juvenile salmonids in relation to habitat type. The study effort in 2000 represents a continuation of a similar study conducted in 1998 and 1999. Juvenile salmonid use was monitored in 18 sites during the 2000 study period. The first survey period was conducted on 1 March 2000, while the final survey was completed on 25 July 2000. Lower Metzler, Blue House, Coho, and Rearing Pond side channels were surveyed during the daytime along with Metzler, O'Grady, and Rootwad gravel bar pools, and USGS, Pipeline, Visual and Big Dog mainstem margins. The remaining six sites (Flaming Geyser, Upper, Middle, and Lower O'Grady, Porter Inlet and Outlet, Slaughterhouse Levee, and Porter Levee) were surveyed at night. One survey site from the 1999 field season (Upper O'Grady Slough) was discontinued in 2000; six sites were added to the study in 2000 (USGS and Pipeline mainstem margins, Metzler and O'Grady pools, and Porter Inlet and Outlet restoration side channels).

A total of 5,189 salmonids were captured during 2000 day/night electrofishing surveys conducted during the 2000 field season. The majority of the juvenile salmonids were rainbow trout (35%), followed by coho (29%), chinook (22%) and chum salmon (13%). The remaining juvenile salmonids were composed of cutthroat trout (0.2%), mountain whitefish (0.1%), and pink and sockeye salmon (<0.05%). Capture rate of salmonids was greater during night surveys (CPUE = 0.08; 7 sites) when compared to day surveys (CPUE = 0.06; 7 sites) during the 2000 day/night electrofishing surveys. In addition to salmon, trout, and whitefish, 1,443 non-salmonids were captured. Non-salmonid species in order of decreasing capture frequency were: coastrange and mottled sculpin; Pacific lamprey; three-spine stickleback; longnose dace; largescale sucker; shorthead sculpin, redside shiner, and brook lamprey.

Catch of all juvenile salmon peaked in the middle Green River during the last week of April for night surveys (CPUE = 0.251) and during the first week of May for daytime surveys (CPUE = 0.127). The catch rate of rainbow trout fry (both day and night) peaked during the survey conducted on 11 July (night CPUE = 0.091; day CPUE = 0.083). Mean chinook salmon capture indices decreased steadily from the initial survey date (1 March) through early June. Chum fry capture indices peaked during the last week of April (night CPUE = 0.076; day CPUE = 0.021). Coho fry capture indices peaked during late April and again in late June. Capture of rainbow trout fry peaked during the survey conducted on 11 July (night CPUE = 0.084; day CPUE = 0.083). Overyearling salmon and trout capture indices peaked during the survey conducted on 28 March. The number of fish captured during middle Green River juvenile salmonid surveys conducted in 2000 increased from the 1999 field season. In 1999, mean CPUE for day/night electrofishing sites was 0.03 fish per second, while in 2000 the relative abundance of juvenile salmonids increased over 120 percent to 0.07 fish per second. These capture rates remained below those experienced in 1998 (CPUE = 0.13). The mean CPUE of juvenile salmon and trout for day electrofishing sites was lower when compared to night electrofishing sites; however, day and night CPUE was not significantly different within years or when all years were combined.

The information collected from this project will be utilized during the formulation of a flow management plan on the Green River. A thorough understanding of life history phases of juvenile salmonids and confirming or rejecting hypotheses of the long-term effects from changes in flow will be important during this process.

1. INTRODUCTION

The Green River, Washington, supports a wide array of fish species, each with a slightly different life history strategy. Populations of sockeye (*Oncorhynchus nerka*), coho (*O. kisutch*), chinook (*O. tshawytscha*), and chum (*O. keta*) salmon, cutthroat (*O. clarki*) and steelhead (*O. mykiss*) trout are present in the system in varying numbers; pink salmon (*O. gorbuscha*) are occasionally found, but not in large numbers. Historically, bull trout (*Salvelinus confluentus*) have been reported to occur in the Green River (Grette and Salo 1986). In the last 50 years, no juvenile bull trout have been reported in the Green River basin; however, solitary adults have been observed periodically in the lower river (E. Warner, Muckleshoot Tribe, pers. comm.). Pacific (*Lampetra tridentatus*) and river *(L. ayresi*) lamprey are also present in the Green River, but little information is available on their present status.

The general life history of Pacific salmon involves constructing nests (redds) in gravel beds for spawning, followed by migration to the ocean for feeding and maturation, and returning to natal sites for spawning and completion of their life cycle (i.e., anadromy) (Meehan and Bjornn 1991). The anadromous life cycle employed by many members of the subfamily Salmoninae appears to have originated while the fish resided in freshwater and allows them to benefit from favorable habitats of two quite different systems (Randall et al. 1987; Wilson 1997). There are many variations on the timing and duration of these life cycles both between species, and year to year for the same species. Each salmonid species present in the Green River has a different length and timing of freshwater residence (Figure 1). Understanding the respective life history characteristics of Green River salmonids will assist water managers to identify and implement strategies to minimize the effects of flow changes on aquatic species.

For example, fall chinook generally spawn during early September through November. Like other salmonids, the duration of incubation varies with location of redds, timing, egg size, and water temperature, but is generally completed by the end of February or early March (Weatherly and Gill 1995). Young chinook reside in stream gravels as alevins for three to six weeks after hatching (Wydoski and Whitney 1979; Beauchamp et al. 1983) before moving to lateral stream habitats (e.g., sloughs, side channels, and pools) for refugia and food during their migration downstream to the estuary. Fry emerge from gravels in late February through April, while downstream migration of newly-emerged fry peaks between 7

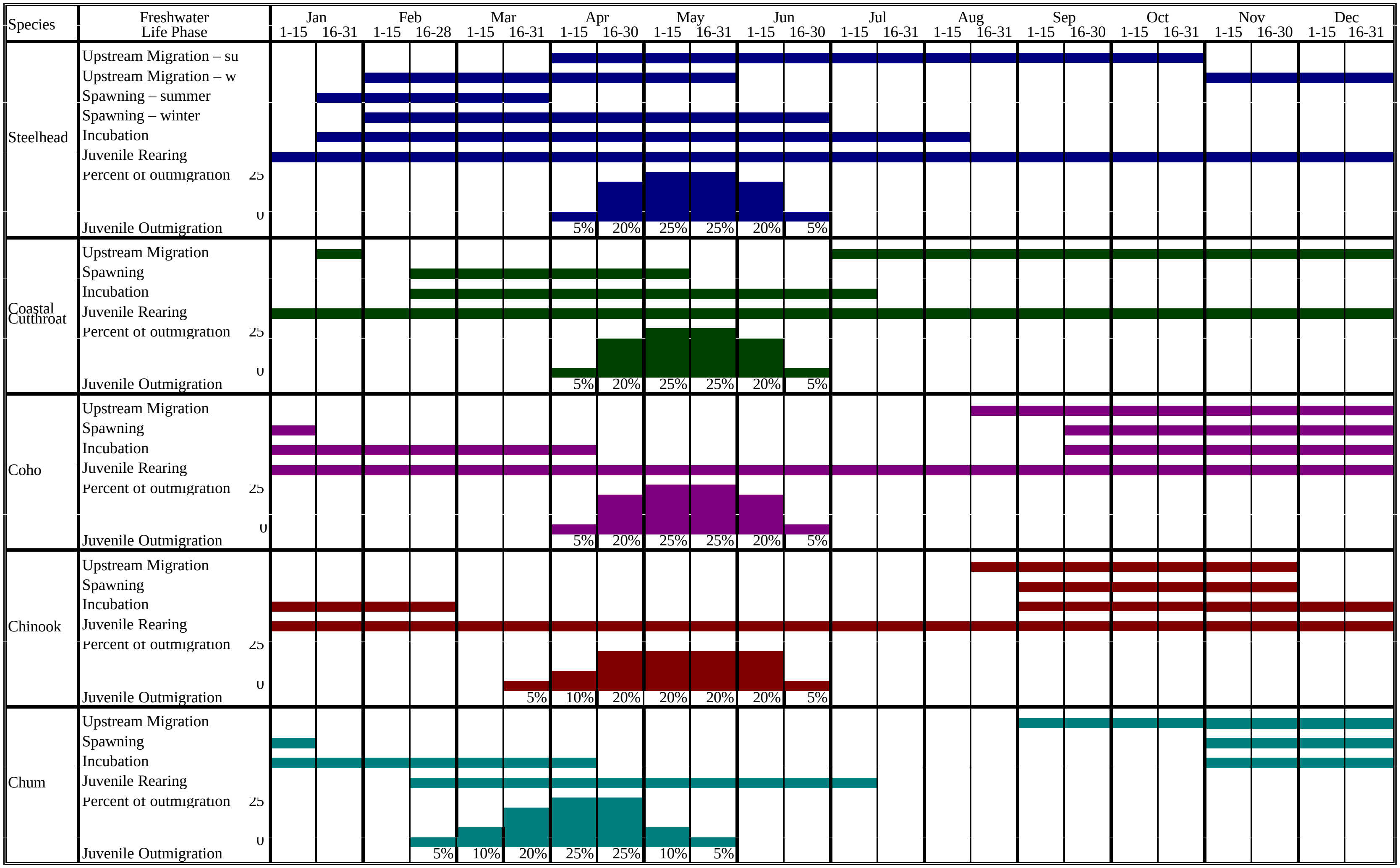

Figure 1. Temporal distribution of adult and juvenile salmonid habitat utilization in the middle Green River, Washington (adapted from Grette and Salo 1986; USACE 1998).

April and 17 April in the Green River (Dunstan 1955; Hilgert and Jeanes 1999, Jeanes and Hilgert 2000). Chinook alevins generally spend more time residing in the gravels before emergence, and are typically larger than other Pacific salmon upon emergence (Weatherly and Gill 1995).

Coho alevins spend three to four weeks (depending on food stored in the yolk sac) absorbing the yolk sac in the gravels of the redd before they emerge (Meehan and Bjornn 1991; Sandercock 1991). Coho begin to emerge approximately one month later than chinook, in early March to mid-May (McMahon 1983; Laufle et al. 1986). Juvenile coho salmon rear in freshwater for approximately 15 months prior to migrating downstream to the ocean, but may extend their freshwater rearing time for up to two years (Meehan and Bjornn 1991; Weitkamp et al. 1995). Complex woody debris structures and side channels are important habitat elements for juvenile coho salmon, particularly during the summer low-flow period on the Green River (Grette and Salo 1986; McMahon 1983; Peters 1996). During studies conducted in 1998, newly-emerged coho (e.g., yolk sac fry) were initially found in the middle Green River on 25 February (Hilgert and Jeanes 1999). Coho fry continued to be present through May, with peak relative abundance occurring in mid-April (Hilgert and Jeanes 1999). As juveniles grow, they move into faster water and aggressively defend their territory, resulting in the displacement of excess juveniles downstream to less favorable habitats (Chapman 1962; Wydoski and Whitney 1979; Sabo 1995; Sabo and Pauley 1997). Aggressive behavior by juvenile coho may be an important factor that maintains the numbers of juveniles within the carrying capacity of the stream (Chapman 1962; Chapman 1966).

In comparison to coho, juvenile chum and pink salmon have an “ocean-type” early life history, rearing in freshwater for only a few days to a few weeks before migrating downstream to saltwater (Grette and Salo 1986; Heard 1991; Salo 1991; Johnson et al. 1997). Chum fry that migrate to sea within several days after emergence exhibit little growth, while fry that rear for longer periods may exhibit an increase in length up to 22 percent in less than four weeks (Hale et al. 1985). Downstream movement in the Green River occurs through late May, but varies annually. Dunstan (1955) captured an initial surge of chum fry in late February, but believed the peak outmigration of chum fry occurred between March 20 and April 3. Chum fry displayed bimodal peaks in emigration occurring on 1 May and 15 in the Elwha River, Washington (Peters 1996). Some freshwater rearing is thought to occur in the middle Green River based on recapture information and increasing mean lengths of chum during a spring 1998 and 1999 study period (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000).

Juvenile sockeye that rear in rivers for one to two years (river-type sockeye) are far less common than the lake-type sockeye, and hence, less is known about them than their counterparts (Gustafson et al. 1997). River-type sockeye migrating as fry to saltwater, or lower river estuaries in the same year as emergence, are termed "sea-type" sockeye (Gustafson et al. 1997). The distribution of sockeye in Puget Sound known to use rivers for spawning and rearing include the North and South Fork Nooksack, Skagit, Sauk, North Fork Stillaguamish, Samish, and Green River populations (Gustafson et al. 1997).

Juvenile steelhead incubation rates vary according to numerous biotic and abiotic factors and require a relatively short incubation period compared to other salmonids. Fry emergence typically occurs from 30 to 60 days after spawning (Pauley 1986). Hilgert and Jeanes (1998) first observed newly emerged steelhead fry in the Green River in late May. Steelhead juveniles rear in freshwater for one or more years before migrating to the ocean (Peven 1990; Busby et al. 1996). In the Green River, most juvenile steelhead emigrate after two years rearing in freshwater (Meigs and Pautzke 1941). An early study of steelhead smolt emigration by Pautzke and Meigs (1940) found that steelhead smolts emigrated from the Green River primarily during April and May. In general juvenile downstream migration for steelhead smolts in Puget Sound occurs from April through June, with peak migration occurring in mid-April (Wydoski and Whitney 1979). Steelhead in smolt condition were captured during juvenile surveys in the middle Green River during the month of May in 1998 1999 (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000).

Like steelhead, coastal cutthroat trout are iteroparous (i.e., do not die after spawning and return to spawn again in subsequent years). Emergence of juvenile cutthroat occurs from March to mid-July, depending on spawning date and water temperature (Trotter 1997; Johnson et al. 1999). Newly-emerged cutthroat trout are very small (<25 mm TL) and are virtually unidentifiable from steelhead. Juvenile cutthroat move immediately to low-velocity habitats where they rear for two or more years, seeking pools and other slow water habitats with root wads and large wood for cover (Trotter 1997). During the marine phase of their life cycle, juvenile and adult coastal cutthroat trout appear to utilize waters near the shore, usually in areas relatively near their natal streams (Moyle 1976; Johnston 1982; Trotter 1997). Both gravel beaches with upland vegetation, and nearshore areas containing large logs and other large woody debris are used during the marine residency phase. The life history strategy of coastal cutthroat trout is termed amphidromous, indicating individuals may enter saltwater periodically as adults, returning to freshwater to spawn (Wilson 1997).

The variety of juvenile rearing strategies expressed by Green River salmonids play a significant role in their response to changing environments (Wilson 1997). The construction of Howard Hanson Dam interrupted the natural hydrology of the Green River and changed fish habitat below the dam. For instance, the reduction in peak river flow isolates the floodplain from the river and reduces the amount of habitat available to juvenile salmonids. The interruption of large woody debris and gravel transport from the headwaters of the Green River decreases the ability of the river to form new gravel bars, side channels, and juvenile salmonid habitat downstream from Howard Hanson Dam (Montgomery and Buffington 1998). Dams are often considered the key factor in the demise of many Pacific salmon stocks (Nehlsen et al. 1991; Huntington et al. 1996; NRC 1996). Fish inhabiting the Green River today have survived in spite of hydrology and habitat changes. The Green River is one of the few rivers in the Greater Seattle Metropolitan Region that contain healthy populations of anadromous salmonids, albeit at lower levels of production than historically observed (WDFW et al. 1994).

Understanding the respective life history characteristics of Green River juvenile salmonids will assist water managers in developing strategies that minimize the effects of flow changes on multiple species and life stages. For example, early-season refill of Howard Hanson Reservoir may have a deleterious effect upon one species or life stage inhabiting the Green River downstream of Howard Hanson Dam, yet benefit another. Likewise, planned short-term, high flow releases from Howard Hanson Dam (i.e., freshets) may facilitate downstream migration for one species, but displace younger fish of the same species to less favorable habitats, exposing them to increased predation. Population dynamics of aquatic species are often driven by the success of early life history cohorts. As with other fishes, the success of early life history is strongly size dependent; small differences in growth and mortality often drive adult recruitment (Quinn and Peterson 1996; Schindler 1999). Studies that identify specific habitat and behavioral characteristics of juvenile salmonids will be integral to developing water management strategies that address anthropocentric needs of the Puget Sound, while minimizing the impacts to salmonids inhabiting the Green/Duwamish River.

2. OBJECTIVES

This study was funded in part by the U.S. Army Corps of Engineers, Seattle District, and Tacoma Public Utilities as part of the Additional Water Storage Project. Funding mechanisms included Planning Assistance to the States (Section 22 of the Water Resources Act of 1974), which included a 50:50 cost-share by the USACE and the City of Tacoma. The objectives of this study were to:

- Monitor the emergence of juvenile salmonids in the middle Green River;
- Measure the growth of juvenile salmonids in lateral habitats;
- Determine the relative abundance of middle Green River juvenile salmonids; and
- Identify the species distribution of juvenile salmonids in relation to habitat type.

The study effort in 2000 represents a continuation of a similar study conducted in 1998 and 1999 (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Results of the 1998 juvenile salmonid survey indicated that a significant portion of chinook fry had already emerged and were widely distributed within lateral habitats of the Green River when the survey was initiated in late-February (Hilgert and Jeanes 1999). Results of the 1998 study also indicated that a large percentage of juvenile chinook fry utilized mainstem margin habitat during portions of their freshwater residence. Thus, the 1999 field season incorporated additional survey sites along the mainstem of the middle Green River to increase sample coverage of this habitat type. A middle Green River Restoration site was also included in the 1999 field season in order to collect pre-construction data for Section 1135 restoration projects. One survey site from the 1999 field season (Upper O'Grady Slough) was discontinued in 2000; six sites were added to the study in 2000 (USGS and Pipeline mainstem margins, Metzler and O'Grady gravel bar pools, and Porter Inlet and Outlet restoration side channels).

This report represents the results of year three of a monitoring program, funded cooperatively by the City of Tacoma and U.S. Corps of Engineers, Seattle District. Information on juvenile salmonids, along with water temperature and physical habitat data, will be compared to flow changes in the middle Green River. This information will assist with adaptive management aspects of the Howard Hanson Dam Additional Water Storage Project (AWSP) (i.e., pre-project baseline monitoring), and provide support for the City of Tacoma's Habitat Conservation Plan (HCP). Results from this study will also be used in the environmental evaluation of the U.S. Corps of Engineers/King County Section 1135 restoration projects and General Investigation studies conducted on the middle Green River.

3. METHODS

The study reach encompassed the middle Green River, beginning at Tacoma Headworks Facility (RM 60.0) and continued downstream to U.S. Highway 18 Bridge (RM 33.8) (Figure 2). The selection of candidate sites was based physical data collected by Coccoli (1996) and USACE (1998), and biological data collected by Hilgert and Jeanes (1999) and Jeanes and Hilgert (2000). Candidate sites were located within the prescribed study reach of the Green River that were documented to contain juvenile salmonids.

3.1 DAY/NIGHT ELECTROFISHING SURVEYS

For the purpose of this study, lateral habitat areas in the middle Green River were separated into the following strata (adapted from Murphy et al. 1989; Hawkins et al. 1993; Coccoli 1996; Hayman et al. 1996; Hilgert and Jeanes 1998; R. Peters, USFWS, pers. comm.):

1) **Mainstem channel habitats**: areas with an immediate connection to the mainstem Green River:
   - *Gravel bar pools* formed within high water mark and separated from the main channel only during low flow conditions;
   - *Sloughs* connected to main channel under all flow conditions; and
   - *Margins* along the channel banks and containing areas with relatively low velocity (≤1.0 fps) and overhead cover in the form of woody debris, vegetation, or undercut banks.

2) **Off channel habitats**: disconnected from the mainstem Green River through a vegetated island or abandoned floodplain:
   - *Backbar channels* located along lateral or point bar formations of the mainstem Green River;
   - *Abandoned channels* consisting of former mainstem Green River channels, presently connected at high flow;
   - *Wallbase channels* located along the base of steep valley slopes and receive a considerable proportion of their water supply from side-slope seepage.

Biological monitoring sites were further separated into day and night survey strata, based on location and access. Nighttime survey sites required reasonable foot accessibility, which tended to be located within one mile of public access points (e.g., state or county parks, or fishing access sites). Daylight survey sites contained the remaining sites and were accessed from a raft launched at Whitney Bridge (218 Avenue SE) near Flaming Geyser State Park and removed at U.S. Highway 18 near Auburn, Washington.

A site reconnaissance in late February 2000 finalized site selection and prepared study sites for biological surveys. Final study site selection and preparation included the following:

- Delineating the upper and lower site boundaries;
- Quantifying available habitat area (water depth, velocity, width, and length);
- Installation of staff gages; and
- Placement of Onset Stowaway® digital temperature recorders.

Permanent photograph locations were established and all information, including detailed site sketches, were transcribed onto data sheets.

Following final study site selection, survey techniques (electrofishing, snorkeling, and visual inspection) were applied at each site based on size (area and water depth), physical condition (amount of debris and vegetation, and visibility) of the habitat, and the methodology used during the 1998 and 1999 field seasons. Surveys began on 1 March and continued through 25 July. Each survey required a minimum of three personnel; personnel were kept as consistent as possible in order to keep continuity with data collection procedures. Biological surveys were conducted in two-week intervals. Each two-day survey period consisted of one daytime trip followed within 24 hrs by a nighttime trip. During each survey period, the initial day survey site was started within 30 minutes of sunrise and the initial night site began within 30 minutes of sunset. Successive site start times depended largely on the amount of time that it required to complete the prior site and travel to the next site. Nighttime surveys were not conducted within four days of a full moon to avoid potential inconsistencies with lunar effects (Roper and Scarnecchia 1999).

Capture techniques were standardized throughout the period of study for each site and follow procedures used in 1998 and 1999 (Hilgert and Jeanes 1999; Jeanes and Hilgert 2000). Increased turbidity levels resulting from the Flaming Geyser landslide (RM 43) prohibited snorkeling and forced us to rely solely upon backpack electrofishing as the capture technique in the middle Green River below RM 43 during the 2000 field season.

