2000 Evaluation of Juvenile Fall Chinook Salmon Stranding on the Hanford Reach of the Columbia River

Prepared for
The Bonneville Power Administration
The Public Utility District Number 2 of Grant County

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Executive Summary

The Washington Department of Fish and Wildlife (WDFW) in cooperation with the Bonneville Power Administration (BPA), Grant County Public Utility District (GCPUD), Pacific Northwest National Laboratory (PNNL), University of Idaho (U of I), Streamside Programs Consultation (SPC), United States Geological Survey Biological Resources Division (USGS/BRD), and Yakama Nation (YN) performed the 2000 Evaluation of Juvenile Fall Chinook Salmon (Oncorhynchus tshawytscha) Stranding on the Hanford Reach of the Columbia River. The 2000 evaluation was the fourth year of a multi-year study to assess the impacts of water fluctuations from Priest Rapids Dam on rearing juvenile fall chinook salmon, other fish species, and benthic macroinvertebrates. The field effort was performed from March 13 through August 28.

The Hanford Reach experienced slightly warmer to near normal air temperatures and wetter than normal conditions during the 2000 juvenile fall chinook salmon emergence and rearing period (March–July). Solar radiation levels, a good indication of cloud cover, were above the 20-year mean (1980-1999) each month during this time period with the exception of March. River flows during juvenile fall chinook salmon emergence and rearing period were below the 10-year mean flows (1990-1999) for each month with the exception of April when flows were 30.6 kcfs above the previous 10-year mean.

Emergence of wild juvenile fall chinook salmon in 2000, as calculated under the terms of the 1988 Vernita Bar Settlement Agreement (GCPUD 1988), was estimated to start on March 20 and population index surveys were subsequently initiated on March 13. Implementation criteria were met on March 19 and the 2000 Interim Protection Program began March 21. Random sampling to assess the effectiveness of the 2000 Interim Protection Program began on March 20 and ended June 25. The protection program continued through June 26.

Priest Rapids Dam (Rkm 639.1) discharges averaged 147.7 kcfs from March 21 through June 26 in 2000. Hourly discharge from the Dam ranged from 62.1 to 293.2 kcf. Mean daily fluctuation during this period was 50.0 kcfs. The primary period of susceptibility of juvenile fall chinook salmon to stranding in 2000 based on fish recorded as "mortalities" and "at risk" in random samples and length frequency distribution from index sampling appears to be from the start of emergence to May 21. Mean daily flow fluctuation from Priest Rapids Dam during the primary period of susceptibility was 46.5 kcfs with 9 days of relatively stable flows (fluctuations < 20 kcfs) and 33 days of flow fluctuations greater than 40 kcfs including 8 days of flow fluctuations greater than 80 kcfs.

A total of 709 juvenile fall chinook salmon were sampled from random plots in 2000 including 138 stranded and 571 entrapped individuals. Field crews recorded 156 direct mortalities consisting of the 138 stranded and 18 thermal induced fatalities. Projected mortalities were estimated at 625 based on revisitation of previous sites to determine if the entrapments drained or reached lethal temperatures (>24^{o}C). Fish were first encountered in random plots on March 24 and last found on June 2. The majority of juvenile fall chinook salmon were sampled from March 26-April 15 and April 23-May 6.

The estimated total number of juvenile fall chinook salmon stranding and entrapment mortalities in 2000 was calculated to be 72,362 with a 95% confidence interval between 34,270 and 110,454. The number of mortalities estimated by revisitation of entrapments was 209,997 with 95% confidence interval between –20,483 and 440,476. Juvenile fall chinook salmon placed at risk of mortality due to stranding and entrapment was calculated to be 255,222 with a 95% confidence interval between 17,743 and 492,701.

Juvenile fall chinook salmon collected in random plots had a mean fork length of 41.7 mm and ranged from 33 to 86 mm. Individuals less than 60 mm comprised 99.2% of the juvenile fall chinook salmon measured. Juvenile fall chinook salmon were found throughout the SHOALS defined study area at a variety of flow bands but the highest concentrations were found at Locke Island (595-605 Rkm) and the downstream end of 100 F Islands (585-590 Rkm) at flows of 120-200 kcfs.