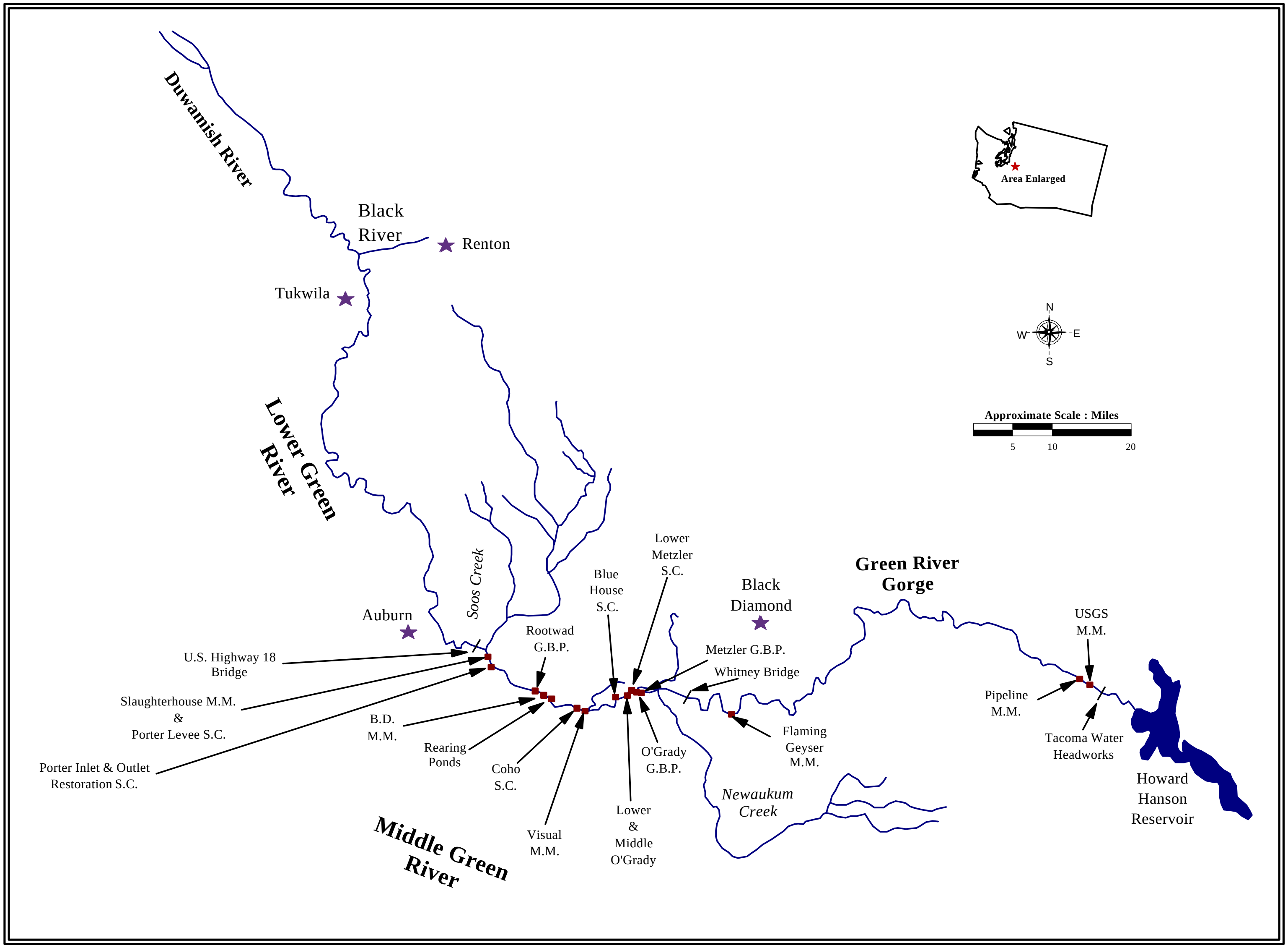

Figure 2. Location of 18 juvenile salmonid survey sites, middle Green River, Washington, 2000.

Beach seine capture techniques used in mainstem sloughs during the 1998 field season appeared to result in undue stress on juvenile salmonids, mainly from problems associated with mud/silt substrates. While not causing direct mortalities, juvenile salmonids captured using this technique required longer periods to recover and occasionally suffered physical abrasions from the beach seine. Accordingly, this survey technique was abandoned during the 1999 and 2000 field seasons.

A SmithRoot, Inc. Model 15-C programmable wave output backpack electrofishing unit, using "straight DC" current was used to conduct electrofishing surveys. A block net was installed at the upstream end of selected sites when feasible. Electrofishing began at the lower site boundary and continued upstream to the block net (i.e., block nets were not used on mainstem margins). One transect (i.e., pass) was electrofished at each survey site; guidelines for electrofishing waters containing salmonids listed under the Endangered Species Act (NMFS 1998) were strictly adhered to during the 2000 field season. This methodology did not provide population estimates but did result in an index of abundance, while minimizing potential injury to the fish.

Fish were captured with a dip net (3-mm nylon mesh) and placed into a darkened recovery unit where they were anesthetized with 75 mg L^{-1} tricaine methanesulfonate (MS 222). Each fish was then identified to species, measured to the nearest mm total length, and marked with a unique fin clip corresponding to each survey month. Stomach contents of randomly selected sculpin and juvenile coho salmon were sampled using techniques adapted from Sheng et al. (1990). Stomach contents were sealed in plastic bags containing 90 percent ethanol. Each sample was labeled with date, survey site, species, total length, and contents (fish tissue, macroinvertebrates, or debris). Captured fish, allowed to recover in fresh water for a minimum of 30 minutes, were then released within the survey site that they were captured. Survey time of electrofishing transects (sec) were recorded along with fish data, staff gage measurements (mm), photographs, and water temperatures (°C) on field data sheets.

3.2 HABITAT SURVEYS

Habitat measurements were conducted at each site beginning on 23 May 2000. Juvenile salmonid habitat characterization methods were based on the hierarchical classification system described by Hawkins et al. (1993). Level one habitat identified the channel type as main channel, braided channel, side channel, slough, or tributary mouth. Habitat levels 2-4 classified the primary geomorphic units (i.e., pool, riffle) of the channel, while level 5 characterized the secondary units (≥20%) located within the primary units (Table 1). Level 2 classification consisted of either fast (>2.0 fps) or slow (<2.0 fps) water. Within each Level 5 habitat type (i.e., the fish survey site) we measured the available habitat length (ft), width (ft), mean velocity (fps), maximum and mean water depth (ft), overhead cover (%), overhanging vegetation (%), and undercut bank (%). Habitat Levels 1-4 were characterized once (on 23 May), while parameters measured within Level 5 habitat types were measured on each survey date after initiation (23 May). Water velocities (to the nearest 0.1 fps) were measured using a Swoffer Model 2100 velocity meter and a 4-ft top-setting rod. Water depths (to the nearest 0.1 ft) were measured using a top-set rode. Bank angle was characterized on a sliding scale from 1 (shallow; ≤ 10º) to 5 (steep; ≥ 90º). Wetted length and width (to nearest 1 ft) were measured with a Bushnell® Compact 800 rangefinder. The rangefinder was calibrated on each survey using a 300 ft tape. Overhead cover, overhanging vegetation, and undercut banks were visually estimated on each survey occasion. The riparian vegetation was classified as coniferous, deciduous (Salix specified if present), grass, open, or shrub. The amount of wetted overhanging vegetation was also visually estimated. Large woody debris was characterized at each site on successive survey dates using a methodology adapted from Schuett-Hames et al. (1999). For data consistency, the same survey personnel recorded all visual habitat data metrics.

3.3 DATA ANALYSIS

Catch per unit effort (CPUE) data were calculated for each species (coho, chinook, and chum salmon, and rainbow and cutthroat trout) and life stage (fry and overyearling). Life stages were differentiated by length frequency analysis. Intra-site data comparisons were conducted to determine relative abundance over the 2000 study period and between study years (1998-2000). Inter-site CPUE data was used to classify peak emigration and emergence of juvenile salmonid species in the middle Green River. Length data was analyzed with recapture information to assign relative growth rates of each species and life stage. Provisional stream data (river stage and discharge) was obtained from the U.S. Geological Survey and compared to available habitat information and water temperature data to analyze the effect of different flow regimes on lateral habitats. Water temperature data were downloaded from Onset Stowaway® digital water temperature recorders and converted to daily mean, minimum, and maximum water temperatures (°C) using an in-house computer program. Relative abundance of juvenile salmonids were compared to available habitat, water temperature, and stream discharge data to determine the effects of flow regime on juvenile salmonids in the middle Green River. Stomach samples were analyzed for the presence of small fish, macroinvertebrates, or debris to determine if a change in diet composition occurs over the duration of the study. All data were entered electronically using MS Excel and cross-referenced with original field data forms for QA/QC purposes. All data analyses were conducted using MS Excel, except where otherwise noted.

Table 1. Description of five-level hierarchical habitat classification system used to characterize 18 juvenile salmonid survey locations, middle Green River, Washington, 2000 (adapted from R. Peters, USFWS, unpublished data).

Habitat Level 2	**Habitat Level 3**	**Habitat Level 4**	**Description**
Fast Water			Riffle or rapid/steep water surface gradient
	Turbulent		Non-laminar flow w/ surface turbulence.
		Falls	Steep, vertical drop in water surface elevation
		Cascade	Series of small falls and shallow pools.
		Rapid	Deeper stream section, standing waves present.
		Riffle	Shallow, lower gradient, often w/ exposed substrate
		Chute	Narrow, confined channel w/bedrock substrate
	Non-Turbulent		Low channel roughness, moderate gradient and lack of surface turbulence
		Sheet	Shallow water flowing over bedrock
		Run	Shallow water flowing over other substrate types
Slow Water			Slowly moving w/ decreased water surface gradient
	Scour Pool		Formed by scour action of current
		Eddy	Formed by circular current pattern often created by bank obstruction, usually occur along the bank
		Trench	Formed primarily by scouring of bedrock, usually located in the main channel
		Mid-Channel	Formed in the main channel by channel constriction usually at the upstream end of pool
		Convergence	Formed in the main channel by converging stream channels
		Lateral	Formed in the main channel where flow is deflected by a partial channel obstruction
		Plunge	Formed in the main channel by water dropping vertically over a channel obstruction
		Deposition	Depositional area within a scour pool usually located along the point bar of a lateral scour pool.
	Dammed Pool		Water impounded by channel blockage
		Debris	Formed by log and debris jams
		Beaver	Formed by beaver activity
		Landslide	Formed by earth of large boulders
		Backwater	Formed by obstruction along stream margin
		Abandoned Channel	Formed along main channel, often associated with gravel deposition zones

4. RESULTS

4.1 DAY/NIGHT ELECTROFISHING SURVEYS

4.1.1 Juvenile Salmonid Data

Juvenile salmonid use was monitored in 18 sites during the 2000 study period (Table 2; Figure 2). The first survey period was conducted on 1 March, while the final survey was completed on 25 July. Lower Metzler, Blue House, Coho, and Rearing Pond side channels were surveyed during the daytime along with Metzler, O'Grady, and Rootwad gravel bar pools, and USGS, Pipeline, Visual and Big Dog mainstem margins. The remaining six sites (Flaming Geyser, Upper, Middle, and Lower O'Grady, Porter Inlet and Outlet, Slaughterhouse Levee, and Porter Levee) were surveyed at night. One survey site from the 1999 field season (Upper O'Grady Slough) was discontinued in 2000; six sites were added to the study in 2000 (USGS and Pipeline mainstem margins, Metzler and O'Grady pools, and Porter Inlet and Outlet restoration side channels).

Table 2. Site name, location (river mile), lateral habitat strata, and survey strata of 18 juvenile salmonid survey sites, middle Green River, Washington, 2000.

Site	River Mile	Habitat Strata	Survey Strata
USGS	60.3	Mainstem Margin	Day
Pipeline	59.5	Mainstem Margin	Day
Flaming Geyser	45.0	Mainstem Margin	Night
Metzler Pool	41.0	Mainstem Gravel Bar Pool	Day
O'Grady Pool	40.7	Mainstem Gravel Bar Pool	Day
Lower Metzler	40.0	Backbar Channel	Day
Middle O'Grady	40.0	Mainstem Margin	Night
Lower O'Grady	40.0	Wallbase Side Channel	Night
Blue House	39.2	Abandoned Side Channel	Day
Visual	38.5	Mainstem Margin	Day
Coho	38.4	Abandoned Side Channel	Day
Rearing Pond	36.9	Abandoned Side Channel	Day
Big Dog	36.6	Mainstem Margin	Day
Rootwad Pool	36.3	Mainstem Gravel Bar Pool	Day
Porter Inlet	34.2	Restoration Side Channel	Night
Porter Outlet	34.1	Restoration Side Channel	Night
Porter Levee	34.0	Abandoned Side Channel	Night
Slaughterhouse Levee	34.0	Mainstem Margin	Night

A total of 5,189 salmonids were captured during 2000 day/night electrofishing surveys (Appendix A; Tables A-1 through A-18). The majority of the juvenile salmonids were rainbow trout (35%), followed by coho (29%), chinook (22%) and chum salmon (13%). The remaining juvenile salmonids were composed of cutthroat trout (0.2%), mountain whitefish (0.1%), and pink and sockeye salmon (<0.05%). Capture rate of salmonids was greater during night surveys (CPUE = 0.08; 7 sites) when compared to day surveys (CPUE = 0.06; 7 sites) during the 2000 day/night electrofishing surveys (Table 3). In addition to salmon, trout, and whitefish, 1,443 non-salmonids were captured. Non-salmonid species in order of decreasing capture frequency were: coastrange and mottled sculpin; Pacific lamprey; three-spine stickleback; longnose dace; largescale sucker; shorthead sculpin, redside shiner, and brook lamprey (Appendix A; Table A-19).

Most (>99%) chinook captured were considered young-of-year (hereafter referred to as fry) (#100 mm TL) based upon their length frequency distribution (Figures 3 and 4). All chum captured were fry (Figure 5), while the majority of coho (91%) were fry as opposed to overyearling (9%) (Figures 6 and 7). Likewise, fry rainbow trout comprised the majority (82%) of all rainbow captured during the 2000 field season (Figures 8 and 9). Nine overyearling cutthroat trout were captured in 2000; the lone sockeye fry was 29 mm TL, while a single pink salmon fry was 42 mm TL per unit effort indices for juvenile salmonids captured during day/night electrofishing for individual sites are presented in Appendix A (Tables A-1 through A-18; Figures A-1 through Figures A-18). Catch (all day survey sites combined) of coho, chinook, chum pink, and sockeye salmon, and rainbow and cutthroat trout are presented in Figure 10, while night indices (all night sites combined) for coho, chinook, and chum salmon, and rainbow and cutthroat trout are presented in Figure 11. Nighttime catch of all juvenile salmon peaked in the middle Green River during the last week of April (night CPUE = 0.251) and daytime catch peaked during the first week of May (day CPUE = 0.127). The catch rate of rainbow trout fry (both day and night) peaked during the survey conducted on 11 July (night CPUE = 0.091; day CPUE = 0.083). Mean chinook salmon capture indices decreased steadily from the initial survey date (1 March) through early June (Figures 10 and 11). Chum fry indices peaked during the last week of April (night CPUE = 0.076; day CPUE = 0.021). Coho fry capture indices peaked during late April and again in late June (Figure 10 and 11). Capture of rainbow trout fry peaked during the survey conducted on 11 July (night CPUE = 0.084; day CPUE = 0.083). Overyearling salmon and trout capture indices peaked during the survey conducted on 28 March

Table 3. Survey strata, species, number captured, percent of total salmonids, and percent of total fish captured during day/night electrofishing surveys in the middle Green River, Washington, 2000.

Survey Strata	**Species**	**No. Captured**	**Percent of**	
			Salmonids	**Total Fish**
Night Survey Sites	Chinook Salmon	537	10.3	8.1
	Chum Salmon	354	6.8	5.3
	Coho Salmon	618	11.9	9.3
	Sockeye Salmon	0	0.0	0.0
	Pink Salmon	0	0.0	0.0
	Rainbow Trout	740	14.3	11.2
	Cutthroat Trout	9	0.2	0.1
	M. Whitefish	5	0.1	0.1
	Sub Total	2,263		
Day Survey Sites	Chinook Salmon	622	12.0	9.4
	Chum Salmon	335	6.5	5.1
	Coho Salmon	905	17.4	13.6
	Sockeye Salmon	1	0.0	0.0
	Pink Salmon	1	0.0	0.0
	Rainbow Trout	1,060	20.4	16.0
	Cutthroat Trout	2	0.0	0.0
	M. Whitefish	0	0.0	0.0
	Sub Total	2,926		
Grand Total		**5,189**		

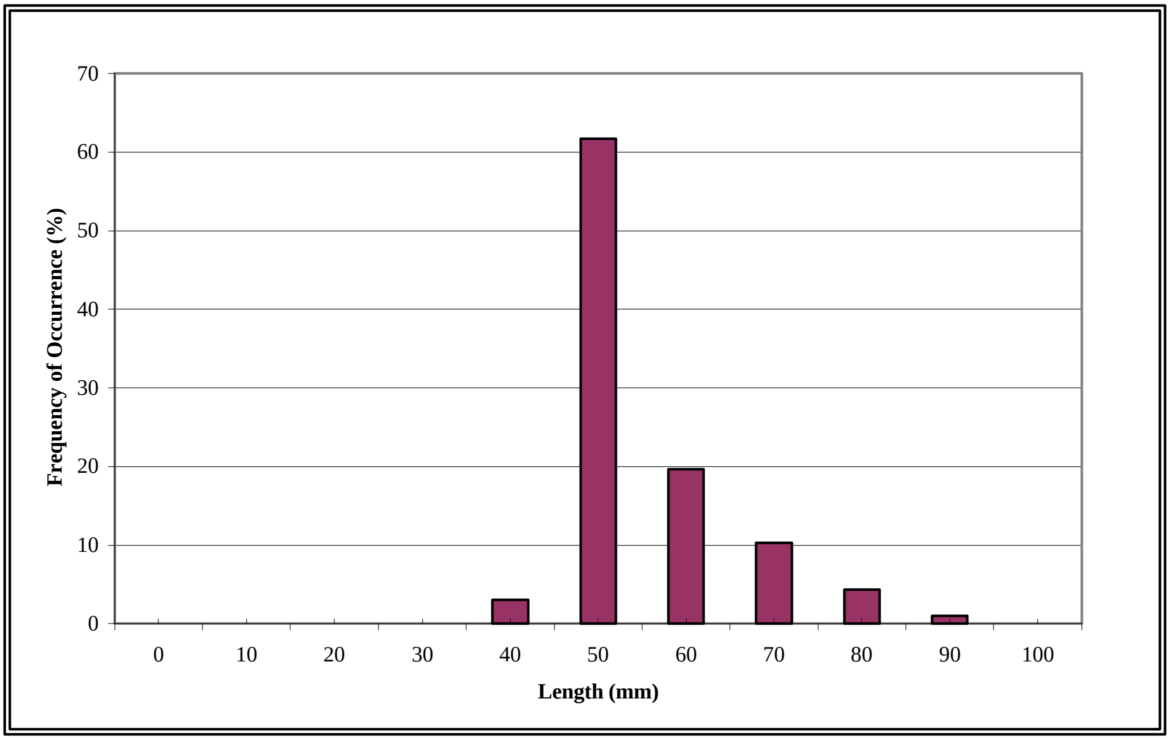

Figure 3. Length frequency of chinook fry captured in middle Green River, Washington, 2000 (N=1,155).

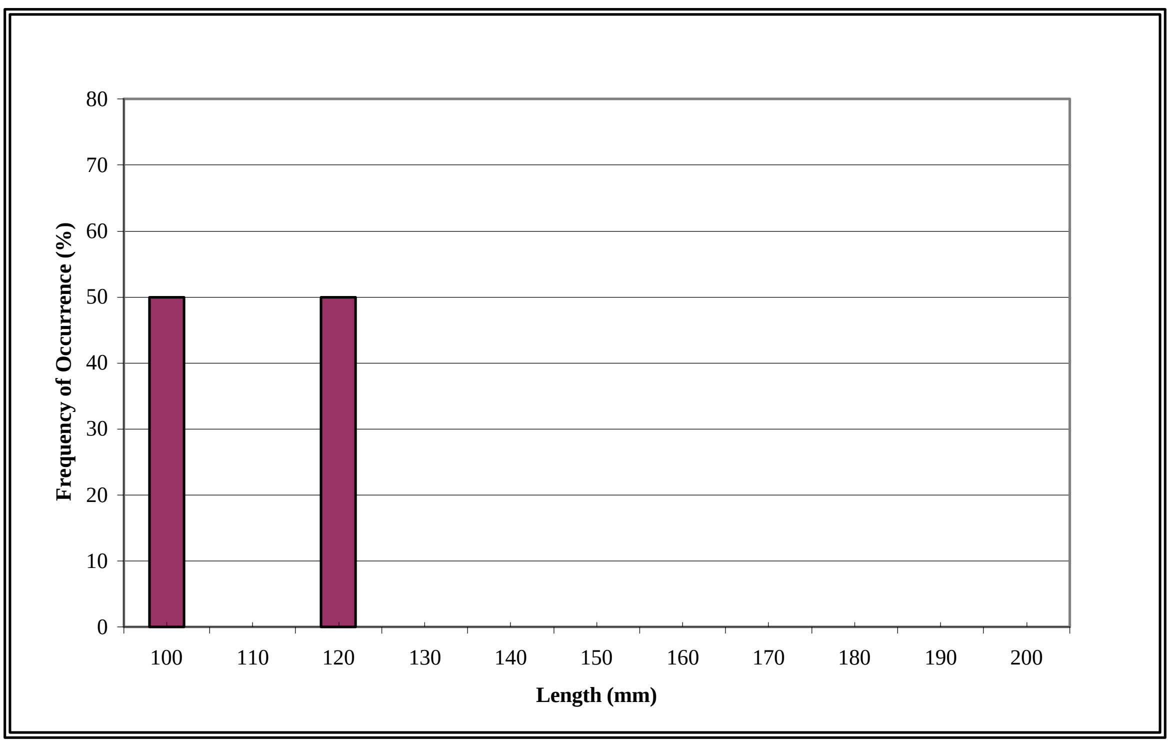

Figure 4. Length frequency of overyearling chinook captured in middle Green River, Washington, 2000 (N=2).

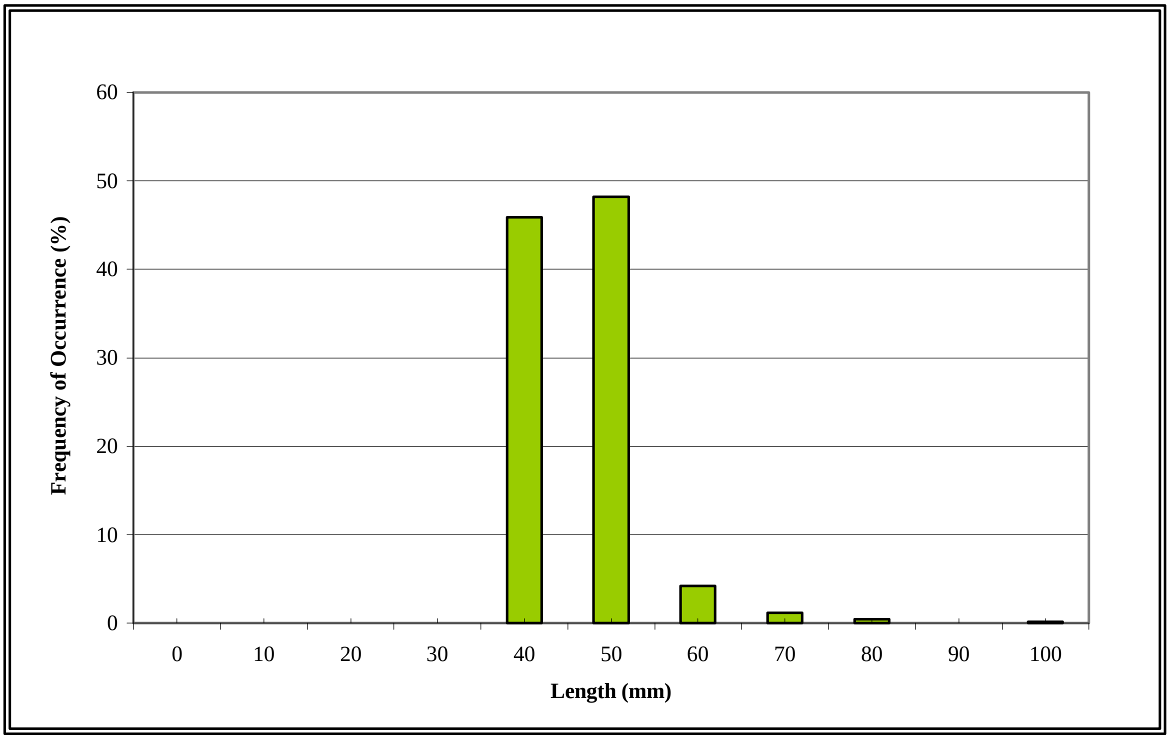

Figure 5. Length frequency of chum fry captured in middle Green River, Washington, 2000 (N=689).

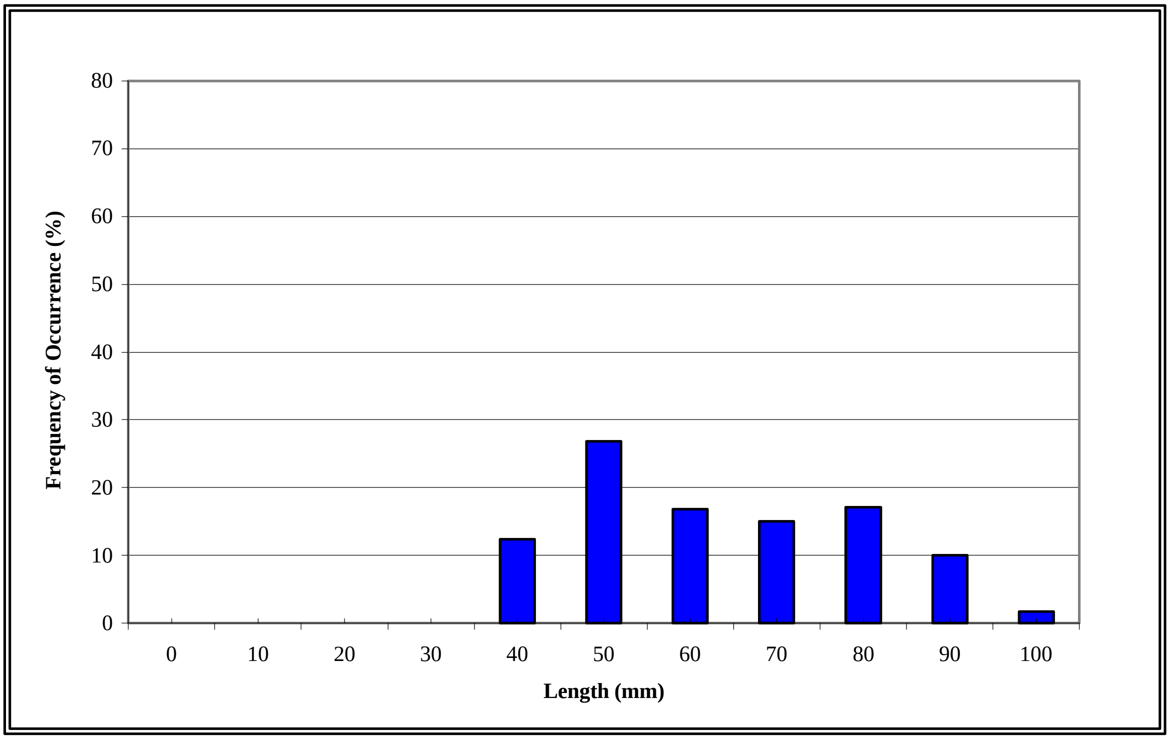

Figure 6. Length frequency of coho fry captured in middle Green River, Washington, 2000 (N=1,383).

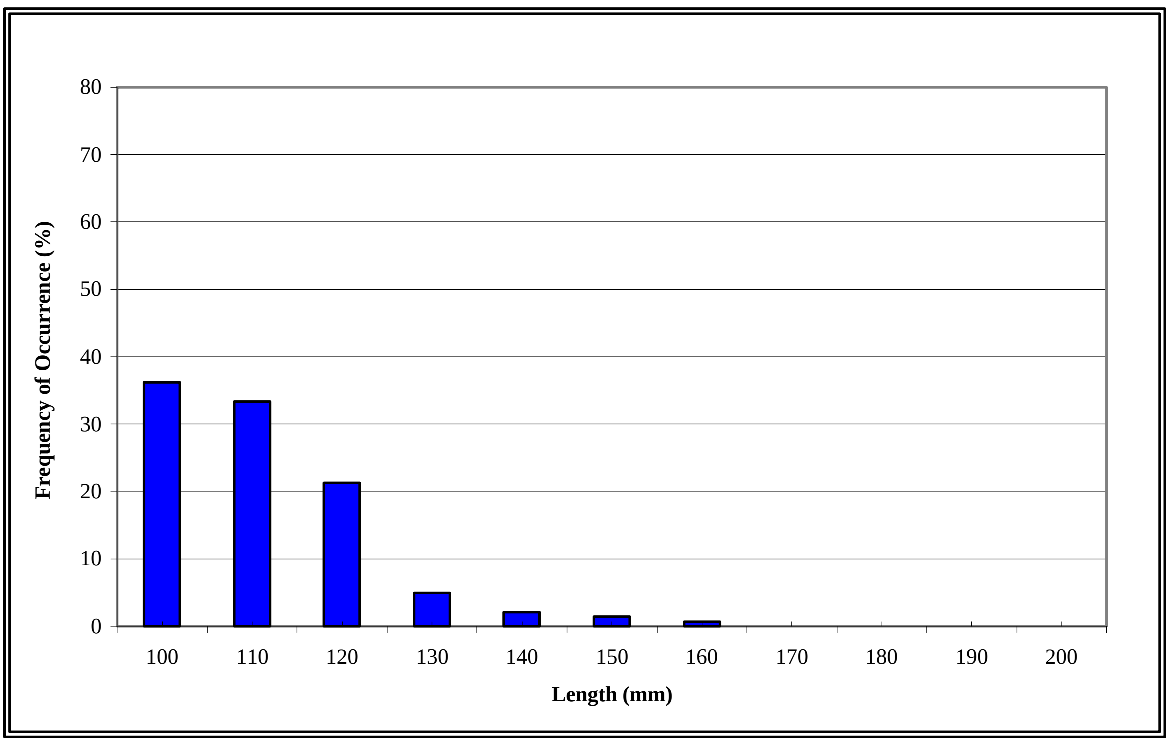

Figure 7. Length frequency of overyearling coho captured in middle Green River, Washington, 2000 (N=140).

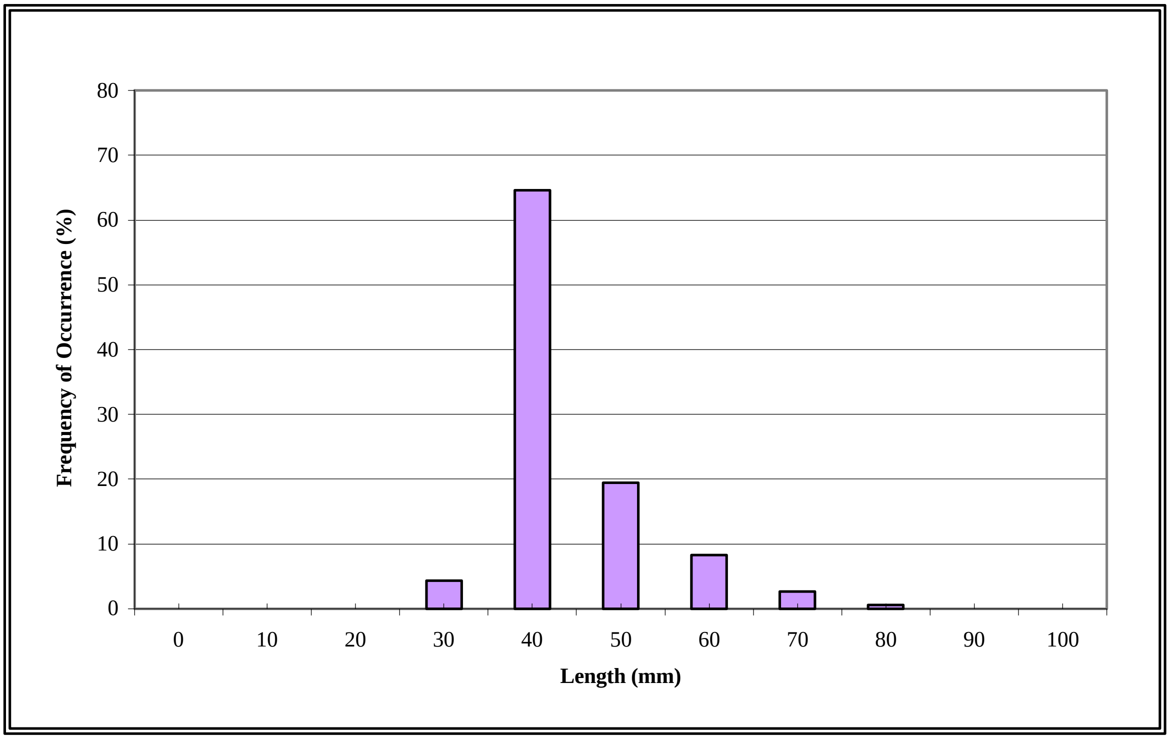

Figure 8. Length frequency of rainbow fry captured in middle Green River, Washington, 2000 (N=1,649).

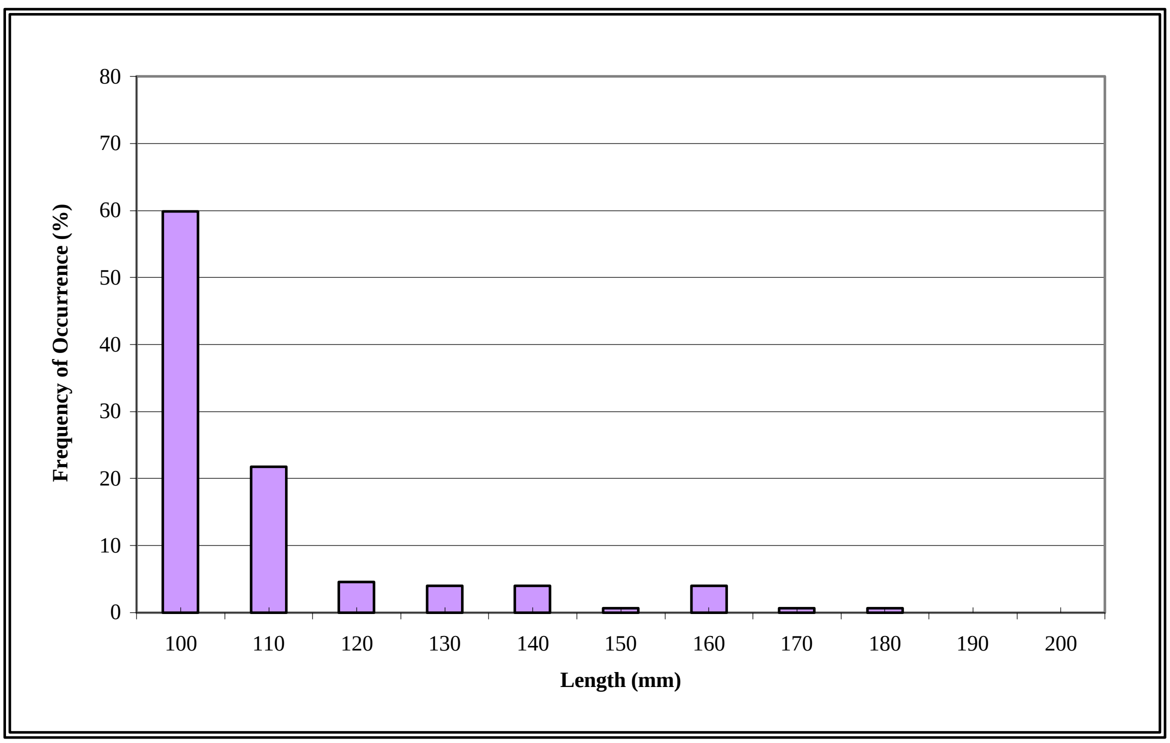

Figure 9. Length frequency of overyearling rainbow captured in middle Green River, Washington, 2000 (N=151).

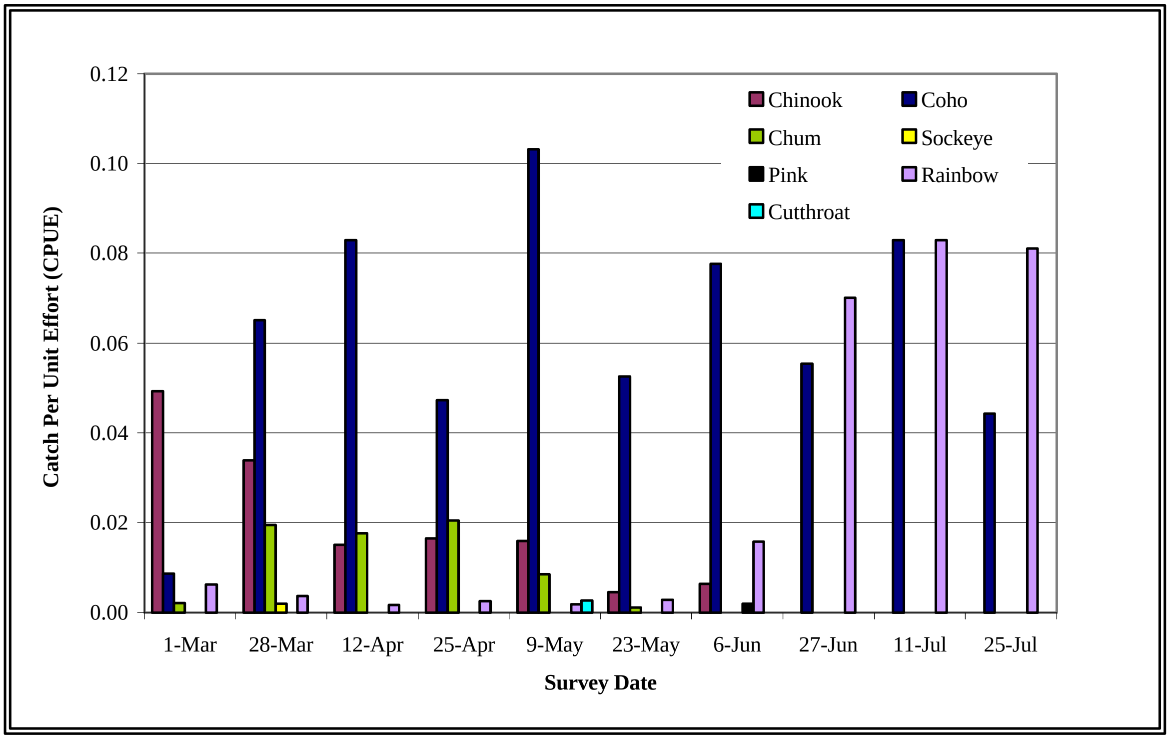

Figure 10. Mean catch per unit effort indices for 11 juvenile salmonid day survey sites in middle Green River, Washington, 2000.

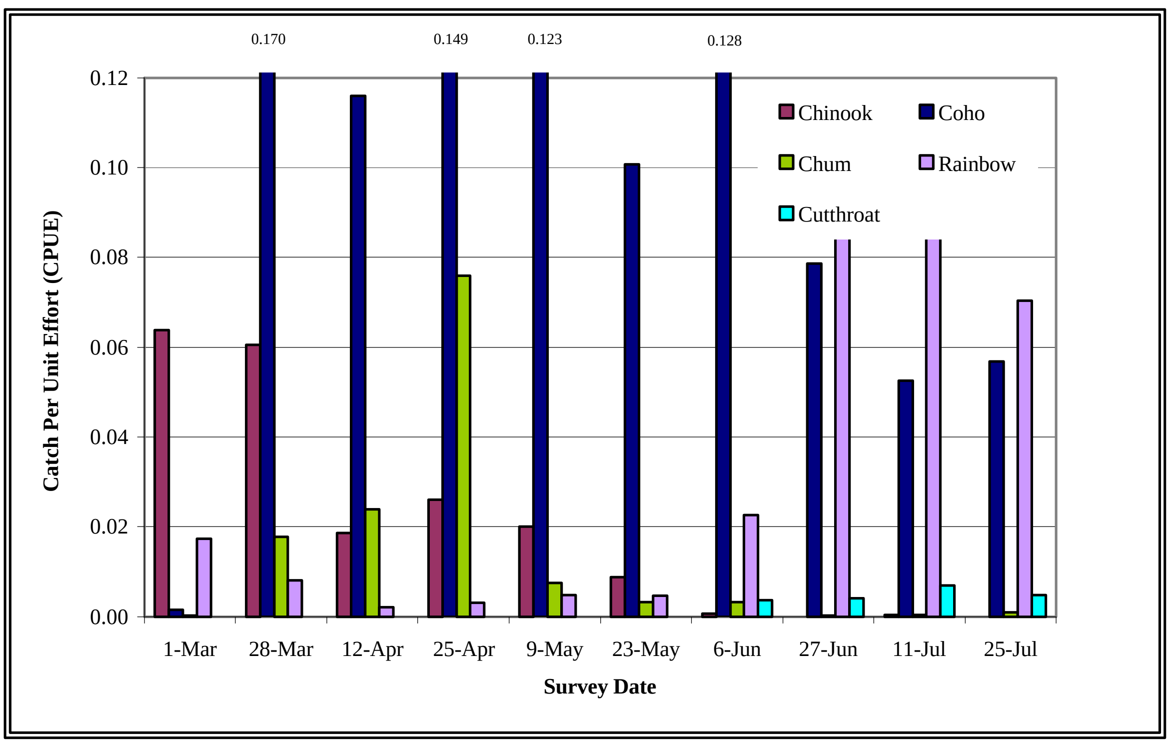

Figure 11. Mean catch per unit effort indices for 7 juvenile salmonid night survey sites in middle Green River, Washington, 2000.

The species composition of salmon and trout fry captured during the study was dominated throughout March by chinook salmon (>73%) (Figure 12). Chum and coho salmon began to emerge in March and composed the majority of the catch by April (chum = 40%; coho = 30%) and May (coho > 54%). Cutthroat and rainbow trout started to emerge in late May and dominated the catch by June (Figure 12). Chinook dominance of the catch ended in April (29%), and by June, contributed less than five percent of the total catch of salmon and trout fry. By July, the catch was composed entirely of rainbow trout (77%) and coho (23%) fry. Rainbow trout, chinook, and coho salmon were the only species of fry captured at the USGS (RM 60.3) and Pipeline (RM 59.5) sites; all species of fry were captured at Flaming Geyser (RM 45.0) and downstream (Appendix Tables A1-A19).

The number of salmon and trout fry captured and recaptured at least once throughout the study period is presented in Appendix A (Table A-20). More chinook (7%) and coho fry (28%) were recaptured than chum salmon (~1%). A small percentage of rainbow (~1%) and cutthroat trout (0%) fry were recaptured during the study period. Cutthroat (33%) and rainbow trout, as well as coho salmon (14%) overyearlings were frequently recaptured throughout the study period. Most recaptures occurred during the months of June (12%) and July (27%) (Table A-20).