An estimated 16,293,584 fall chinook salmon fry were produced on the Hanford Reach in 2000. Sampling to assess juvenile fall chinook salmon abundance and fish size began on March 13, just prior to the estimated start of emergence on March 20 (Carlson 2000), and ended on June 26. A total of 5,624 juvenile fall chinook salmon were seined during this period. Juvenile fall chinook salmon were collected from six index locations once per week during this period. Peak abundance was observed from April 24 to May 29. The largest catch of the season was

obtained on May 29 when 870 individuals were sampled. Juvenile fall chinook salmon with fork lengths at or below 42 mm comprised 30% or more of the fish seined in the Hanford Reach until May 15 and fish of this size remained in the samples through June 19. Juvenile fall chinook salmon with fork lengths greater than 59 mm, the size threshold that individuals are thought to become less susceptible to entrapment (Nugent et al. 2001a and 2001b), began to appear in the samples on April 24 but were not collected in considerable numbers until May 23.

The emergency management team (EMT) monitored entrapments in primary fall chinook salmon rearing areas from March 20 to June 24. A total of 10,705 juvenile fall chinook salmon were seined from 158 entrapments during this time period. Many of the same entrapments were sampled on multiple days in conjunction with EMT monitoring. Field crews recorded 311 direct mortalities at the time entrapments were sampled. Projected mortalites were estimated at 4,451 based on drainage or lethal temperatures monitored in entrapments. Criteria for emergency action were reached on 10 days (March 27, April 2, April 6, April 15, April 27, April 30, May 2, May 6, May 26, and June9) in 2000. GCPUD provided additional water to re-inundate (or increase river elevations) entrapments on six of these days (March 27, April 2, April 6, April 15, April 27, and June 9).

Minimum numbers of fish other than fall chinook salmon were sampled during the implementation and evaluation of the Interim Protection Program in 2000 (March 13-June 26). Spring chinook salmon (Oncorhynchus tshawytscha) and at least 10 other species of fish were collected in nearshore sites and random plots during the spring and early summer sampling period. Resident species found consisted of mountain whitefish, northern pikeminnow, peamouth, redside shiner, sculpin, smallmouth bass, sucker, threespine stickleback, dace, and yellow perch. Spring chinook salmon, peamouth, smallmouth bass, dace, and yellow perch were not represented in random plots.

In 2000, the summer and early fall sampling program began on July 11 and ended August 28. Species collected in nearshore sites during this time period consisted of American shad, common carp, peamouth, northern pikeminnow, dace, redside shiner, undetermined minnow species, sucker, threespine stickleback, bluegill, smallmouth bass, undetermined bass species, and sculpin.

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Introduction

The Washington Department of Fish and Wildlife (WDFW) has been contracted through the Bonneville Power Administration (BPA) and the Grant County Public Utility District (GCPUD) to perform an evaluation of juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) stranding on the Hanford Reach. The evaluation, in the fourth year of a multi-year study, has been developed to assess the impacts of water fluctuations from Priest Rapids Dam on rearing juvenile fall chinook salmon, other fishes, and benthic macroinvertebrates of the Hanford Reach. This document provides the results of the 2000 field season.

Background

The background section for this document includes: the impetus for the evaluation, a description of the environmental conditions that exist on the Hanford Reach, a summary of the 1997, 1998, and 1999 reports, and an outline of the 2000 Interim Protection Program for Hanford Reach juvenile fall chinook salmon.

Impetus for the Evaluation

The BPA has been directed by the National Marine Fisheries Service (NMFS) under the Endangered Species Act - Section 7 - Biological Opinion on the Reinitiating of Consultation on 1994-1998 Operation of The Federal Columbia River Power System and Juvenile Transportation Program to perform the following:

> <u>"Beginning in 1995, BPA will evaluate the affect of power peaking operations on juvenile and adult salmon passage and on the river ecology downstream of Bonneville Dam and on the Hanford Reach, downstream of Priest Rapids Dam. Contingent on the results of these evaluations BPA will develop a plan to decrease power peaking operations from mid-March through mid-December on the lower Snake and Columbia Rivers (page 162, #11)".</u>

In addition, as an objective of the 1994 Columbia River Basin Fish and Wildlife Program, BPA has been directed to perform the following:

> <u>"Beginning in 1995, evaluate alternative ramping rates for flow fluctuations at mainstem Snake and Columbia River dams to constrain reductions and increases in total flow per 24-hour period at these projects (Page 5-20, 5.1D.4)".</u>

This evaluation of juvenile fall chinook salmon stranding on the Hanford Reach is consistent with both of these objectives.