The length of chinook fry remained constant during March (mean = 45.2 mm; std. dev. = 3.8 mm), and April (mean = 52.1 mm; std. dev7.0 mm) (Figure 13). Mean length increased dramatically during May (mean = 64.4 mm; std. dev. = 10.7 mm), and June (mean = 72.0 mm; std. dev. = 6.1 mm). Likewise, the length of coho fry remained similar between March (mean = 38.9 mm) and April (mean = 43.0 mm; std. dev. = 5.2 mm), increasing in May (mean = 51.5 mm; std. dev. = 7.4 mm) and June (mean = 67.1 mm; std. dev. = 9.3 mm). Unlike chinook and coho, however, chum fry remained fairly constant throughout March-May (mean = 41.9 mm; std. dev. = 2.1 mm) and increased dramatically in June and July (mean = 66.6 mm; std. dev. 13.3 mm) (Figure 13). Rainbow and cutthroat trout fry lengths also remained fairly constant from March through June (mean = 38.4 mm; std. dev. = 2.0 mm) and increased in July (mean = 41.4 mm; std. dev. = 9.8 mm). By early May, chinook and coho emergence was complete and the fry observed were actively holding and rearing in the study reach. Rainbow and cutthroat trout emergence appeared to be complete by the last survey date, which occurred on 25 July. Emergence at the USGS (RM 60.3) and Pipeline (RM 59.5) sites appeared to be three weeks behind that of the survey locations located downstream of Flaming Geyser (RM 45.0). The mean lengths of fry captured at the two upstream-most locations (USGS and Pipeline) (chinook = 45.0 mm; coho = 41.3 mm;

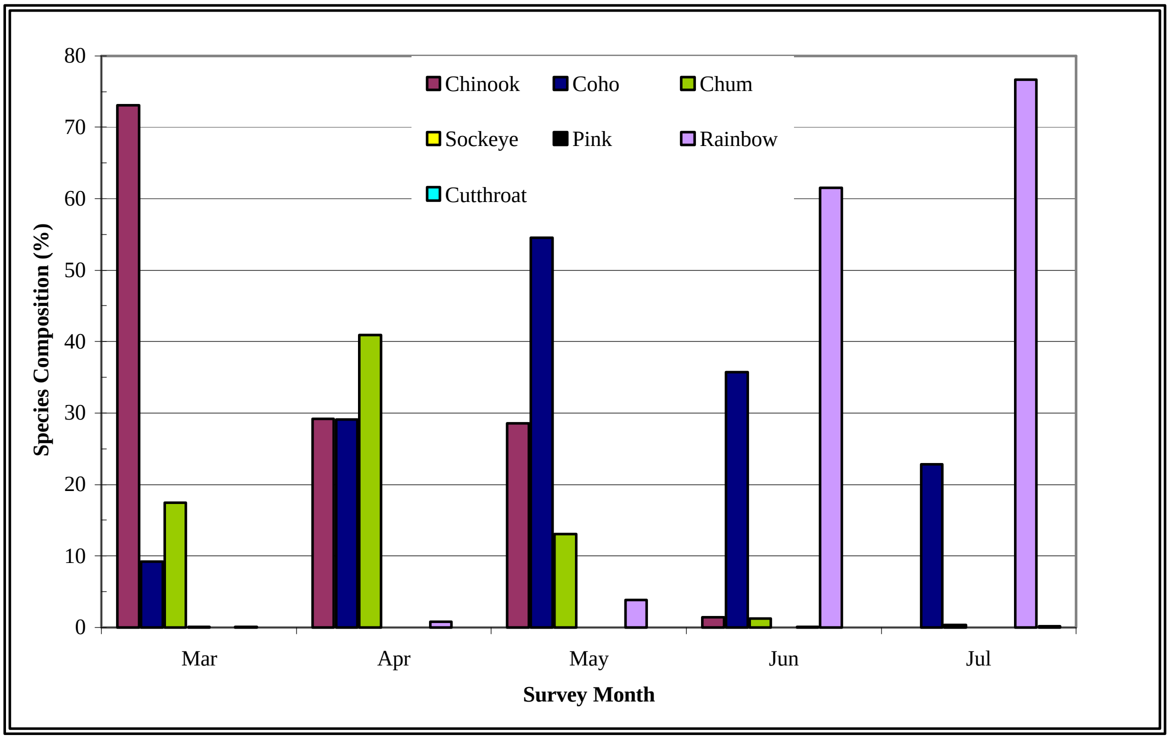

Figure 12. Species composition of salmon and trout fry captured in middle Green River, 2000.

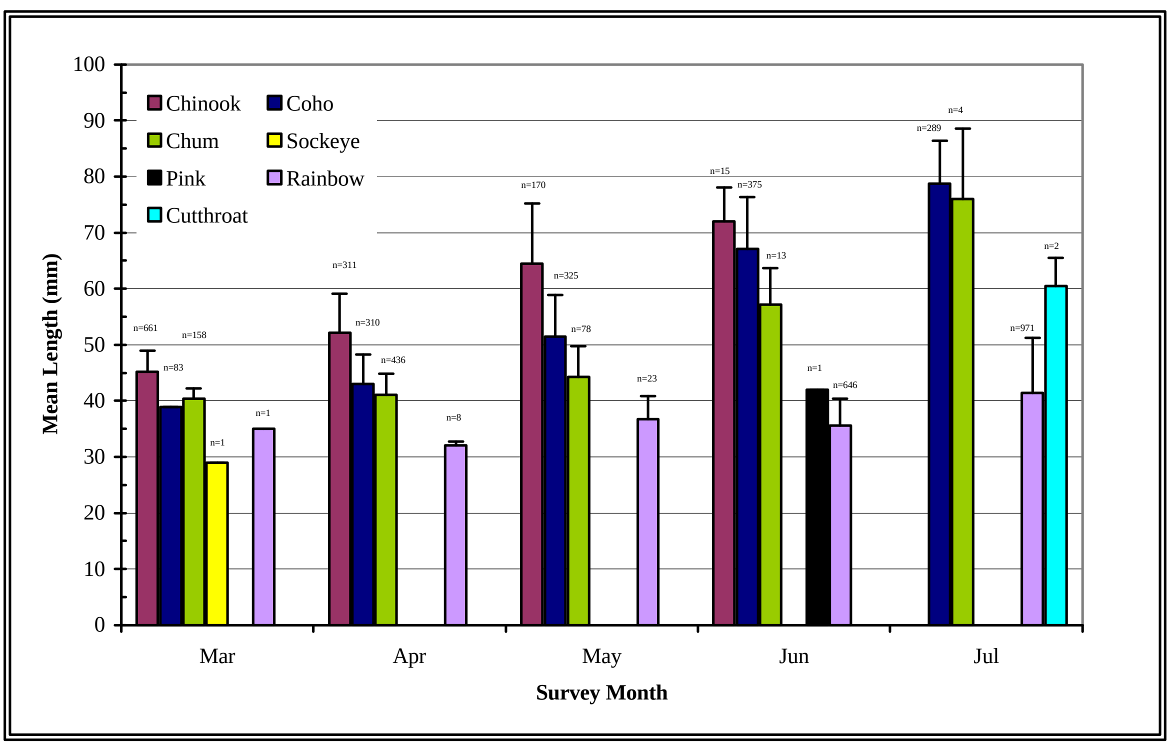

Figure 13. Mean length (mm) of salmon and trout fry captured in middle Green River, 2000.

rainbow = 34.9 mm) were consistently smaller than the mean length of fry at downstream locations (chinook = 50.8 mm; coho = 59.2 mm; rainbow = 40.6 mm).

Results of diet analyses of overyearling coho salmon are presented in Appendix A (Table A-21). Insects dominated the stomach contents of the majority of overyearling coho throughout the study period, comprising more than 60 percent of the stomach contents from February through May. Fish flesh (March and May) and debris (March) were the only other items that comprised more than ten percent of the stomach contents for an individual month. Approximately 11 percent of the stomachs were empty in April. No overyearling coho were captured after the 9 May survey.

4.2 FLOW AND WATER TEMPERATURE DATA

Mean daily discharge remained greater than 750 cfs until 27 June (mean = 1,552 cfs; std. dev. = 435 cfs) (Figure 14). Discharge peaked briefly (3,010 cfs) in the Green River on 2 February, and remained fairly constant (~1,5000 cfs) throughout the juvenile salmonid rearing period of February through June 1999. Discharge decreased rapidly in late June and July, reaching a low of 280 cfs by the end of July.

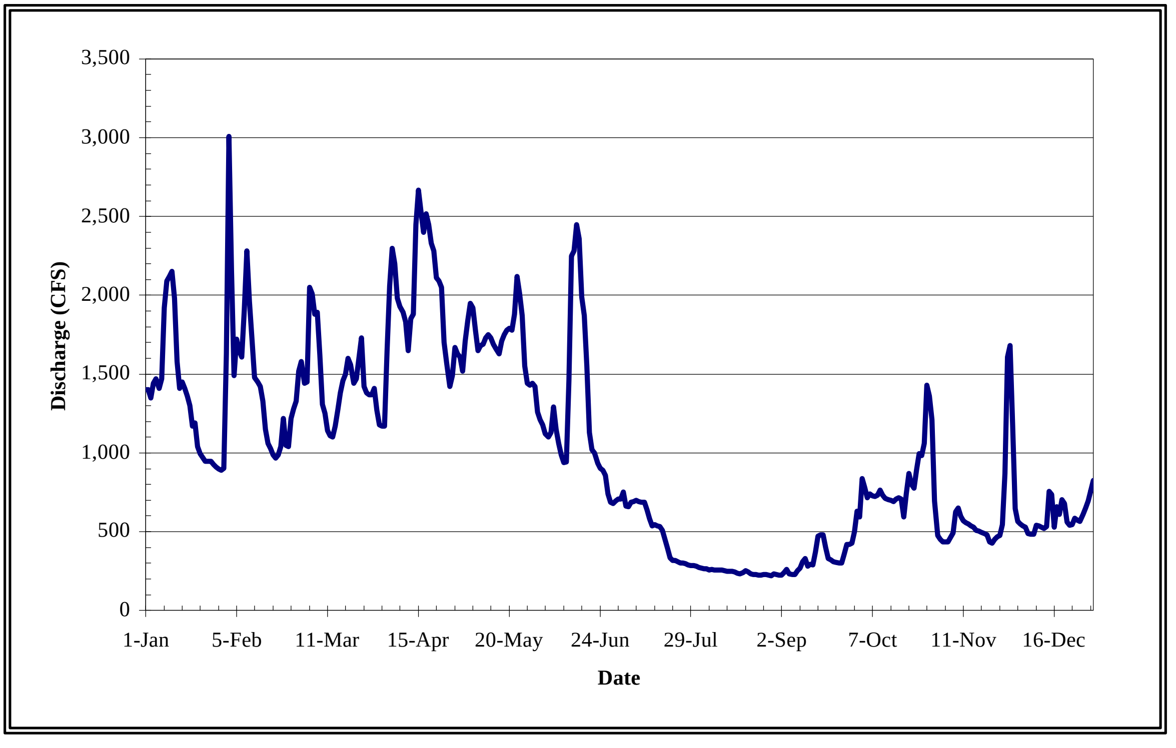

Figure 14. Mean daily discharge (cfs) as measured in middle Green River, Auburn, Washington, 2000 (USGS Gage 12113000).

Daily minimum, mean, and maximum water temperatures (°C) for six (6) survey sites are presented in Appendix A (Figures A-19 through A-24). Daily water temperatures were the highest (median = 12.0°C) and fluctuated the most in the Rootwad Gravel Bar Pool (RM 36.3) (Appendix A; Figure A-23). Daily water temperatures remained fairly constant and not significantly different at the Lower O'Grady Wallbase Side Channel (RM 40.0) and Coho Abandoned side channel slough (Appendix A; Figures A-21-22) (Student-Newman-Keuls Multiple Comparison Method; $p = 0.574$). Daily water temperatures were significantly lower at the USGS Mainstem Margin (RM 60.3) (median = 8.15°C) when compared to all other sites (Student-Newman-Keuls Multiple Comparison Method; $P < 0.05$) (Table 4).

Table 4. Student-Newman-Keuls multiple comparison of mean daily water temperature between 6 survey sites, middle Green River, Washington, 2000 (+ indicates that the first survey site was significantly greater than the second survey site; - indicates there is no significant difference).

Comparison	**q**	**P-value**	**Significant**
Rootwad vs **USGS**	10.96	<0.05	+
Rootwad vs Coho	11.31	<0.05	+
Rootwad vs Lower O'Grady	13.47	<0.05	+
Rootwad vs Lower Metzler	10.51	<0.05	+
Rootwad vs Slaughterhouse	11.24	<0.05	+
Slaughterhouse **USGS**	8.64	<0.05	+
Slaughterhouse vs Coho	8.51	<0.05	+
Slaughterhouse vs Lower O'Grady	10.45	<0.05	+
Slaughterhouse vs Lower Metzler	4.51	<0.05	+
Lower Metzler vs **USGS**	8.54	<0.05	+
Lower Metzler vs Coho	8.34	<0.05	+
Lower Metzler vs Lower O'Grady	11.16	<0.05	+
Lower O'Grady vs **USGS**	3.95	<0.05	+
Lower O'Grady vs Coho	1.34	0.57	**-**
Coho vs **USGS**	4.57	<0.05	+

4.3 PHYSICAL HABITAT SURVEYS

From initiation of the habitat survey metric (23 May) juvenile salmonid survey sites without an immediate and continuous connection with the mainstem Green River (i.e., gravel bar pools, and backbar, abandoned, and wallbase channels) decreased in mean surface area gradually over time (Figure 15). On 27 June, the mean surface area of all 11 juvenile salmonid survey sites without an immediate connection to the mainstem decreased in size dramatically. At this time, several sites also lost their connection with the mainstem through either the stranding of inlet and/or outlets of side channels or disassociation of gravel bar pools from the river channel. The point inflection point of the habitat area v. mainstem discharge occurred at/near 750 cfs (as measured at USGS Gage at Auburn, Washington. Unlike off-channel habitats, with respect to discharge, the surface area of mainstem margins did not function in the same manner. The habitat area stayed the same, but was displaced either higher or lower on the bank of the river. Habitat area of mainstem margins was removed from cover components such as large woody debris, overhanging vegetation, wetted vegetation, and mats of small woody debris, however (Tables B-1 through B-3).

With the exception of the Slaughterhouse Mainstem Margin, all juvenile salmonid survey sites contained large woody debris (Table B-3). In general, site-specific habitat parameters were similar between the mainstem and off-channel habitat units. The main differences occurred in the amount of habitat with water velocities less than 1 and 2 fps. In all instances, the amount of mainstem margin habitat area with water velocities less than 2 fps decreased as discharge in the Green River increased (Table B-2). The site-specific habitat data obtained from 18 juvenile salmonid survey sites in the middle Green River are presented in Appendix B (Tables B-1 through B-3). Photographs of juvenile salmonid survey sites are also presented for reference in Appendix B (Figures B-1 through B-15).

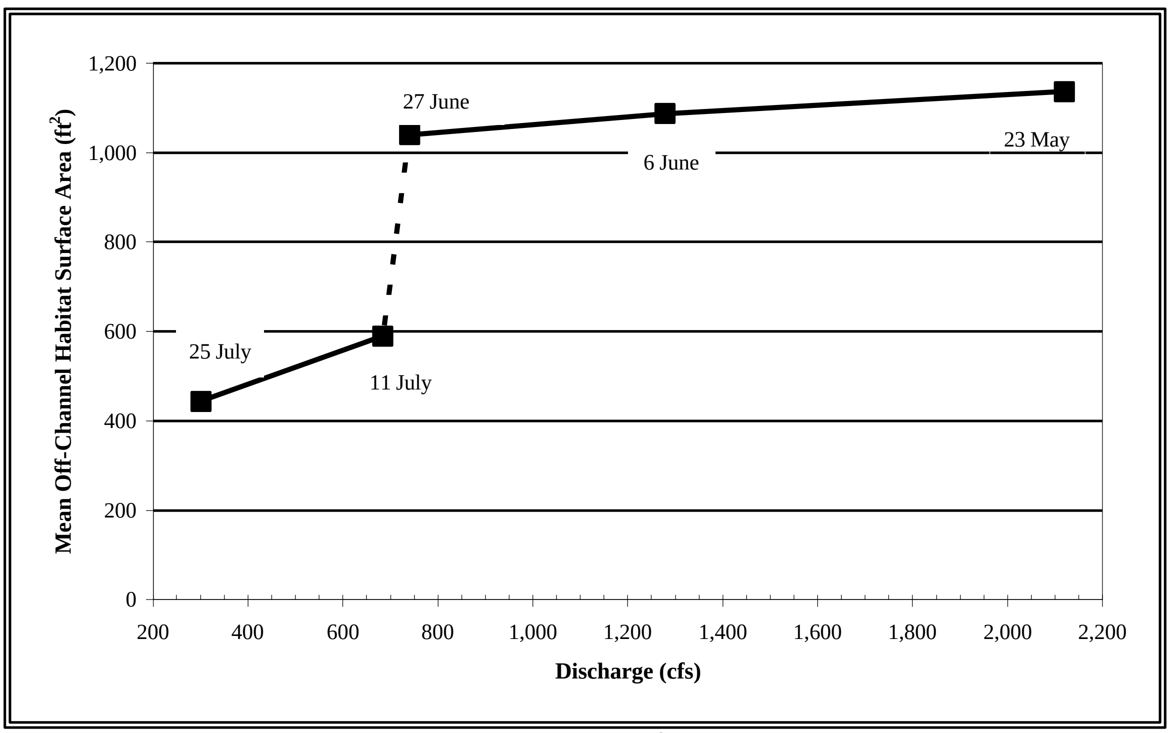

Figure 15. Mean off-channel habitat surface area (ft^2) measured at 11 juvenile salmonid survey sites at various discharge levels in middle Green River, Washington, 2000 (flow data source = USGS Gage 12113000, Auburn, Washington).

5. DISCUSSION

5.1 DAY/NIGHT ELECTROFISHING SURVEYS

5.1.1 Electrofishing Injury

As we develop natural resources to benefit man, we often alter natural ecosystem functions and impact the long-term stability of the natural environment. In an effort to minimize the impact of resource extraction, we survey, observe, and sometimes kill the very organisms we are trying to protect. During the 1998, 1999, and 2000 study seasons, we collected 4,687 juvenile chinook in the middle Green River. Of these, 4,468 (>95%) were collected using a backpack electrofishing unit utilizing straight DC current. Although we monitored these fish for only about 30 minutes before releasing them back into their site of capture, we observed only 12 immediate injuries/mortalities to chinook while electrofishing, or approximately one-fourth of one percent. In 1998 we captured 2,586 juvenile chinook (mean length = 48.2 mm; min. length = 31 mm; max. length = 208 mm; std. dev. = 9.8 mm) using the backpack electrofishing technique and 203 juvenile chinook using the fyke net (Table 5). In 1999, we captured 723 juvenile chinook using electrofishing techniques and 16 using the fyke net; all juvenile chinook were captured using backpack electrofishing in 2000 (Table 5). During 1998 and 1999, we captured a total of 219 chinook fry using the fyke net and observed three injuries/mortalities, or approximately 1.4 percent (Jeanes and Hilgert 2000).

Schill and Elle (2000) indicate that the severity of electroshock-induced hemorrhages increase initially and begin to decline by 15 d postshocking, resulting in few (<2%) long-term detrimental impacts to the rainbow trout (mean length ~ 270 mm that they studied. Fredenberg (1992) found that electrofishing using smooth (i.e., straight) electrical waveforms injured significantly fewer rainbow trout and brown trout (*Salmo trutta*) in Montana river systems than using other electrical waveforms (i.e., rectified AC, pulsed DC, and CPS). In a study to evaluate the incidence of sub-lethal spinal injuries on fish that were not visibly harmed by electrofishing, Dalbey et al. (1996) found that, when X-rayed, approximately 37 percent of the fish suffered from spinal injuries. None of these fish displayed visible injuries, but were much larger (153-388 mm FL) than the fish captured in the middle Green River. Like Fredenberg (1992), Dalbey et al. (1996) showed that smooth DC injured fewer fish (12%) than pulsed DC (40-54%). Injury and severity of injury rates were positively correlated with fish length ($r = 0.70$-0.83, $P < 0.02$) (Dalbey et al. 1996). Hollender and Carline (1994) reported injury rates of 14 percent on small (<125 mm TL) brook trout

(*Salvelinus fontinalis*) captured using backpack electrofishing units. However, unlike Dalbey et al. (1996) and Fredenberg (1992), they did not test smooth DC current, which could have lowered the injury rate to less than 14 percent (Hollender and Carline 1994).

Table 5. Year, number captured, visible injuries, and immediate mortalities for chinook captured during middle Green River biological surveys, 1998-2000.

Year	Survey Technique	Number of Chinook Captured	Visible Injuries	Immediate Mortalities	Total Immediate Injury/Mortality
1998	electrofish	2,586	1	1	2
1998	fyke net	203	1	1	2
Total		*2,789*	*2*	*2*	*4*
1999	electrofish	723	2	1	3
1999	fyke net	16	1	0	1
Total		*739*	*3*	*1*	*4*
2000	night electrofishing	537	4	0	4
2000	day electrofishing	622	3	6	9
Total		*1,159*	*7*	*6*	*13*
Grand Total		***4,687***	***12***	***9***	***21***

We have attempted to minimize injury to juvenile salmonids by several methods. Electrical current is supplied by using two hand-held wands as the anode and cathode, instead of the traditional format of a hand-held “wand” anode, and a “rat-tail” cathode (see Nielsen 1998 photographs). Juvenile fish captured using this technique are exposed to a brief electrical current before they are captured in the dip net. In addition, waters suitable to juvenile salmonids are much more “calm” environments than adult fish typically inhabit. This fact enables us to utilize brief periods of electrical current, capture the fish quickly, and transfer them to a live container to avoid excessive exposure to electrical current.