Description of Stranding and Entrapment Conditions on the Hanford Reach

The Hanford Reach supports the larger of the only two remaining healthy naturally spawning fall chinook salmon populations in the Columbia River System (Huntington et al.1996). This population is a primary source of ocean and freshwater sport, commercial and in-river tribal fisheries (Dauble and Watson 1997) and is a primary component of the Pacific Salmon Treaty between the United States and Canada. River flows for this section of the Columbia River are manipulated by discharge from Priest Rapids Dam. Flow fluctuations from Priest Rapids Dam occur rapidly due to changes in hydroelectric power generation (power peaking), irrigation, water storage, and flood control. These fluctuations have been observed to cause stranding and entrapment of juvenile fall chinook salmon on gently sloped banks, gravel bars and in pothole depressions on the Hanford Reach (Page 1976, Becker et al. 1981, DeVore 1988, Geist 1989, Wagner 1995, Ocker 1996, Wagner et al. 1999, Nugent et al. 2001a and 2001b).

Stranding of juvenile fall chinook salmon occurs when the fish are trapped on or beneath the unwatered substrate as the river level recedes. Entrapment occurs when the fish are separated from the main river channel in depressions as the river level recedes. Entrapped fish may become stranded when depressions drain completely. Fish mortality occurs from stranding, thermal stress (warming of water in entrapments), and by piscivorous and avian predation in small shallow entrapments.

The impact of river fluctuations due to operation of hydroelectric facilities on rearing salmonids has been assessed on numerous Columbia River tributaries and other river systems (Thompson 1970, Witty and Thompson 1974, Phinney 1974a and 1974b, Bauersfeld 1978, Tipping et al. 1978 and 1979, Becker et al. 1981, Woodin 1984, and Beck 1989) but limited research has been conducted on the Hanford Reach (Page 1976, Becker et al. 1981). The 2000 evaluation has been performed to estimate the loss of juvenile fall chinook salmon on the Hanford Reach to stranding and entrapment and for directing the future management of flows from Priest Rapids Dam.

Description of the Hanford Reach

The Hanford Reach stretches from Priest Rapids Dam 82 km downstream to Richland, Washington (**Figure 1**). The physiography, river dynamics, and climate of the area create a unique habitat for wildlife and fish populations.

Physiography

The United States Atomic Energy Commission requisitioned the lands surrounding the Hanford Reach for the siting of facilities to produce plutonium for the first atomic weapons in 1943. The Hanford Site has been owned and maintained by the United States Department of Energy (DOE) with portions of the site being managed by the United States Fish and Wildlife Service (USFWS), and WDFW. Due to the secure nature of the facilities, the Hanford Reach and the surrounding lands have remained protected and only limited development has occurred in small intensely disturbed areas adjacent to the facilities. The security of the site has unintentionally preserved many significant biological resources and cultural, archaeological, geological, and historic sites. The undeveloped areas contain one of the largest remnant sections of shrub-steppe ecosystem in the Columbia River Basin. The uniqueness of the Hanford Reach was recognized on June 9, 2000 when it was proclaimed a national monument by then President William J. Clinton.

For descriptive purposes, the Hanford Reach can be broken down into five distinct river sections. These sections are Priest Rapids Dam (Rkm 639.1) to Coyote Rapids (Rkm 615.6), from Coyote Rapids to the beginning of the White Bluffs (Rkm 605.1), from the beginning of the White Bluffs to Hanford Slough (Rkm 582.6), Hanford Slough to Savage Island (Rkm 572.9), and from Savage Island to the McNary Pool (Rkm 545.6) in Richland. Detailed plan views of the Hanford Reach are provided in **Figures 2, 3, and 4**.

The first segment of river from Priest Rapids Dam to Coyote Rapids flows to the east. This section of river consists of a series of gentle meanders. The meanders are characterized by cutbanks on the outside of the meanders and point bars on the inside downstream portion of the meanders. The cutbanks in this section are typified by steep embankments or to a lesser extent rock walls. The cutbank from Rkm 637.3 to Rkm 632.4 is an outcropping of basalt associated with the terminus of Umtanum Ridge. Gentle embankments, flats and downstream gravel bars distinguish the point bars in this section. Notable downstream gravel bars critical to fall chinook salmon spawning are Vernita Bar (Rkm 632.4) and a gravel bar immediately upstream of Coyote Rapids at Rkm 616.4. At Coyote Rapids the river turns and flows to the northeast. The next section of river from Coyote Rapids to the beginning of the White Bluffs is straight and channelized with relatively steep embankments. Some fall chinook salmon spawning occurs at the top of the island at Rkm 606.7.