Often, stress, not electrofishing injury, has been correlated to the reduced survival of juvenile salmonids exposed to electrofishing (Nielsen 1998). Other factors such as operator expertise, frequency, voltage level, band width and pulse rate, and forms of electrical current are known to affect injury rates while employing this capture technique (Dalbey et al. 1996). As in 1998, guidelines for electrofishing waters containing salmonids listed under the Endangered

Species Act (NMFS 1998) were strictly adhered to during the 2000 field season. "Smooth or straight" DC current has been used and will continue to be used for this project. "Smooth" DC current at voltages of less than 400 have proven effective in the waters of the middle Green River. These electrofishing guidelines are within the standards cited by the National Marine Fisheries Service for backpack electrofishing waters containing fish species that are listed under the endangered species act (NMFS 1998), and State of Washington Scientific Collection Permit Application guidelines.

5.1.2 Relative Abundance of Juvenile Salmonids

The rate of fish capture during middle Green River juvenile salmonid surveys conducted in 2000 increased from the 1999 field season (Figure 16). In 1999, mean CPUE for day/night electrofishing sites was 0.03 fish per second of electrofishing effort, while in 2000 the relative abundance of juvenile salmonids increased to 0.07 fish per second. These rates are below 1998 capture levels of 0.13 fish per second of electrofishing effort. The mean CPUE of juvenile salmon and trout for day electrofishing sites was lower when compared to night electrofishing sites, but the difference was not statistically different (Table 6). Day and night CPUE was not significantly different within each year (One Way Repeated Measures ANOVA; $P = 0.188$) or when all years were combined (Kruskal-Wallis One Way ANOVA; $P = 0.660$), however the power of the statistical analysis was low (<0.80) and the significance of the tests should be viewed cautiously. Numerous researches have indicated juvenile salmonids become more active shortly after sunset than during the day, especially as water temperature drops below 8°C (Campbell and Neuner 1985; Don Chapman Consultants 1989; Riehle and Griffith 1993; Goetz 1994; Contor and Griffith 1995; Peters et al. 1998). Thus, the increase in relative abundance between day and night electrofishing sites, while not significant, was expected.

During 1999, the decrease in relative abundance of juvenile salmonids in the middle Green River was lower than expected. Adult escapement levels in the middle Green River were much lower during the 1999 brood year compared to 1998 (Table 7), but the decrease did not approach that observed for juvenile salmonids (Table 6). Another possible explanation for the decrease in relative abundance from 1998 to 1999 were elevated sediment levels caused by the Flaming Geyser landslide. However, examination of the data collected upstream from the landslide (i.e., Flaming Geyser backbar side channel) indicates the decline in relative abundance of juvenile salmonids from 1998 to 1999 (Jeanes and Hilgert 2000) occurred both above and below the landslide.

Relative abundance of juvenile salmonids between 1998 and 1999 did not decrease as drastically in abandoned and wallbase side channels as did CPUE in mainstem survey sites. A possible explanation is that low fall flows in 1999 may have concentrated spawning chinook closer to the thalweg of the channel which would cause eggs deposited in this area to be vulnerable to scour resulting from sudden increases in discharge (DeVries 1997; Harvey and Lisle 1999). Relative abundance of juvenile salmonids in the middle Green River rebounded in 2000 to levels similar to those experienced in 1998 (One Way ANOVA; P = 0.406).

In effort to evaluate the effects of the Flaming Geyser Landslide, two additional mainstem margin sites were added upstream from Flaming Geyser Park during the 2000 study period (i.e., USGS and Pipeline mainstem margins). Median juvenile salmonid indices measured during the 2000 field season were significantly greater at mainstem margins located downstream from Flaming Geyser (CPUE = 0.1345) than those located upstream (CPUE = 0.0214) (Mann-Whitney Rank Sum Test; P <0.01); however, the landslide at Flaming Geyser was not active during 2000.

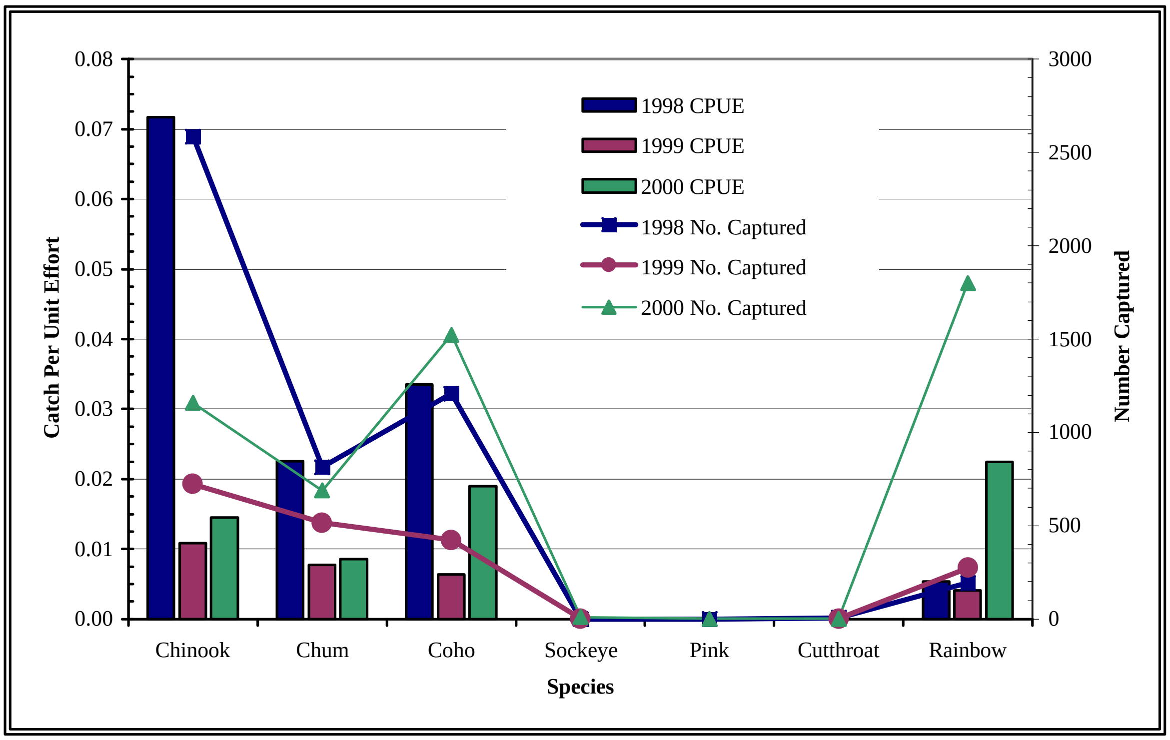

Figure 16. Catch per unit effort indices and total number of juvenile salmon and trout captured during juvenile salmonid surveys conducted in middle Green River, Washington, 1998-2000.

Table 6. Catch per unit effort indices of juvenile salmon and trout by day/night survey strata during middle Green River biological surveys, 1998-2000.

Species	**1998**		**1999**		**2000**	
	Day	**Night**	**Day**	**Night**	**Day**	**Night**
Chinook salmon	0.0534	0.0874	0.0073	0.0144	0.0120	0.0189
Chum salmon	0.0405	0.0072	0.0075	0.0081	0.0064	0.0125
Coho salmon	0.0245	0.0412	0.0037	0.0091	0.0174	0.0218
Sockeye salmon	0	0	0	0.00003	0.00001	0
Pink salmon	0	0	0	0	0.00001	0
Cutthroat trout	0.0002	0.0002	0	0.00003	0.00004	0.0003
Rainbow trout	0.0018	0.0084	0.0047	0.0035	0.0204	0.0261
Total	***0.1204***	***0.1444***	***0.0232***	***0.0352***	***0.0565***	***0.0798***

Table 7. Estimated escapement for chinook and steelhead in middle Green River, 1997-1999 (adapted from T. Cropp, WDFW, unpublished data).

River Section	**River Mile**		**Estimated Number of Redds**		
	Upper	**Lower**	**1997**	**1998**	**1999**
	Chinook Salmon				
Kummer Bridge to Old Geyser Bridge	47.0	43.0	307	160	126
Old Geyser Bridge to Slide	43.0	42.6	66	33	66
Landslide to Whitney Bridge	42.6	41.4	19	58	94
Whitney Bridge to Neely Bridge	41.4	35.0	641	583	690
Neely Bridge to Hwy. 18 Bridge	35.0	33.8	279	331	235
Totals			***1,312***	***1,165***	***1,211***
	Steelhead				
Kummer Bridge to Landslide	47.0	42.6	n/a	168	370
Landslide to Whitney Bridge	42.6	41.4	n/a	83	13
Whitney Bridge to Neely Bridge	41.4	35.0	n/a	372	160
Neely Bridge to Hwy. 18 Bridge	35.0	33.8	n/a	40	11
Totals			***n/a***	***663***	***554***
Landslide to Whitney Bridge	42.6	41.4	n/a	83	13

5.1.3 Habitat Use

The highest level of juvenile salmonid habitat use in 2000 occurred at the Slaughterhouse Mainstem Margin (mean CPUE = 0.1374) (Figure 17). As in past years, the relative use of mainstem lateral habitats in the middle Green River by juvenile salmonids was greater than commonly reported in other river systems (Figure 18). The use of mainstem habitat for juvenile salmonid rearing is not unique, and has been reported by other researchers in Washington (Hayman et al. 1996; R. Peters, USFWS, pers. comm.), Alaska (Thedinga et al. 1988), Idaho (Edmundson et al. 1968), California (USFWS et al. 1999), and Oregon (Reimers et al. 1971). Chinook salmon fry preferred the edge of the stream where low water velocities and structural cover was present in the Trinity River, California (USFWS et al. 1999). As they became larger, juvenile chinook became less dependent on edge habitats and moved into areas containing higher water velocities. A similar niche shift was observed on the middle Green River. In 2000, button-up chinook fry (i.e., yolk attached) were observed using only the shallow mainstem margins in the middle Green River. By late March and early April, juvenile chinook (TL = 50 mm) were using areas in the thalweg and associated with scour pools behind boulders and mats of large woody debris. Mean water column velocities in these habitats were less than 2.0 fps (E. Jeanes, R2, unpublished data).

Overyearling (primarily coho) use of wallbase side channel habitat was greater (CPUE = 0.0101) than use of other off channel habitat strata during the 2000 study period (Figure 18). We also found more overyearling salmonids in gravel bar pools (mean CPUE = 0.0063) than other mainstem habitat strata during 2000. For all study years, overyearling salmonids were observed most often in wallbase side channels (Median = 0.0102), but the difference was not statistically significant (One Way ANOVA; $P > 0.7$). Overyearling salmonids occupying wallbase side channels were generally associated with complex woody debris (i.e., debris accumulations). Often times, these debris accumulations formed in association with a piece of large woody debris (e.g., rootwad or large log). Peters et al. (1998) also found a strong relationship between chinook and coho fry, and total juvenile salmonid densities and large woody debris surface area. A lone piece of large woody debris did not appear to provide the habitat complexity needed for juvenile salmonids, but high densities were observed where smaller pieces of wood collected around larger pieces. Unlike coho, overyearling rainbow trout appeared to reside more often in mainstem, rather than off channel habitats. Steelhead parr density increased in habitats with increased gradient in five western Washington streams (Gibbons et al. 1985). Habitats with increased gradient did not occur at many of our off channel sites, possibly explaining the relatively low observed use of off channel habitat by overyearling rainbow trout in the middle Green River.

The off-channel sites were connected to the mainstem at all times though the mid-June survey period. In particular, gravel bar pool sites are prone to severe fluctuations in connectivity to the mainstem. This habitat strata is generally small in size and infrequently distributed throughout the middle Green River, but consistently have contained large numbers of juvenile salmonids throughout the study period (Figure 19). During the planned flow release conducted in 1998, juvenile salmon were present in the gravel bar pool immediately before the flow release (site was disconnected from the mainstem), during the flow release (site became re-connected), and immediately after the flow release (site was disconnected from the mainstem). When properly instituted, the planned flow release appears to be an effective management strategy to allow dispersal of salmonids from this habitat type. All off-channel areas surveyed from 1998-2000 remained connected with the mainstem when flows in the Green River at Auburn were greater than 850 cfs.

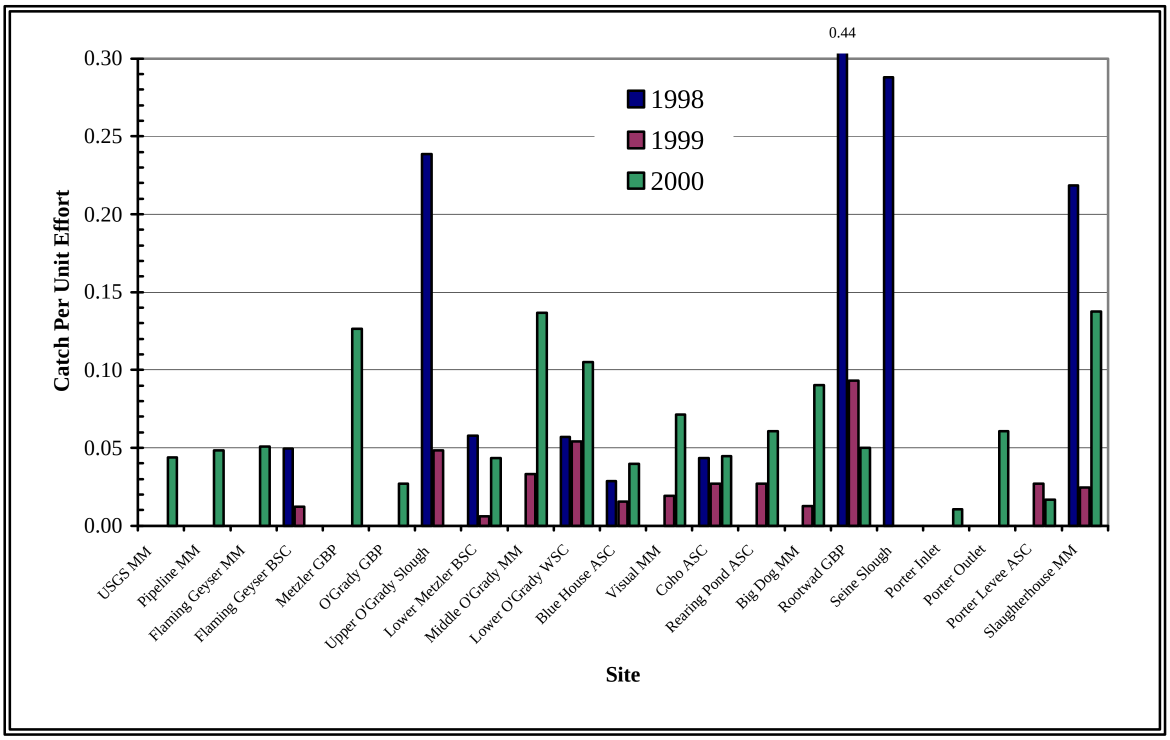

Figure 17. Catch per unit effort indices for each day/night electrofishing site, middle Green River, 1998-2000.

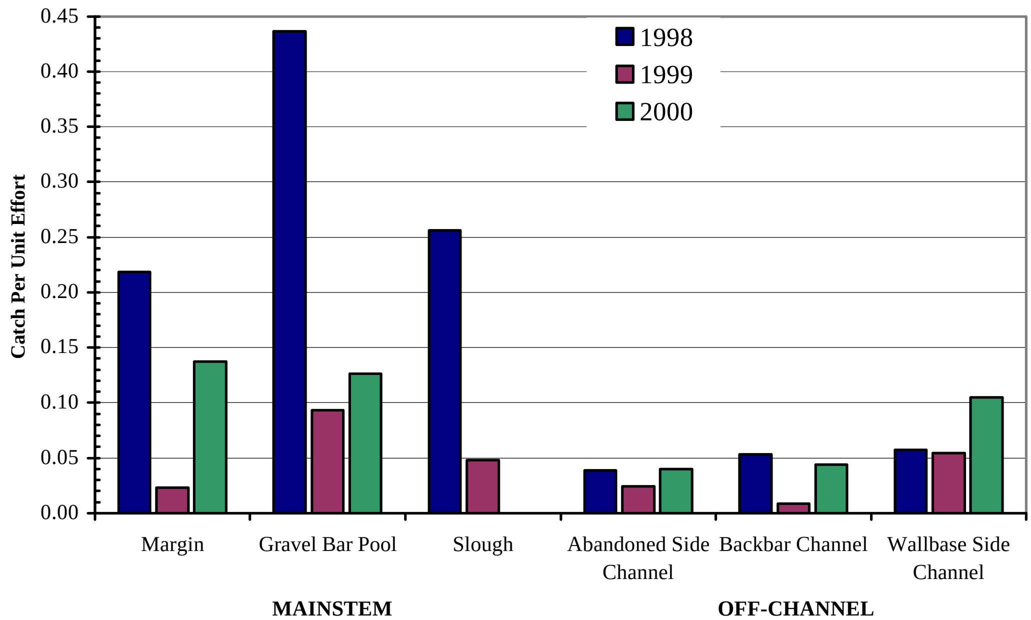

Figure 18. Relative use of mainstem (margin, gravel bar pool, and slough), and off-channel (abandoned side channel, backbar side channel, and wallbase side channel) habitat by juvenile salmonids in the middle Green River, Auburn, Washington, 1998-2000.

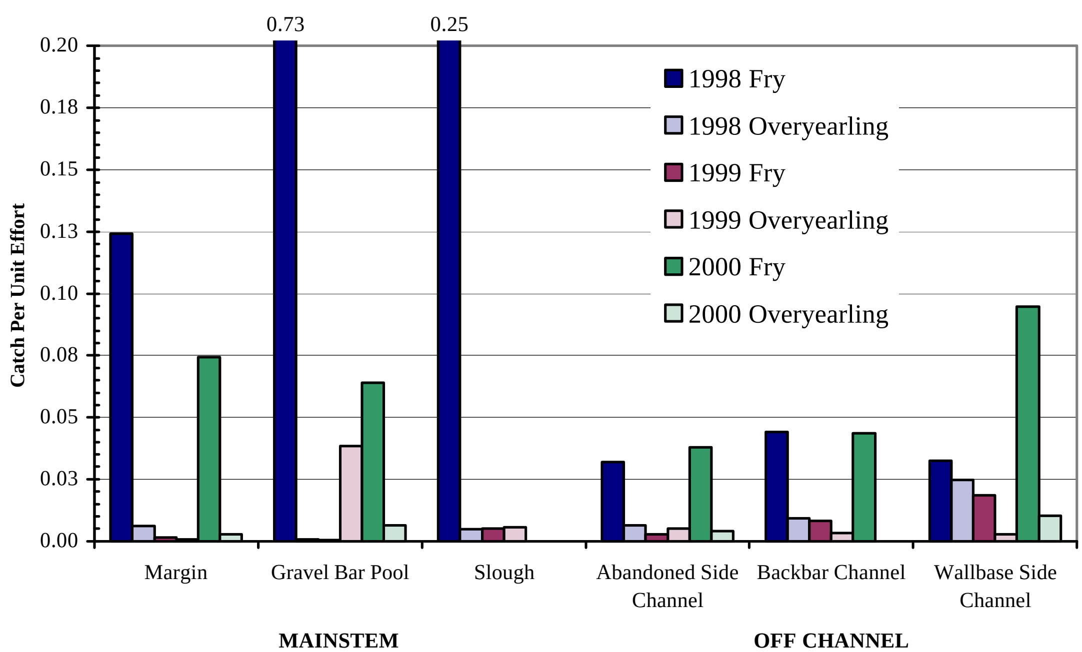

Figure 19. Relative use of mainstem (margin, gravel bar pool, and slough), and off-channel (abandoned side channel, backbar side channel, and wallbase side channel) habitat by age category (fry and overyearling) in middle Green River, Auburn, Washington, 1998-2000.

5.1.4 Juvenile Size and Growth

The mean size of chinook fry was larger than that of chum or coho throughout the study period (Figure 20). Mean length of chinook fry increased at a rate of 0.288 mm per day, while coho and chum increased at 0.293 and 0.242 mm per day, respectively (Figure 20). Growth of all species was probably underestimated because of ongoing migration of newly emerged fry into the study area. We expected fry rearing in some habitat strata (i.e., mainstem) to grow faster than others because of differences in water temperatures; however this was not evident. Sommer et al. (2001) found that growth of juvenile chinook was significantly increased in seasonally flooded agricultural floodplains compared to mainstem Sacramento River channels. The increased growth was primarily attributed to higher water temperatures that occurred in the floodplain areas.

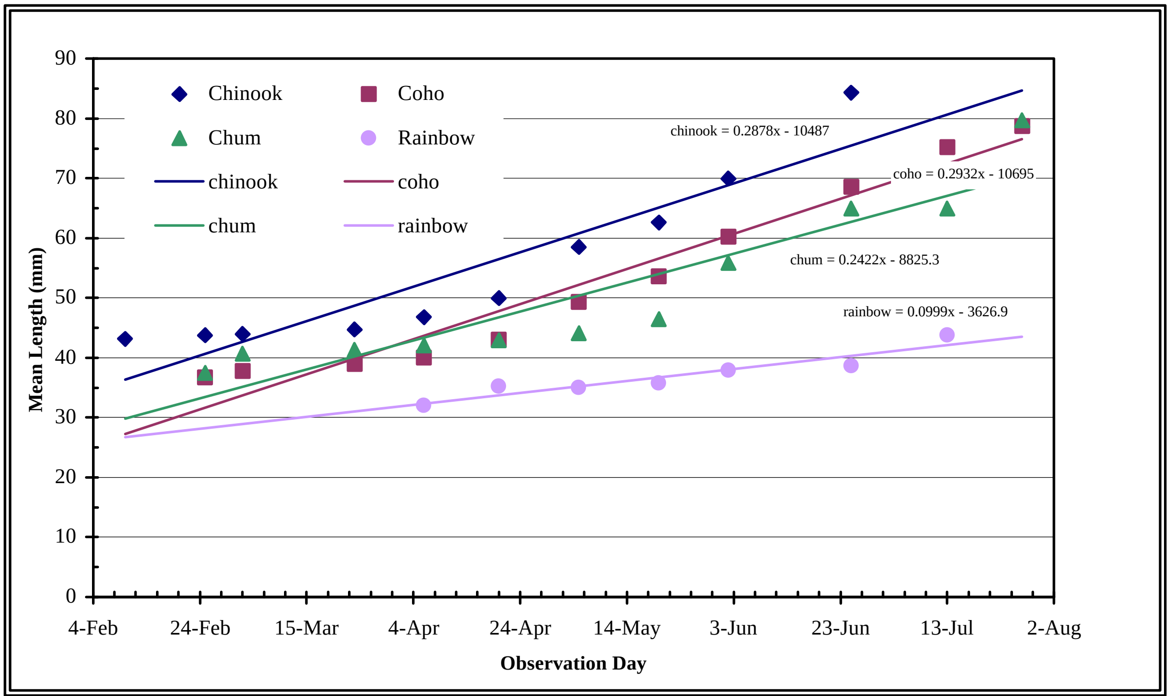

Figure 20. Mean size (mm) and growth characteristics of chinook, coho, and chum fry in the middle Green River, Auburn, Washington, 1998-2000.

Growth of chinook fry in the middle Green River is almost twice as fast as that of chinook fry in the Taku River, Alaska (Murphy et al. 1989). Apparent growth rates were less than those (i.e., mainstem = 0.43 mm day^{-1}, floodplain = 0.55 mm day^{-1}) reported in the Sacramento River, California during 1999 (Sommer et al. 2001). The large discrepancy may occur from the difference in water temperatures between these systems. The size and growth discrepancy between chinook, coho, and chum fry may impart differential survival of the three species while they rear in the middle Green River, as early life history success is often strongly size dependent (Miller et al. 1988; Schindler 1999). Sommer et al. (2001) hypothesized floodplain rearing increased survival of juvenile chinook; however these results were inconclusive and the benefits to survival derived from increased growth remain circumstantial. Finally, the apparent growth of chinook salmon fry measured by this study is corroborated by that measured from chinook captured in a downstream-migrant trap (screw trap) located near our downstream-most site at RM 34.0 (D. Seiler, WDFW, unpublished data). Chinook fry captured from juvenile salmonid surveys were smaller (mean = 50.5 mm; Std. Dev. = 9.79 mm) than their counterparts captured in the screw trap (mean = 51.4 mm; Std. Dev. = 16.53 mm) (Table 8). The size discrepancy was expected, however, as we noticed a similar difference in size as we progressed downstream.

Table 8. Mean fork length of chinook salmon fry captured from screw trap and during juvenile salmonid surveys, February - July, 2000, middle Green river, Washington.

Week Ending	**Screw Trap Data**					**Lateral Habitat Data**				
	Mean	**Std Dev**	**Min**	**Max**	**N**	**Mean**	**Std Dev**	**Min**	**Max**	**N**
13-Feb-00	38.6	1.20	35	41	40					
20-Feb-00	37.8	1.88	34	43	146					
27-Feb-00	39.3	1.62	36	44	88					
5-Mar-00	38.9	2.18	35	45	76	44.2	2.45	35	57	382
12-Mar-00	38.8	2.28	34	46	71					
19-Mar-00	43.7	7.58	34	60	86					
26-Mar-00	57.0		57	57	1	47.5	6.85	37	95	280
2-Apr-00	45.8	9.84	36	68	40					
9-Apr-00	52.0	12.58	34	73	36	49.7	5.72	38	67	143
16-Apr-00	52.2	7.78	41	73	26					
23-Apr-00	57.2	6.55	47	65	9	54.2	7.40	35	75	168
30-Apr-00	59.6	7.75	40	78	28					
7-May-00	63.1	7.78	50	84	47	62.0	9.42	42	90	120
14-May-00	68.1	8.10	50	90	92					
21-May-00	69.5	7.14	55	82	35	70.3	11.49	46	101	50
28-May-00										
4-Jun-00	79.0	8.15	60	93	33	72.0	6.05	63	82	15
11-Jun-00	82.4	10.10	49	104	33					
18-Jun-00	79.4	6.70	65	92	38					
25-Jun-00	76.3	11.93	63	86	3					
2-Jul-00										
9-Jul-00	92.8	5.50	88	98	4	95.0		95	95	1
Totals	***51.4***	***16.53***	***34***	***104***	***932***	***50.5***	***9.79***	***35***	***101***	***1,159***

5.1.5 Flow Management

Annual variation in freshwater survival rate of juvenile salmonids is often affected by the severity of fall flow conditions (D. Seiler, WDFW, unpublished data). The number of juvenile salmonids we observed in the Green River during the 2000 field season were thus affected by both the fall 1999 escapement and flow conditions during spawning and incubation. During the fall of 1999, reservoir storage was used to supplement flow releases. Howard Hanson Reservoir pool elevation was 1,115.8 ft, inflows to the project were 120 cfs, and releases were set at 260 cfs on 1 October 1999. Normal release from the project during this period is 223 cfs (110 cfs fish enhancement; 113 cfs water supply). During the fall of 1999, the City of Tacoma did not withdraw the entire portion of their water allotment, and flows at Auburn remained above 300 cfs on all occasions, except 7 October (287 cfs). From 9 December 1999, the normal flood control pool elevation of 1,075-1,080 ft was maintained (except for short-term storm events) throughout the winter (T. Murphy, USACE, pers. comm.).

The maximum flood control pool during the 1999/2000 flood season was 1,126.6 ft (16,603 ac ft) and was achieved on 26 December 1999. Peak streamflows reached 8,950 cfs on 27 December 1999 on the Green River at Auburn gage. This flow was well below the authorized maximum flow event (12,000 cfs), and was the largest release from HHD during WY 2000. All planned flow releases were designed to mimic natural conditions while capturing several feet off the peak and delaying the release of that water to prevent downstream flooding. Attempts to lower the pool elevation below 1,070 ft prior to freshets and to redistribute sediments accumulating in the reservoir were not successful during WY 2000 (T. Murphy, USACE, pers. comm.).

Refill criteria were established in coordination with various resource agencies. Annual spring refill began on 13 March 2000 with a pool elevation at approximately 1,077 ft. Initial refill criteria included capturing approximately 15 percent of the inflow to the reservoir, setting the minimum discharge from the project at 600 cfs, and a maximum discharge at Auburn of 2,400 cfs. Full pool (1,141 ft) was reached on 16 May 2000, while refill continued to pool elevation 1,147 ft in order to capture additional water to augment discharge downstream of HHD during early summer rearing periods. The discharge at the Auburn gage was held at 700 cfs until 15 July 2000, when gradual decreases began to occur (T. Murphy, USACE, pers. comm.).

The 2000 Green River biological monitoring study represents the third year in a multiple year study of juvenile salmonid behavior during the spring freshwater rearing months. The study objectives are focused on the spring period since under the AWSP, water is stored for later release during summer low flow periods. These studies are funded through the AWSP and are designed to help identify operational procedures to minimize impacts of the AWSP on instream resources. Multiple years of data are necessary to identify the variation of fish response to man-induced changes in their environment. These data will be beneficial while making flow management decisions under the AWSP, which is currently scheduled to come online in 2005.

One objective of flow management in the Green River should be to mimic the flow regime that would occur in the absence of man-induced changes. Accomplishing this objective is particularly challenging while the USACE and the City of Tacoma simultaneously attempt to meet flood control, water supply, and low flow augmentation responsibilities. By releasing a percentage of inflow during the spring, HHD operations may mimic the variation, if not the magnitude of inflow into HHD. Forecasting the total runoff and identifying the correct percentage to store is an inexact science and decisions to alter the percent of water storage as the reservoir fills will benefit from knowledge of fish response to flow conditions. In the interest of optimizing multiple use of the water, it may be more efficient to store a greater percentage of high flows and cease storing water when inflow naturally drops for short periods. Storing water in March will have different effects on instream resources than storing water in May. In each of the above scenarios, understanding the risk to instream resources associated with different water storage and release strategies will be critical to minimize impacts of the AWSP.

The life history of fish residing in the Green River will be very important to identify HHD operational procedures that minimize the risks to instream resources. Life history strategies of salmonids have been defined as a set of reproductive and behavioral traits that result from selection in a specific environment (Stearns 1976). Life history strategies of juvenile fall chinook are complex and tend to vary from river to river (Healey 1991; Myers et al. 1998). Green River chinook are one of the few Puget Sound fall chinook stocks that consistently meet or exceed escapement quotas, yet little research has been conducted on their freshwater rearing strategies. A thorough understanding of their life history phases must be understood while implementing HHD storage and release operations. The following discussion details certain aspects of juvenile fall chinook phases.

In general, upon emergence from the gravels, chinook follow one of two life history strategies while residing in freshwater as juveniles. Stream-type juveniles reside in streams for a year to eighteen months before moving downstream to saltwater, while ocean-type juveniles migrate to saltwater sometime during their first year (Taylor 1990). Certain gradations or behavioral tendencies within the ocean- and stream-type rearing strategies have also been identified in fall chinook populations (Table 9) (Reimers 1971; Hayman et al. 1996).

Table 9. Life history phenotypes identified in juvenile fall chinook salmon in Sixes River, Oregon, and status of life history phenotypes in the Green River (adapted from Reimers 1971).

Life History Category	Life History Description	Status in the Green River
Phase I	Chinook alevins emerge from the gravel and move immediately downstream to saltwater within two weeks of emergence.	Present
Phase II	Chinook alevins emerge from the gravel and move into lateral rearing habitat of the mainstem (or tributary) until early summer before migrating downstream to the estuary.	Present
Phase III	Chinook alevins emerge from the gravel and move into lateral rearing habitat of the mainstem (or tributary) until late summer before migrating downstream to the estuary.	Unknown
Phase IV	Chinook alevins emerge from the gravel and stay in the tributary streams (or the mainstem river) until autumn rains before moving downstream.	Unknown
Phase V	Chinook alevins emerge from the gravel and stay in the tributary streams (or the mainstem river) until the next spring and migrate downstream as yearlings.	Present

Juvenile Pacific salmon exhibit behavioral responses to environmental conditions while still in the sub-gravel environment (Dill 1969). Upon hatching salmonid alevins initiate a downward movement into the gravels. The extent of the downward movement is often related positively to the size of the gravel. Alevins generally exhibit a strong negative phototaxism during this time. A general upward movement of alevins within the gravel environment then follows, typically within one month after hatching and is often associated with absorption of the yolk sac (Dill 1969). Sub-gravel behavioral tendencies may have adapted as a protective mechanism during periods of redd dewatering (Becker et al. 1982).

Redd dewatering is known to increase the mortality of chinook eggs, embryos, and alevins (Becker et al. 1982; Stevens and Miller 1983; Reiser and White 1983). Redd dewatering often occurs when chinook spawn in shallow water following periods of short-term high water levels following a storm (Stevens and Miller 1983). The degree of mortality is different between developmental stages in a chinook redd (Becker et al. 1983). An embryo is relatively resistant to mortality (up to 80% survival under 22-hr dewatering for 20 consecutive days) as long as it remains somewhat moist and within areas of high relative humidity (Becker et al. 1983; Reiser and White 1983). Upon hatching, however, the degree of resistance to dewatering decreases dramatically. Alevins experienced almost total mortality when dewatered for six consecutive hours (Becker et al. 1983).

As chinook fry emerge from the gravel environment they rapidly disperse downstream from the redd. This behavior has been hypothesized as a mechanism to reduce predation and minimize energy expenditures that are needed to adjust population levels to available food and space (Reimers 1971). Generally, this behavior occurs during the night with fry drifting downstream in the current until reaching calm water or until daylight. Passive migration downstream may occur for several days after emergence from the redd, and before fry adopt the social behavior of resident fish (i.e., social interactions) (Reimers 1971). Under this hypothesis, late emerging chinook fry may be selected against, whereby the most productive rearing habitats are already occupied upon their emergence and smaller, less-developed fish, are displaced into unfavorable habitat conditions.

The distribution of juvenile chinook in freshwater is often positively correlated with water depths, and more importantly velocities, in proportion to their body size (Chapman and Bjornn 1969; Lister and Genoe 1970; Reimers 1971; Everest and Chapman 1972; Wright et al. 1973; Don Chapman Consultants 1989; Bjornn and Reiser 1991; Healey 1991; Spence et al. 1996; Cramer et al. 1999). Hayman et al. (1996) and Beamer and Henderson (1998) found that most juvenile chinook in the Skagit River, Washington occupied "near-shore" areas. The authors developed three near-shore strata: 1) bank habitat (vertical or near shore); 2) bar habitat (shallow, low-gradient shore interface); and 3) backwater habitat (enclosed, low-velocity areas separated from the main river channel). Juvenile chinook use of these areas was highest in backwater (0.17 chinook per ft^2) followed by natural banks (0.09 chinook per ft^2) and bar habitat (0.04 chinook per ft^2). Likewise, Murphy et al. (1989) found chinook in the Taku River, Alaska primarily occupied mainstem habitats, rarely using off-channel areas. Diurnal migrations into shallow, slow, sandy mainstem margins is common among larger (>60 mm) chinook fry that occupy deeper and faster daytime habitats (Don Chapman Consultants 1989).

The diet of juvenile chinook salmon also varies greatly between estuaries in the Pacific Northwest (Healey 1991). Juvenile chinook salmon captured in the Duwamish estuary primarily fed on benthic amphipods, mysid shrimp, and insect drift (Cordell et al. 1999a). The differences in diet composition between the Duwamish and other Puget Sound estuaries are thought to be related to habitat type (i.e., lack of emergent vegetation in the Duwamish estuary), and indicate the ability of juvenile chinook to opportunistically feed on a variety of insects (Cordell et al. 1999a; 1999b). After spending a year in Puget Sound, ocean type chinook generally migrate north along the shoreline, rarely exceeding 600 miles (as revealed by a relative lack of recoveries in the southeastern Alaska troll fishery).

Juvenile chinook salmon exhibit a range of freshwater life history strategies. These strategies may help the population persist in the face of annual variations in habitat availability in both freshwater and marine environments. The relative contribution of each of the life history strategies to total adult returns is difficult to quantify and may vary from year to year (Reimers 1971). Springtime operation of HHD will affect the different life history strategies and could benefit the survival of one juvenile strategy over another. Structural modifications associated with the AWSP will provide fisheries managers the opportunity to influence flow releases and affect the survival of different juvenile strategies. Unfortunately, the rudimentary understanding of the influence of habitat changes on chinook survival limits the value of the opportunity to modify springtime flows. As part of the pre-construction engineering and design phase of the AWSP, monitoring of lateral habitats in the Green River will provide a species-specific understanding of the start, peak and end of salmon emergence, rearing, and downstream migration. On-going studies will identify annual variations in observed life history patterns and provide an environmental baseline of salmonid behavior to compare the effects of future actions.

For example, initial emergence of chinook from gravels in the middle Green River has not been concisely narrowed down. In 1998, surveys began on 25-26 February, while in 1999 we began on 10 February. In both years, newly emerged chinook were present in the study area, however, the mean size of chinook on 10-11 February (mean = 43.33 mm; n=33) and the large percentage of button-up fry (defined as incomplete absorption of the yolk sac) indicate that emergence had just begun in 1999. During 2000, button-up chinook were also present on the first survey date (1 March). Over the 1999-2000 study periods, 40 out of 1,882 chinook fry (~2%) were captured with incompletely absorbed yolk sacs (Table 10). This is opposed to later-emerging species such as coho salmon (13; 1%); chum salmon (99; 8%); and rainbow trout (58; 3%) (Table 10). Ideally, future studies should begin as early as late December to definitively identify the start of chinook emergence. These data should be

Table 10. Number and length (mm) of button-up (BU) fry captured during middle Green River biological surveys, 1999-2000.

Month	No. Fry Captured	No. BU Fry	Percent BU Fry	Mean BU Length (mm)	Std. Dev. Length (mm)
			Chinook Salmon		
Feb	101	4	4	42.5	1.3
Mar	964	33	3	41.5	2.4
Apr	518	3	1	41.0	3.0
May	257	0	0	0.0	0.0
Jun	41	0	0	0.0	0.0
Jul	1	0	0	0.0	0.0
Totals	***1,882***	***40***	***2***	***41.6***	***2.4***
latest button-up date = 27 April					
			Coho Salmon		
Feb	29	0	0	0.0	0.0
Mar	229	3	1	35.0	2.0
Apr	445	10	2	37.5	2.1
May	515	0	0	0.0	0.0
Jun	438	0	0	0.0	0.0
Jul	290	0	0	0.0	0.0
Totals	***1,946***	***13***	***1***	***36.9***	***2.3***
latest button-up date = 27 April					
			Chum Salmon		
Feb	0	0	0	0.0	0.0
Mar	214	24	11	39.0	2.7
Apr	563	74	13	38.8	1.9
May	384	1	0	42.0	0.0
Jun	40	0	0	0.0	0.0
Jul	4	0	0	0.0	0.0
Totals	***1,205***	***99***	***8***	***38.9***	***2.1***
latest button-up date = 9 May					
			Rainbow Trout		
Feb	18	0	0	0.0	0.0
Mar	107	0	0	0.0	0.0
Apr	46	4	9	32.0	0.8
May	71	2	3	29.5	3.5
Jun	842	30	4	30.5	1.9
Jul	984	22	2	29.9	1.9
Totals	***2,068***	***58***	***3***	***30.4***	***1.9***
latest button-up date = 27 July					

combined with temperature degree-day and spawning information to predict the start of chinook emergence in any given year. Under one scenario of the AWSP, increasing water withdrawals in early February would primarily affect the portion of the chinook population that moves downstream shortly after emergence. Most of the chinook captured during this study (1998 through 2000) were captured in March (mean = 44.3%) and April (mean = 31.5%) (Figure 21), suggesting that water withdrawals in early February would impact a smaller proportion of juvenile chinook. An unknown portion of chinook emerging prior to mid-February, as well as coho (Figure 22), chum (Figure 23), and rainbow trout fry (Figure 24) would likewise be unaffected by the AWSP under this scenario.

Early reservoir refill will impact chinook fry that emerge from the gravels and move immediately downstream to saltwater by decreasing migration flows in the Green River. Reimers (1971) indicated that this life history phase (termed Phase I) were relatively unimportant to the returning spawning population. He found that chinook fry that reared in the river until early summer (~90 days) composed more than 90 percent of the spawning chinook in the Sixes River, based on scale characteristics. We are not suggesting that Phase I chinook are not important to the Green River chinook population as a whole, rather attempting to develop a programmatic methodology that identifies the risks and benefits of flow manipulation. By mid-April, most chinook emergence is complete and chinook fry that rear in the Green River have developed resident territories. By the end of April, we see a noticeable decline in the number of chinook fry present in the middle Green River (Figure 21), indicating that downstream movement away from the project reach is occurring.

The goal of the flow management plan for the Green River is to minimize impacts from the AWSP. Increasing the rate of water storage in March or May affects each species depending on the timing of emergence and downstream migration. Until better information is developed, perhaps the least risk scenario would involve spreading the risk of impact uniformly across all months. The “least risk” strategy may be difficult to attain, and even attempting that strategy involves more risk to some species than others. For example, during a forecasted “wet” spring, a relatively low percentage rate of storage may be employed at the start of the refill season to spread storage uniformly over the entire spring period. If the late spring should actually be relatively “dry,” the percentage rate of storage may have to be increased to achieve congressionally authorized storage volumes. This storage pattern would result in greater impacts to fry (Figure 25) and overyearling (Figure 26) during the February through April period as opposed to May through June. An adaptive refill schedule utilizing a juvenile salmonid monitoring plan and mid-season correction could prove to be very important. A thorough understanding of life history phases of juvenile salmonids and confirming or rejecting hypotheses of the long-term effects from changes in discharge will be important to help make mid-season decisions.

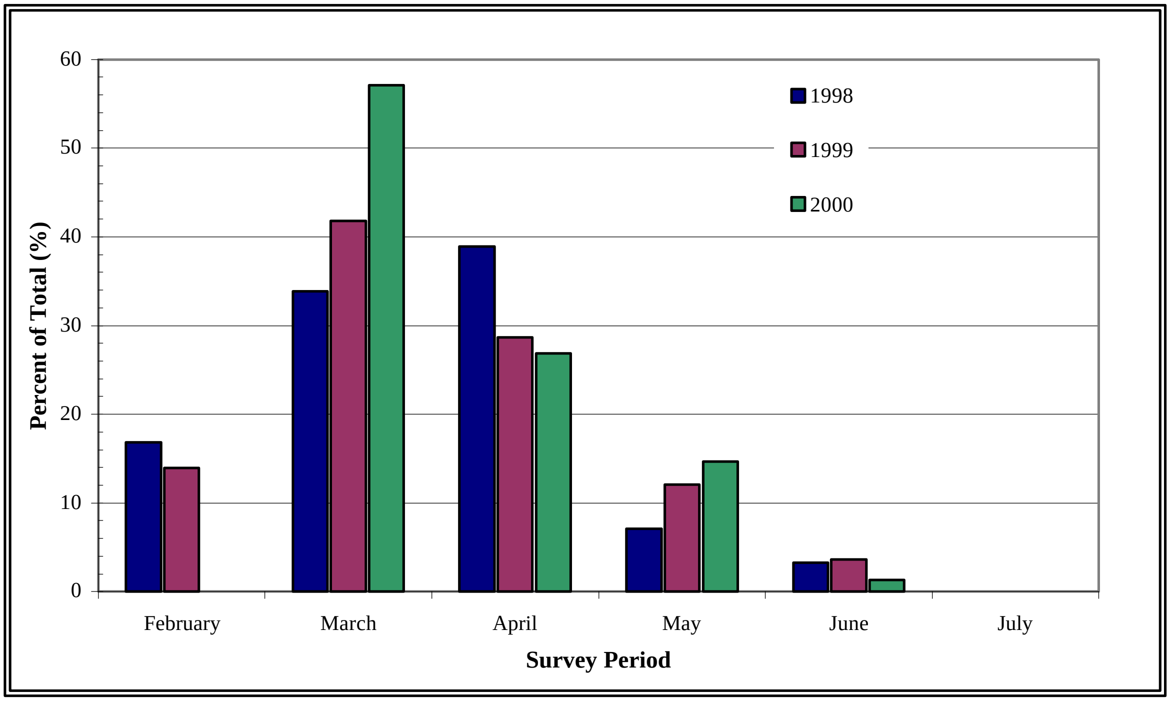

Figure 21. Percentage of total chinook salmon fry captured by survey month during 1998 (N=2,279), 1999 (N=723), and 2000 (N=1,157) juvenile salmonid surveys conducted in middle Green River, Washington.