At the beginning of the White Bluffs, the river makes an abrupt turn to the southeast. Unconsolidated bluffs on the northeast bank and island complexes dominate this next section of river from the beginning of the White Bluffs to the bottom of Hanford Slough. The river becomes braided through this segment and the bluffs rise to greater than 150 m above the surface of the river. The island complexes with associated islands, gravel bars and backwater sloughs provide extensive critical spawning and rearing habitat for fall chinook salmon. Below Hanford Slough the river continues to flow to the southeast to the bottom of Savage Island. This section of the river from the bottom of Hanford Slough to the bottom of Savage Island is straight and channelized with relatively steep embankments. No observed fall chinook salmon spawning occurs in this section of the river. Below Savage Island the river turns to the south. Unconsolidated bluffs on the eastern bank and sand dunes and steep embankments on the western bank dominate this final section of the Hanford Reach, from the bottom of Savage Island to the top of the McNary Pool in Richland. The river channel is incised and straight and island formation appears restricted by the river channel. Braiding is less pronounced than in upper stretches of the river providing less gravel bar and backwater areas. Fall chinook salmon spawning occurs at the top of the main channel island adjacent to the Ringold fish hatchery (Rkm 570.5) and near Wooded Island (Rkm 561.6).

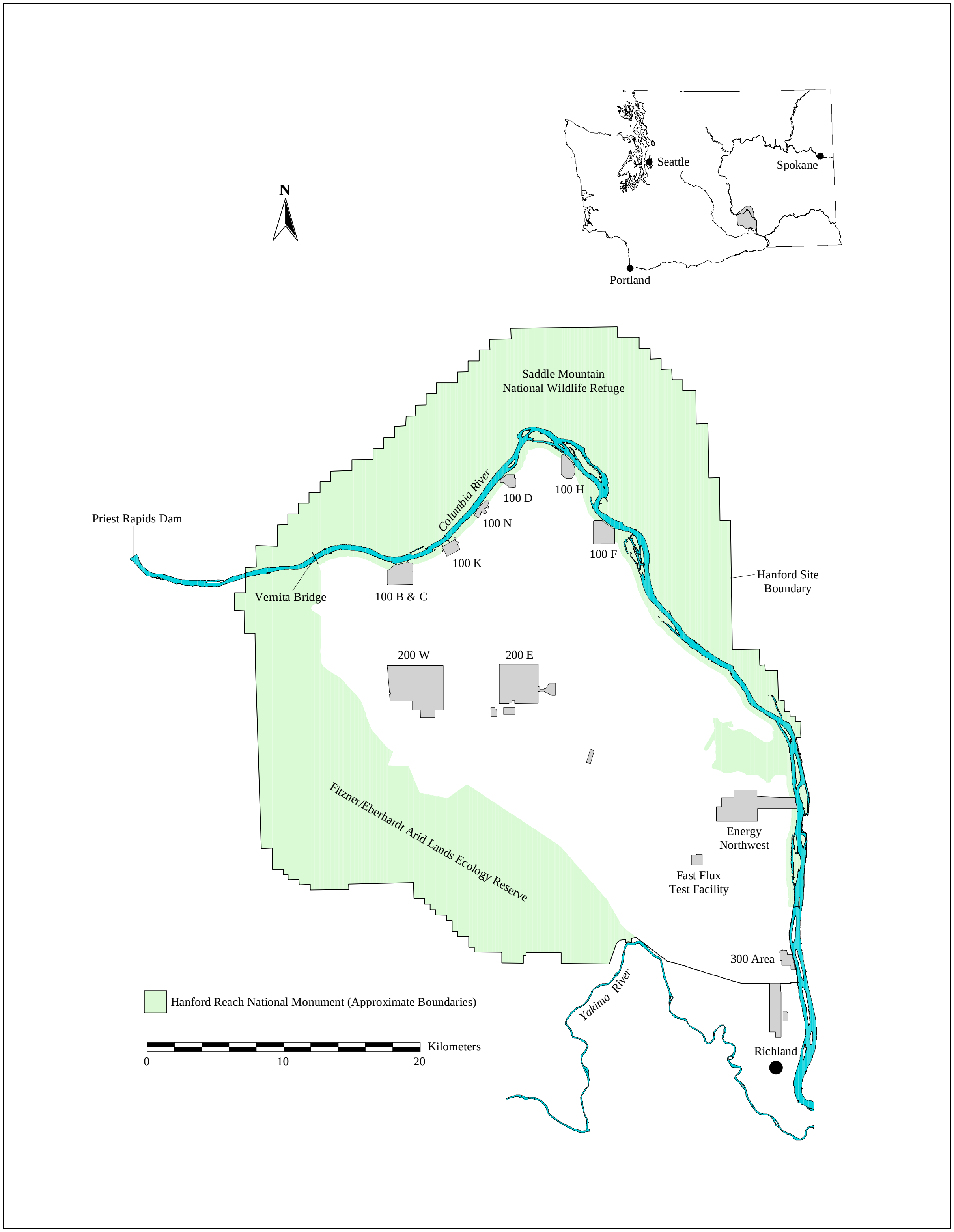


Figure 1. The Hanford Reach of the Columbia River, Washington.

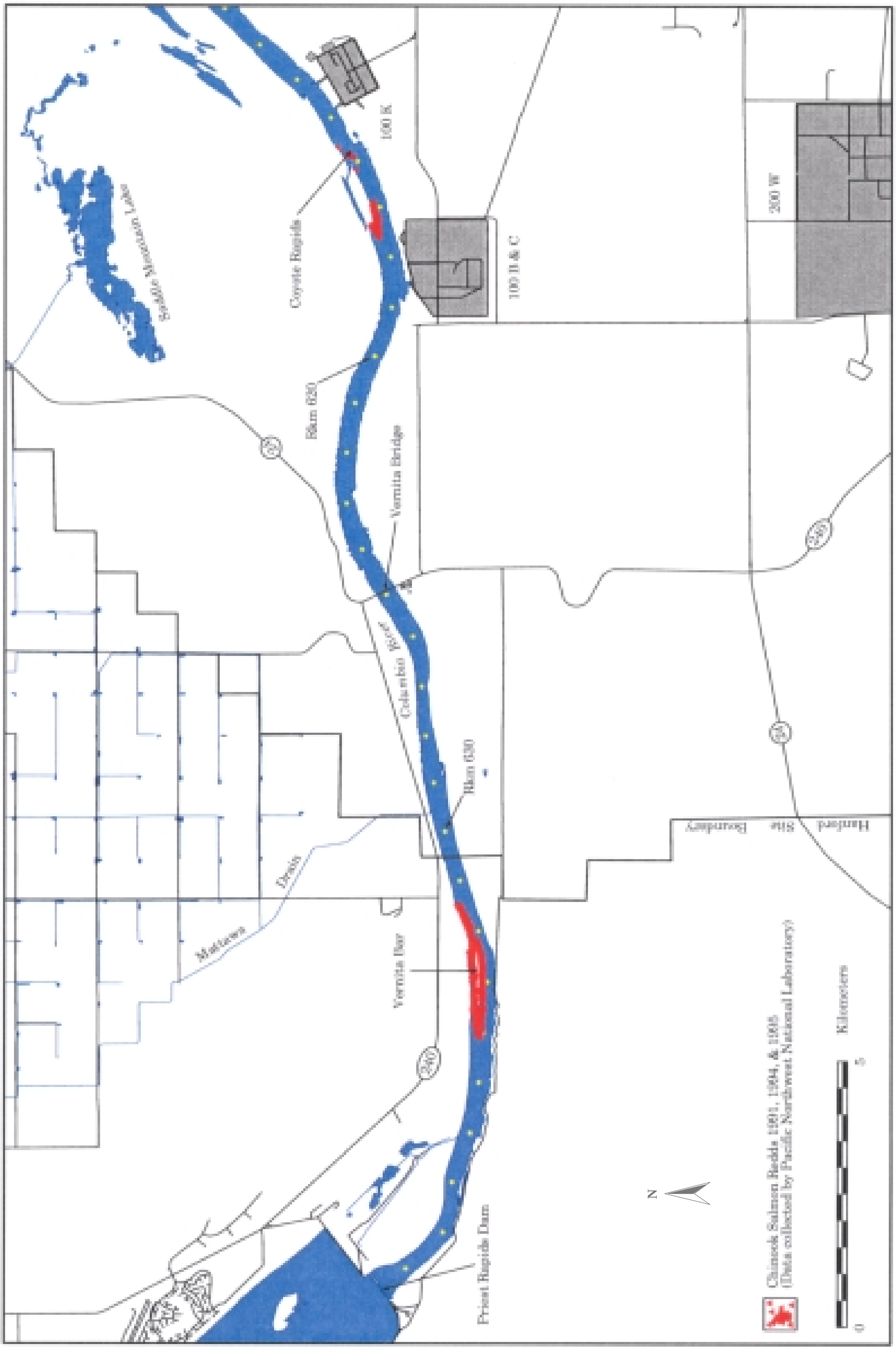


Figure 2. Plan view of the Hanford Reach of the Columbia River from Priest Rapids Dam to Coyote Rapids.