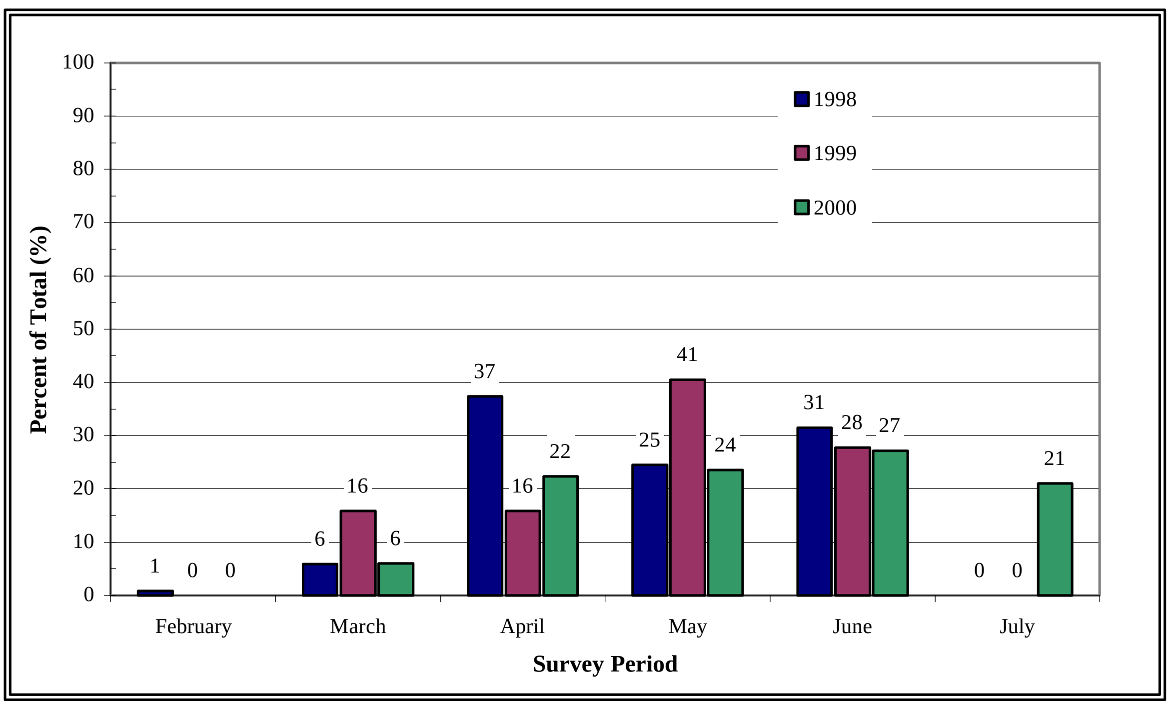

Figure 22. Percentage of total coho salmon fry captured by survey month during 1998 (N=1,016), 1999 (N=227), and 2000 (N=1,381) juvenile salmonid surveys conducted in middle Green River, Washington.

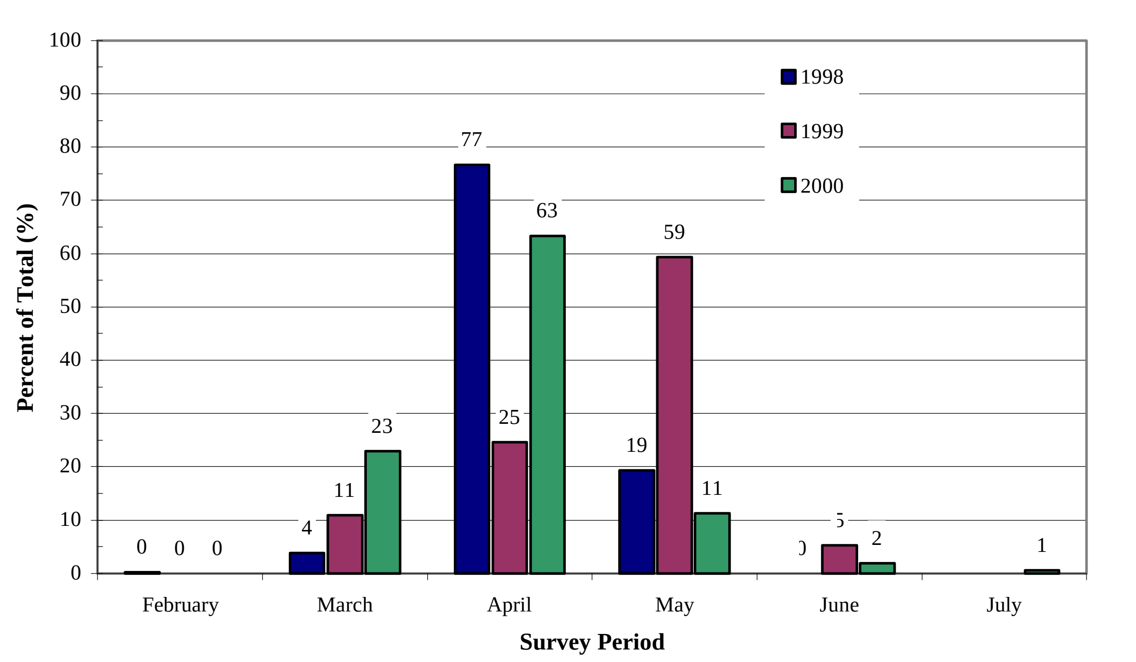

Figure 23. Percentage of total chum salmon fry captured by survey month during 1998 (N=813), 1999 (N=516), and 2000 (N=689) juvenile salmonid surveys conducted in middle Green River, Washington.

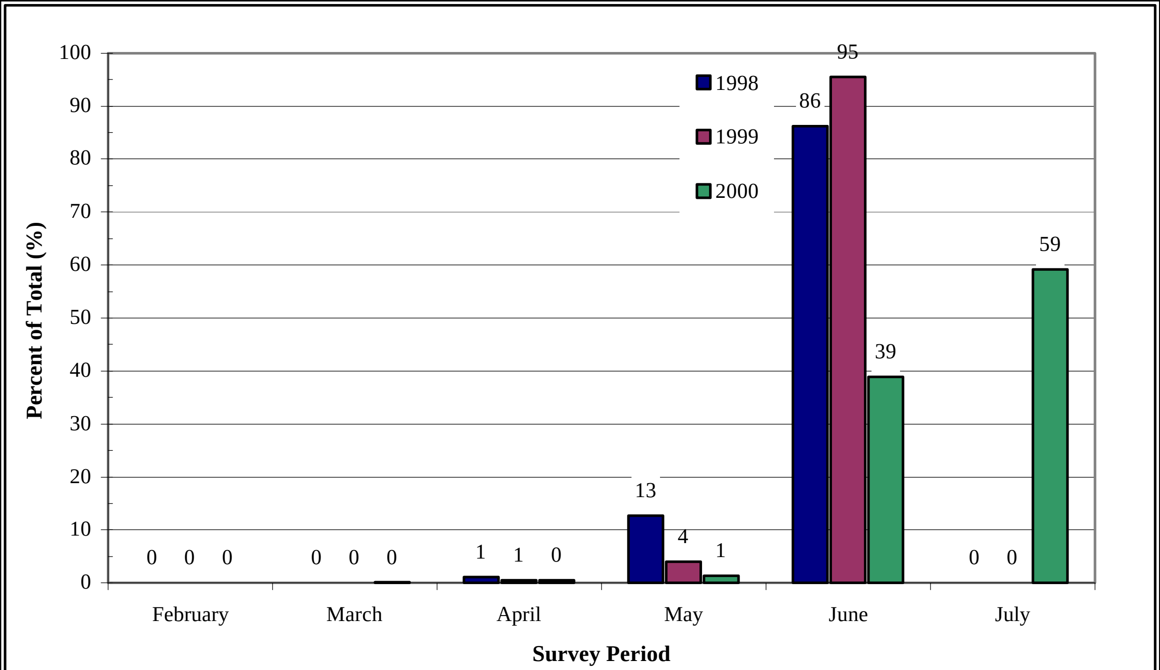

Figure 24. Percentage of total rainbow trout fry captured by survey month during 1998 (N=87), 1999 (N=176), and 2000 (N=1,662) juvenile salmonid surveys conducted in middle Green River, Washington.

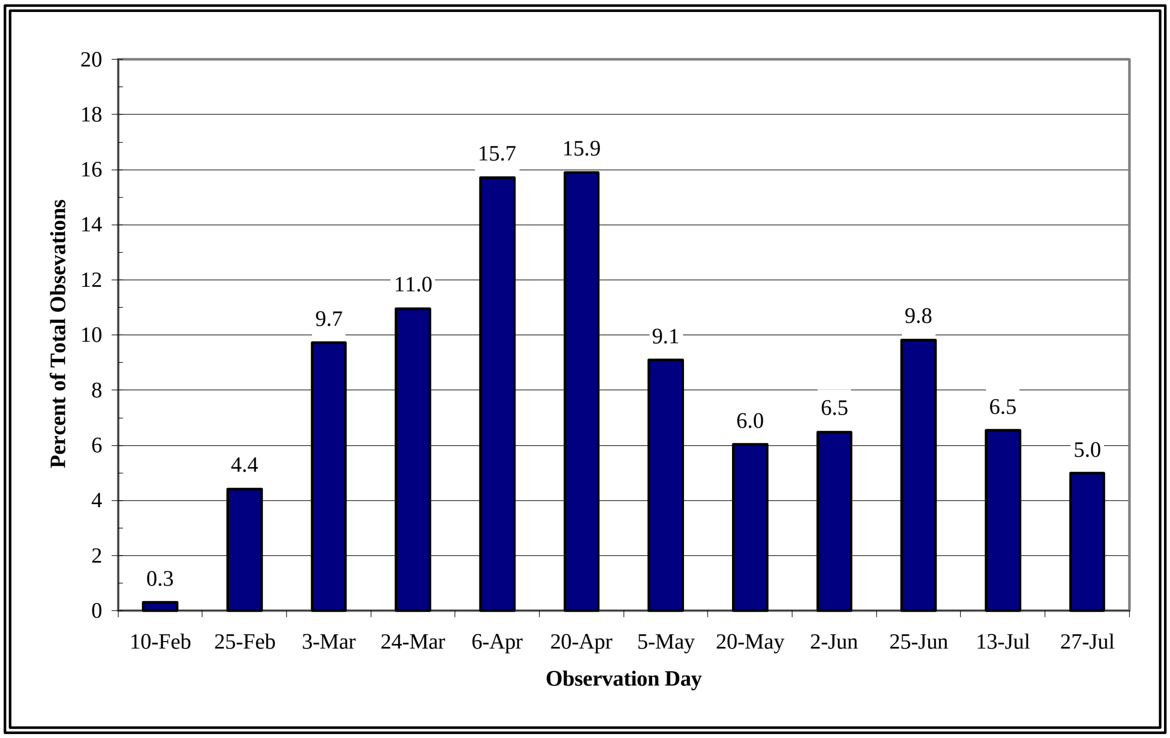

Figure 25. Percent of total observations of salmon and trout fry (N = 11,023) in middle the Green River, Auburn, Washington, 1998-2000.

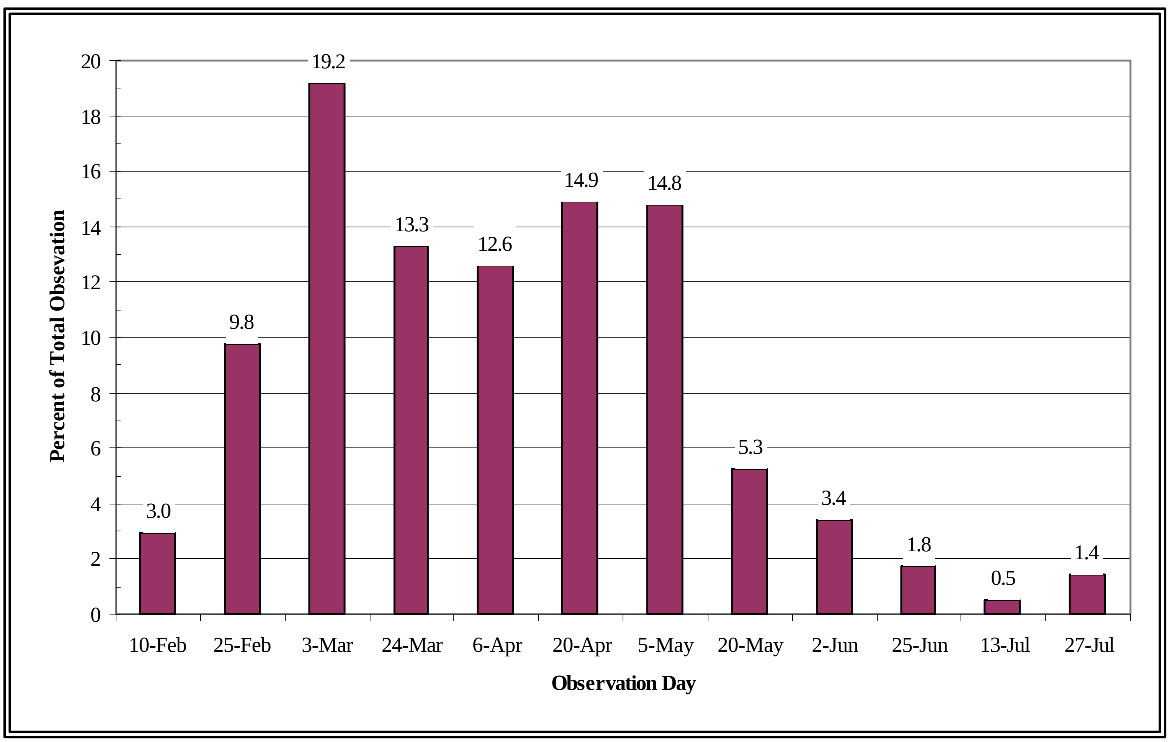

Figure 26. Percent of total observations of salmon and trout overyearlings (N = 911) in middle the Green River, Auburn, Washington, 1998-2000.

6. SUMMARY & RECOMMENDATIONS

Our study has concentrated on sites that retain a connection with the mainstem Green River so that juvenile salmonids could be monitored throughout their rearing period. We have not quantified the quality or distribution of habitats within the study reach. Similar research is now being conducted on the Cedar River, Washington, a system that contains more bank modification (i.e., levees and revetments) than the middle Green River. We have documented that juvenile salmonids in the middle Green River utilize a variety of habitat types. Salmonid fry (primarily chinook) were observed to use mainstem habitats in the middle Green River much more than off-channel habitats. Overyearling (primarily coho and cutthroat) tend to be found in association with off channel habitats that contain complex woody debris structures. Juvenile salmonid use of large woody debris with an attached root system and an accumulated “mat” of small woody debris was prevalent within our study reach. The structural complexity of this habitat allows for visual isolation from other aquatic biota as well as avian and terrestrial predators. The abundance of large woody debris in the Green River is an order of magnitude lower than other Pacific Northwest streams (Fuerstenberg et al. 1996; Perkins 1999). Restoration and mitigation activities utilizing complex large woody debris are a plausible and effective technique (Quinn and Peterson 1996; Perkins 1999; Solazzi et al. 2000; Roni and Quinn 2001), and efforts to restore large woody debris to sections of the Green River are currently scheduled to occur in the next two to five years.

Multiple years of data are necessary before we may identify the range of variation of fish response to man-induced changes in their environment. Fish response to the presence or absence of extreme high or low flow events, extended periods of stable flows and short-term flow increases may vary depending on the timing of the event, the stage of juvenile development, and background environmental conditions such as water temperatures, lunar phase. Repeat studies are required to confirm the response to a single flow variable. In order to predict fish response, multiple years of study are required to understand the complex interaction of these variables. Reeves et al. (1991) indicated that biological evaluations should be conducted over a minimum of two generations. At a minimum, pre- and post-project biological monitoring should each be conducted for three to five years to ensure that several generations of fish and environmental conditions are evaluated. Other main summary points from the juvenile salmonid surveys conducted on the middle Green River from 1998 through 2000 are as follows:

1) This study was designed to monitor the emergence of juvenile salmonids in the middle Green River, measure the growth of juvenile salmonids in lateral habitat, determine the relative abundance of middle Green River juvenile salmonids, identify the species distribution of juvenile salmonids in relation to habitat type, provide for pre-project baseline biological information for the AWSP, identify key habitat types, and develop water management strategies to protect those and other habitats in the Green River.

2) Smooth or straight DC current at voltages of less than 400 have proven to be an effective method for monitoring the use of the middle Green River by juvenile salmonids. These electrofishing guidelines are within the standards cited by the National Marine Fisheries Service for backpack electrofishing waters containing fish species listed under the endangered species act (NMFS 1998) and State of Washington Scientific Collection Permit Application guidelines and have a relatively low (<1.0%) rate of immediate injury/mortality.

3) The species composition of salmon and trout fry captured during the study was dominated throughout March by chinook salmon (>73%). Chum and coho salmon began to emerge in March and composed the majority of the catch by April (chum = 40%; coho = 30%) and May (coho > 54%). Cutthroat and rainbow trout started to emerge in late May and dominated the catch by June. Chinook dominance of the catch ended in April (29%), and by June, contributed less than five percent of the total catch of salmon and trout fry. By July, the catch was composed entirely of rainbow trout (77%) and coho (23%) fry. Rainbow trout, chinook, and coho salmon were the only species of fry captured at the USGS (RM 60.3) and Pipeline (RM 59.5) sites; all species of fry were captured at Flaming Geyser (RM 45.0) and downstream.

4) The planned flow release conducted in 1998 indicated that a freshet (2,020 cfs = >200% increase over background discharge of 975 cfs) increased the rate of downstream movement of juvenile salmonids by more than 300 percent. The 1999 fyke net survey occurred in absence of a freshet and did not result in a net increase in the rate of downstream movement. Based on the juvenile chinook data collected from 1998 through 1999, we suggest that in the absence of a natural freshet (i.e., discharge stays within 200% of previous 24-hr discharge) during late April or early May, an artificial freshet should be tested to facilitate downstream movement for Phase II chinook fry. In the absence of a natural freshet, planned flow events

should also be considered during mid- to late May to facilitate the downstream dispersal of chum and coho salmon fry. Events scheduled at this time will take advantage of the natural tendency of coho fry to establish summer rearing areas in off channel habitats and the peak abundance of chum fry in the middle Green River.

5) The number of fish captured during middle Green River juvenile salmonid surveys conducted in 2000 increased from the 1999 field season. In 1999, mean CPUE for day/night electrofishing sites was 0.03 fish per second, while in 2000 the relative abundance of juvenile salmonids increased over 120 percent to 0.07 fish per second, but remained below 1998 levels (0.13 fish per second). The mean CPUE of juvenile salmon and trout for day electrofishing sites was lower when compared to night electrofishing sites. Day and night CPUE was not significantly different within each year or when all years were combined, however the power of both tests was low and the significance of the tests should be viewed cautiously.

6) An explanation for the decrease in relative abundance from 1998 to 1999 is that adult escapement levels in the middle Green River were much lower during the 1999 brood year. Data collected from the study area indicate that a small decrease did occur, but the decrease did not approach that observed for juvenile salmonids. Another possible explanation for the decrease in relative abundance from 1998 to 1999 is elevated sediment levels caused by the Flaming Geyser landslide. Examination of the data collected upstream from the landslide (i.e., Flaming Geyser backbar side channel) indicates that this site also experienced a decline in relative abundance of juvenile salmonids from 1998 to 1999. Relative abundance of juvenile salmonids did not decrease as drastically in abandoned and wallbase side channels as did CPUE in mainstem survey sites. Low fall flows may have concentrated spawning chinook closer to the thalweg of the channel which would cause eggs deposited in this reach to be vulnerable to scour resulting from sudden increases in discharge.

7) The highest level of juvenile salmonid habitat use in 2000 occurred at the Slaughterhouse Mainstem Margin (mean CPUE = 0.1374). As in past years, the overall relative use of mainstem lateral habitats in the middle Green River by juvenile salmonids was greater than expected. The use of mainstem habitat for juvenile salmonid rearing has been reported by other researchers in Washington, Alaska, Idaho, California, and Oregon. As they became larger, juvenile chinook in the middle Green River were observed using only the shallow mainstem margins in

the middle Green River. By late March and early April, juvenile chinook (TL = 50 mm) were using areas in the thalweg and associated with scour pools behind boulders and mats of large woody debris. Mean water column velocities in these habitats ranged from <2.0 fps.

8) Overyearling (primarily coho) use of wallbase side channel habitat was greater (CPUE = 0.0101) when compared to other off channel habitat strata during the 2000 study period. We also found more overyearling salmonids in gravel bar pools (mean CPUE = 0.0063) than the remaining four habitat strata during 2000. For all study years, overyearling use of wallbase side channels was relatively more important (Median = 0.0102), but not significantly different than other habitat strata. Overyearling salmonids occupying wallbase side channels were generally associated with complex woody debris (i.e., debris accumulations). Often times, these debris accumulations formed in association with a piece of large woody debris (e.g., rootwad or large log). Fry were also associated with this habitat feature. A lone piece of large woody debris did not appear to provide the habitat complexity needed for juvenile salmonids, as many of these were devoid of fish. Unlike coho, overyearling rainbow trout appeared to reside more often in mainstem, rather than off channel habitats.

9) Microhabitat data and habitats greater than 1.5 m deep were not surveyed during this study. The off-channel sites were connected to the mainstem at all times though the mid-June survey period. In particular, the gravel bar pool sites are prone to severe fluctuations in connectivity to the mainstem. This habitat strata is generally small in size and infrequently distributed throughout the middle Green River, but consistently have contained large numbers of juvenile salmon throughout the study period. During the planned flow release conducted in 1998, juvenile salmon were present in the gravel bar pool immediately before the flow release (site was disconnected from the mainstem), during the flow release (site became re-connected), and after the flow release (site was disconnected from the mainstem). All off-channel areas surveyed from 1998-2000 remained connected with the mainstem when flows in the Green River at Auburn were greater than 850 cfs.

10) The 2000 Green River biological monitoring study represents the third year in a multiple year study of juvenile salmonid behavior during the spring freshwater rearing months. At a minimum pre- and post-project biological monitoring should each be conducted for three to five years to ensure that several generations of fish

and environmental conditions are captured. We suggest that information collected from a screw trap located in the lower reaches of the study area should be combined with information collected during juvenile salmonid surveys to corroborate each other.

11) Information collected from this study, as well as similar studies conducted in the Cedar and Sammamish rivers should be combined to determine the relative use of three systems by juvenile salmonids that exhibit varying degrees of urbanization. This information will prove valuable while judging the utility of individual activities that are intended to provide for mitigation or restoration of juvenile salmonid rearing habitats throughout these basins.

7. ACKNOWLEDGEMENTS

We would to thank the volunteers that suffered many sleepless nights during their participation in our study. In particular, Fred Goetz, Dean Paron, Carolyn Fitzgerald, Dennis Mekers, and Jeff Dillon (USACE), and Paul Hickey (Tacoma Public Utilities) spent countless hours working at night in rather inclement weather. We also extend our sincere appreciation to the staff of Flaming Geyser State Park and King County Water and Land Resource Division for allowing us entry into sites beyond normal operating hours. Funding for this research was administered by the U.S. Army Corps of Engineers, Seattle District and Tacoma Public Utilities, City of Tacoma, Washington.

8. REFERENCES

Beamer, E.M., and R.A. Henderson. 1998. Juvenile salmonid use of natural and hydromodified stream bank habitat in the mainstem Skagit River, Northwest Washington. Prepared for the U.S. Army Corps of Engineers, Seattle District. Seattle, Washington. 51 p.

Beauchamp, D.A., M.F. Shepard, and G.B. Pauley. 1983. Species profiles: life histories and environmental requirements (Pacific Northwest) chinook salmon. Prepared by the U.S. Army Corps of Engineers, Waterways Experiment Station, and Coastal Engineering Research Center. U.S. Fish and Wildlife Service FWS/OBS-83. January 1983. Washington, D.C.16 p.

Becker, C.D., D.A. Neitzel, and C.S. Abernethy. Effects of dewatering on chinook salmon redds: tolerance of four development phases to one-time dewatering. North American Journal of Fisheries Management 3:373-382.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food stream flow, cover, and population density. Transactions of the American Fisheries Society 100(3):423-438.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 *in* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19. Bethesda, Maryland.

Burgner, R.L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). Pages 1-118 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press. Vancouver, British Columbia.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-27. 261 p.

Campbell, R.F., and J.H. Neuner. 1985. Seasonal and diurnal shifts in habitat utilized by resident rainbow trout in western Washington Cascade Mountain streams. Pages 39-48 *in* F.W. Olson, R.G. White, and R.H. Hamre, editors. Proceedings of the symposium on small hydropower and fisheries. 1-3 May 1985. Aurora, Colorado.

Chapman, D.W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. Journal of Fisheries Research Board of Canada 19(6):1047-1080.

Chapman, D.W. 1966. Food and space as regulators of salmonid populations in streams. The American Naturalist 100:345-357.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. Pages 153-176 *in* T.G. Northcote, editor. Symposium on salmon and trout in streams. 22-14 February 1968. Vancouver, British Columbia.

Coccoli, H.A. 1996. Effects of springtime flow alteration on side channel habitat in the Green River. Master's thesis. University of Washington, Seattle, Washington. 78 p.

Contor, C.R., and J.S. Griffith. 1995. Nocturnal emergence of juvenile rainbow trout from winter concealment relative to light intensity. Hydrobiologia 299:179-183.

Cordell, J.R., L.M. Tear, K. Jensen, and H.A. Higgins. 1999a. Duwamish River coastal America restoration and reference sites: results from 1997 monitoring studies. Fisheries Research Institute FRI-UW-9903. May 1999. University of Washington. Seattle, Washington. 41 p.

Cordell, J.R., C. Tanner, and J.K. Aitkin. 1999b. Fish assemblages and juvenile salmon diets at a breached-dike wetland site, Spencer Island, Washington 1997-1998. Fisheries Research Institute FRI-UW-9905. June 1999. University of Washington. Seattle, Washington. 13 p.

Cramer, S.P., J. Norris, P.R. Mundy, G. Grette, K.P. O'Neal, J.S. Hogle, C. Steward, and P. Bahls. 1999. Status of chinook salmon and their habitat in Puget Sound. Final report prepared for Coalition of Puget Sound Businesses. June 1999. Gresham, Oregon.

Dalbey, S.R., T.E. McMahon, and W. Fredenberg. 1996. Effect of electrofishing pulse shape and electrofishing-induced spinal injury on long-term growth and survival of wild rainbow trout. North American Journal of Fisheries Management 16:560-569.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Canadian Journal of Fisheries and Aquatic Sciences 54:1685-1698.

Dill, L.M. The sub-gravel behaviour of Pacific salmon larvae. Pages 89-99 *in* T.G. Northcote, editor. Symposium on salmon and trout in streams. 22-14 February 1968. Vancouver, British Columbia.

Don Chapman Consultants, Inc. (Chapman). 1989. Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final Report to Chelan County Public Utility District. June 1989. Wenatchee, Washington. 301 p.

Dunstan, W. 1955. Green River downstream migration. Puget Sound Stream Studies. Progress Report. Washington Department of Fisheries. Olympia, Washington.

Edmundson, E., F.E. Everest, and D.W. Chapman. Permanence of station in juvenile chinook and steelhead trout. Journal of Fisheries Research Board of Canada 25(7):1453-1464.

Emmett, R.L., S.L. Stone, S.A. Hinton, and M.E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: species life history summaries. NOAA/NOS Strategic Environmental Assessments Division ELMR Report No. 8. Rockville, Maryland. 329 p.

Everest, F.H., and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of Fisheries Research Board of Canada 29:91-100.

Folmar, L.C., and W.W. Dickhoff. 1980. The parr-smolt transformation (smoltification) and seawater adaptation in salmonids: a review of selected literature. Aquaculture 21:1-37.

Fredenberg, W. 1992. Evaluation of electrofishing-induced spinal injuries resulting from field electrofishing surveys in Montana. Montana Department of Fish, Wildlife and Parks. 1 March 1992. Helena, Montana.

Fuerstenberg, R.R., K. Nelson, and R. Blomquist. 1996. Ecological conditions and limitations to salmonid diversity in the Green River, Washington, USA: structure, function and process in river ecology. Draft report prepared by King County Department of Natural Resources, Surface Water Management Division. 31 p.

Gibbons, R,G., P.K. Hahn, T.H. Johnson. 1985. Methodology for determining MSH steelhead spawning escapement requirements. Washington State Game Department Report 85-11. Olympia, Washington. 39 p + appendices.

Goetz, F.A. 1994. Distribution and juvenile ecology of bull trout (*Salvelinus confluentus*) in the Cascade Mountains. MS Thesis. Oregon State University. Corvallis, Oregon. 173 p.

Grette, G. B. and E. O. Salo. 1986. The status of anadromous fishes of the Green/Duwamish River System. Submitted to U.S. Army Corps of Engineers, Seattle District. Seattle, Washington. 213 p.

Gustafson, R.G., T.C. Wainwright, G.A. Winans, F.W. Waknitz, L.T. Parker, and R.S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-33. 282 p.

Hale, S.S., T.E. McMahon, and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: chum salmon. U.S. Fish and Wildlife Service Biological Report 82(10.108). 48 p

Hawkins, C.P., J.L. Kershner, P. A. Bisson, M.D. Bryant, L.M. Decker, S.V. Gregory, D.A. McCullough, C.K. Overton, G.H. Reeves, R.J. Steedman, and M.K, Young. A hierarchical approach to classifying stream habitat features. Fisheries 18(6):3-12.

Hayman, R.A., E.M. Beamer, and R.E. McClure. 1996. FY 1995 Skagit River chinook restoration research: chinook restoration research Progress Report No. 1. Prepared by the Skagit System Cooperative. Final Project Performance Report NWIFC Contract No. 3311 for FY95. August 1996. LaConnor, Washington. 54 p + appendices.

Healey, M.C. 1980. Utilization of the Nanaimo River estuary by juvenile chinook salmon, *Oncorhynchus tshawytscha*. Fisheries Bulletin 77:488-496.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: the life support system. Pages 315-341 in V.S. Kennedy, editor. Estuarine Comparisons. Academic Press, New York, New York.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*) Pages 311-394 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, Canada. 564 p.

Heard, W.R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*) Pages 119-230 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, Canada. 564 p.

Hilgert, P.J., and E.D. Jeanes. 1999. Juvenile salmonid use of lateral stream habitats middle Green River, Washington. 1998 Data Report. Prepared for the U.S. Army Corps of Engineers, Seattle District, and City of Tacoma Public Utilities, Tacoma Water by R2 Resource Consultants, Inc. January 1999. 150 p.

Hollender, B.A. 1994. Injury to wild brook trout by backpack electrofishing. North American Journal of Fisheries Management 14:643-649.

Huntington, C., W. Nehlsen, and J. Bowers. 1996. A survey of healthy native stocks of anadromous salmonids in the Pacific Northwest and California. Fisheries 21(3):6-14.

Jeanes, E.D., and P. J. Hilgert. 2000. Juvenile salmonid use of lateral stream habitats middle Green River, Washington. 1999 Data Report. Prepared for the U.S. Army Corps of Engineers, Seattle District by R2 Resource Consultants, Inc. July 2000. ~200 p.

Johnson, O.W., M.H. Ruckelshaus, W.S. Grant, F.W. Waknitz, A.M. Garret, G.J. Bryant, K. Neely, and J.J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-37. 292 p.

Johnson, O.W., W.S. Grant, R.G. Cope, K. Neely, R.W. Waknitz, and R.S. Waples. 1997. Status review of chum salmon from Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-32. 280 p.

Johnston, J.M. 1982. Life histories of anadromous cutthroat trout with emphasis on migratory behavior. Pages 123-127 *in* E.L. Brannon and E.O. Salo, editors. Salmon and trout migratory behavior symposium. University of Washington School of Fisheries. Seattle, Washington.

Laufle, J.C., G.B. Pauley, and M.F. Shepard. 1986. Specie profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) – coho salmon. U.S. Fish and Wildlife Service Biological Report 82(11.48). 18 p.

Levy, D.A., and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Canadian Journal of Fisheries and Aquatic Sciences 39:270-276.

Lister, D.B., and H.S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmonids. Journal of Fisheries Research Board of Canada 27:1215-1224.

McMahon, T.E. 1983. Habitat suitability models: coho salmon. U.S. Fish and Wildlife Service. FWS/OBS 82/10.49. Fort Collins, Colorado. 29 p.

Meehan, W.R., and T.C. Bjornn. 1991. Salmonid distributions and life histories. Pages 47-82 *in* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publications 19. Bethesda, Maryland.

Meigs, R.C., and C.F. Pautzke. 1941. Additional notes on the life history of the Puget Sound steelhead (*Salmo gairdneri*). State of Washington Department of Game Biological Bulletin No. 3. Seattle, Washington. October 1941. 13 p.

Meyer, J.H., T.A. Pearce, and S.B. Patlan. 1981. Distribution and food habits of juvenile salmonids in the Duwamish estuary Washington, 1980. Prepared for the U.S. Army Corps of Engineers, Seattle District. March 1981. Seattle, Washington. 42 p.

Miller, T.J., L.B. Crowder, J.A. Rice, and E.A. Marschall. 1988. Larval size and recruitment mechanisms in fishes: toward a conceptual framework. Canadian Journal of Fisheries and Aquatic Sciences 45:1657-1670.

Montgomery, D.R., and J.M. Buffington. 1998. Channel processes, classification, and response. Pages 13-42 *in* R.J. Naimam and R.E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal Ecoregion. Springer-Verlag New York, Inc. New York, New York. 705 p.

Moyle, P.B. 1976. Inland fishes of California. University of California Press. Berkeley, California.

Murphy, M.L., J. Heifetz, J.F. Thedinga, S.W. Johnson, and K.V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 46:1677-1685.

Murray, C.B., and M.L. Rosenau. 1989. Rearing juvenile chinook salmon in nonnatal tributaries of the lower Fraser River, British Columbia. Transactions of the American Fisheries Society 118:284-289.

Myers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grant, F.W. Waknitz, K. Neeley, S.T. Lindley, and R.S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-35. 443 p.

National Marine Fisheries Service (NMFS). 1998. Suggested protocol for the use of backpack electrofishing equipment in waters containing fish listed under the Endangered Species Act (ESA). Portland, Oregon. December 1998.

National Research Council (NRC). 1996. Upstream: salmon and society in the Pacific Northwest. National Academic Press. Washington, D.C. 452 p.

Nehlsen, W., J.E. Williams, and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries (16) 2:4-21.

Neilsen, J.L. 1998. Electrofishing California's endangered fish populations. Fisheries 23(12):6-12.

Pauley, G.B., B.M. Bortz, and M.F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)--steelhead trout. U.S. Fish and Wildlife Service Biological Report 82(11.62). U.S. Army Corps of Engineers, TR EL-82-4.

Pautzke, C.F., and R. C. Meigs. 1940. Studies on the life history of the Puget Sound steelhead (*Salmo gairdneri*). State of Washington Department of Game Biological Bulletin.

Perkins, S.J. 1993. Green River channel migration study. Prepared by King County Department of Public Works, Surface Water Management Division, River Management Section. Seattle, Washington 46 p.

Perkins, S.J. 1999. Geomorphic feasibility report for large woody debris placement in the middle Green River, Washington. Prepared by Perkins Geosciences for U.S. Army Corps of Engineers, Seattle District. 16 November 1999. Seattle, Washington 29 p.

Peters, R.J. 1996. Emigration of juvenile chum salmon in the Elwha River and implications for timing hatchery coho salmon releases. Prepared for the National Park Service, Olympic National Park. September 1996. Port Angeles, Washington. 15 p.

Peters, R.J., B.R. Missildine, and D.L. Low. 1998. Seasonal fish densities near river banks stabilized with various stabilization methods: first year report of the flood technical assistance project. Prepared by the U.S. Fish and Wildlife Service. December 1998. Lacey, Washington. 34 p.

Peven, C.M. 1990. The life history of naturally produced steelhead trout from the Mid-Columbia River basin. Master's thesis. University of Washington. 1 June 1990. Seattle, Washington. 96 p.

Quinn, T.P., and N.P. Peterson. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon *(Oncorhynchus kisutch*) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:155-1564

Randall, R.G., M.C. Healey, and J.B. Dempson. 1987. Variability in length of freshwater residence of salmon, trout, and char. American Fisheries Society Symposium 1:27-41.

Reeves, G.H., D.B. Hohler, B.E. Hansen, F.H. Everest, J.R. Sedell, T.L. Hickman, and D. Shively. 1997. Fish habitat restoration in the Pacific Northwest: Fish Creek of Oregon. Pages 335-359 *in* J.E. Williams, C.A. Wodd, and M.P. Dombeck, editors. Watershed restoration: principles and practices. American Fisheries Society, Bethesda, Maryland. 561 p.

Reeves, G.H., J.D. Hall, T.D. Roelofs, T.L. Hickman, and C.O. Baker. 1991. Rehabilitating and modifying stream habitats. Pages 519-557 *in* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19. Bethesda, Maryland. 751 p.

Reimers, B.E. 1971. The length of residence of fall chinook salmon in the Sixes River, Oregon. Doctoral dissertation. Oregon State University. Corvallis, Oregon. 99 p.

Reiser, D.W., and R.G. White. 1983. Effects of complete redd dewatering on salmonid egg-hatching success and development of juveniles. Transactions of the American Fisheries Society 112:532-540.

Riehle, M.D., and J.S. Griffith. 1993. Changes in habitat use and feeding chronology of juvenile rainbow trout (*Oncorhynchus mykiss*) in fall and the onset of winter in Silver Creek, Idaho. Canadian Journal of Fisheries and Aquatic Sciences 50:2119-2128.

Roni, P., and T.P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:282-292.

Roper, B.B., D.L. Scarnecchia, and T.J. LaMarr. 1994. Summer distribution and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. Transactions of the American Fisheries Society 123:298-308.

Roper, B.B., and D.L. Scarnecchia. 1999. Emigration of age-0 chinook salmon (*Oncorhynchus tshawytscha*) smolts from the upper South Umpqua River basin, Oregon, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 56:939-946.

Sabo, J.L. 1995. Competition between stream-dwelling cutthroat trout *(Oncorhynchus clarki clarki*) and coho salmon (*O. kisutch*): implications for community structure and evolutionary ecology. Master's thesis. University of Washington. Seattle, Washington. 82 p + appendices.

Sabo, J.L., and G.B. Pauley. 1997. Competition between stream-dwelling cutthroat trout *(Oncorhynchus clarki clarki*) and coho salmon (*O. kisutch*): effects of relative size and origin. Canadian Journal of Fisheries and Aquatic Sciences 54:2609-2617.

Salo, E.O. 1969. Final report for the period June 1, 1965-September 30, 1968, estuarine ecology research project. Prepared by the Fisheries Research Institute. 29 April 1969. University of Washington. Seattle, Washington. 80 p.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). Pages 231-310 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press. Vancouver, British Columbia.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 395-446 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press. Vancouver, British Columbia.

Schill, D.J., and F.S. Elle. 2000. Healing of electroshock-induced hemorrhages in hatchery rainbow trout. North American Journal of Fisheries Management 20:730-736.

Schindler, D.E. 1999. Migration strategies of young fishes under temporal constraints: the effect of size-dependent overwinter mortality. Canadian Journal of Fisheries and Aquatic Sciences 56:61-70.

Sheng, M.D., M. Foy, and A.Y. Fedorenko. 1990. Coho salmon enhancement in British Columbia using improved groundwater-fed side channels. Prepared by the Department of Fisheries and Oceans, Vancouver, British Columbia. Canadian Manuscript of Fisheries and Aquatic Sciences No. 2071. 80 p.

Shepard, M. F. 1981. Status and review of the knowledge pertaining to the estuarine habitat requirements and life history of chum and chinook salmon juveniles in Puget Sound. Final Report. University of Washington, College of Fisheries, Cooperative Fishery Research Unit, Seattle, Washington.

Shreffler, D.K., C.A. Simenstad, and R.M. Thom. 1990. Temporary residence by juvenile salmon in a restored estuarine wetland. Canadian Journal of Fisheries and Sciences 47:2079-2084.

Simenstad, C.A., K.L. Fresh, and E.O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon. An unappreciated function. Pages 343-364 *in* V. S. Kennedy, editor. Estuarine comparisons. Academic Press, New York, New York.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. Management Technology TR-4501-96-6057. December 1996. 356 p.

Solazzi, M.F., T.E. Nickelson, S.L. Johnson, and J.D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 57:906-914.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, and W.J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:325-333.

Stearns, S.C. 1976. Life history tactics: a review of the ideas. Quarterly Review of Biology 51:3-47.

Stevens, D.E., and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. North American Journal of Fisheries Management 3:425-437.

Swales, S, R.B. Lauzier, and C.D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two rivers in British Columbia. Canadian Journal of Zoology 64:1506-1514.

Swales, S. 1988. Utilization of off-channel habitats by juvenile coho salmon (*Oncorhynchus kisutch*) in interior and coastal streams in British Columbia. International Association of Theoretical and Applied Limnology 23:1676.

Taylor, E.B. 1990. Phenotypic correlates of life-history variation in juvenile chinook salmon, *Oncorhynchus tshawytscha*. Journal of Animal Ecology 59:455-468.

Thedinga, J.F., M.L Murphy, and K.V. Koski. 1988. Seasonal habitat utilization by juvenile salmon in the lower Taku River, Southeast Alaska. Prepared for Auke Bay Laboratory, Northwest and Alaska Fisheries Center, and National Marine Fisheries Service. Auke Bay, Alaska. 32 p.

Trotter, P.C. 1997. Sea-run cutthroat trout: life history profile. Pages 7-15 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout biology, management, and future conservation. Oregon Chapter of the American Fisheries Society. Corvallis, Oregon.

U.S. Army Corps of Engineers (USACE). 1998. Side channel habitats in the Green River, Washington. Pages 420-476 in USACE. Additional Water Storage Project, Draft Feasibility Report and EIS: Appendix F, Environmental (Part 1, Fish Mitigation and Restoration). Prepared by the U.S. Army Corps of Engineers, Seattle District. April 1998. 626 p.

U.S. Fish and Wildlife Service (USFWS), and Hoopa Valley Tribe. 1999. Trinity River flow evaluation: final report. Prepared for U.S. Department of Interior. June 1999. Arcata, California. 308 p + appendices.

Washington Department of Fish and Wildlife (WDFW) and Western Washington Treaty Indian Tribes. 1994. 1992 Washington State salmon and steelhead stock inventory, Appendix 1: Puget Sound stocks. Olympia, Washington. 371 p.

Weatherly, A.H., and H.S. Gill. 1995. Growth. Pages 101-158 *in* C. Groot, L. Margolis, and W.C. Clarke, editors. Physiological ecology of Pacific salmon. University of British Columbia Press, Vancouver, Canada. 510 p.

Weitkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-24. 258 p.

Wilson, M.F. 1997. Variation in salmonid life histories: patterns and perspectives. U.S. Forest Service Research Paper PNW-RP-498. February 1997. Juneau, Alaska. 50 p.

Wright, S., M. Fraidenburg, and R. Brix. 1973. Observation and marking of juvenile chinook salmon in the Humptulips River, Washington. The Progressive Fish Culturist 35(3):154-156.

Wydoski, R.S., and R.R. Whitney. 1979. Inland fishes of Washington. University of Washington Press. Seattle, Washington.