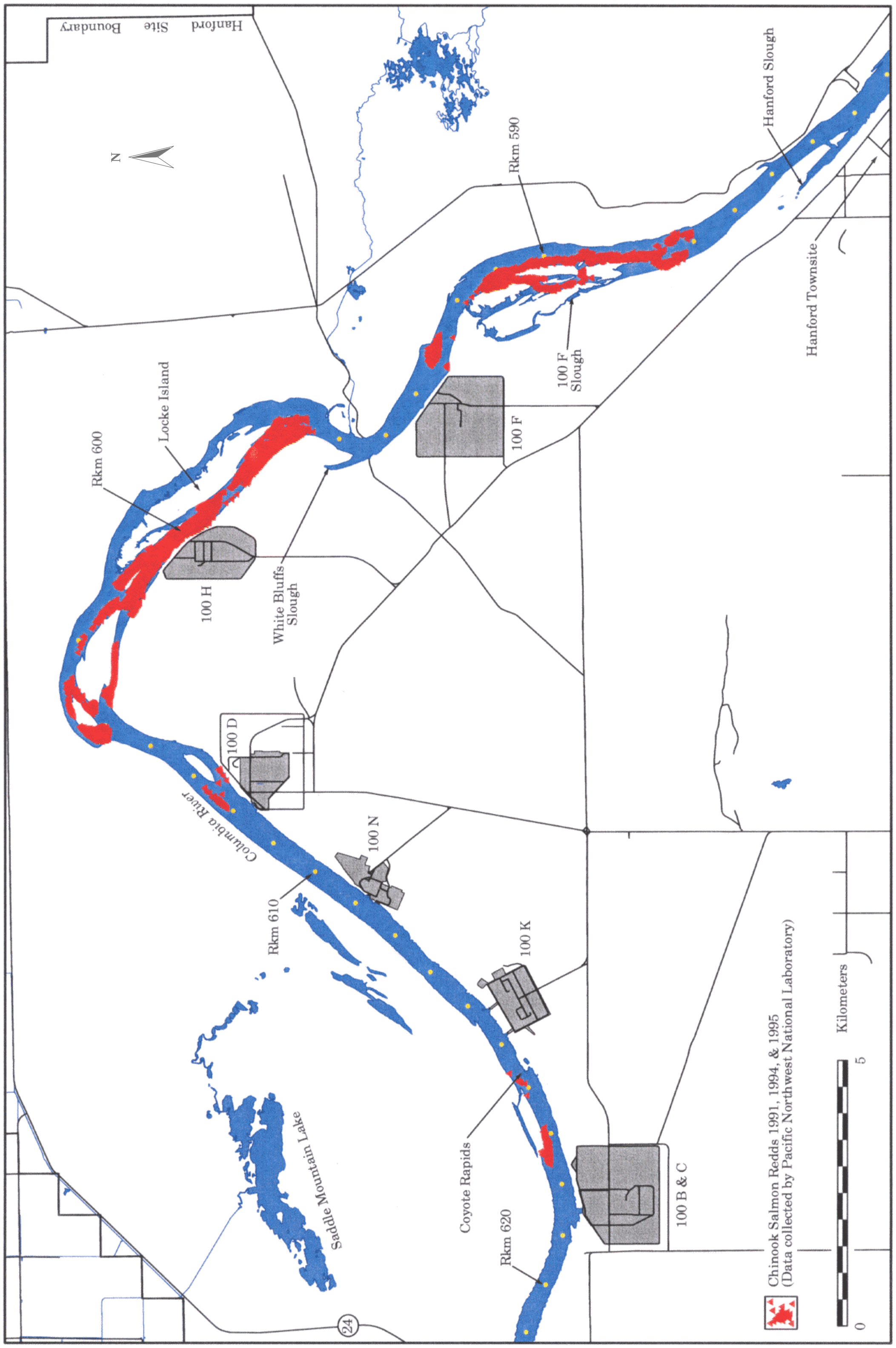


Figure 3. Plan view of Hanford Reach of the Columbia River from Coyote Rapids to Hanford Slough.

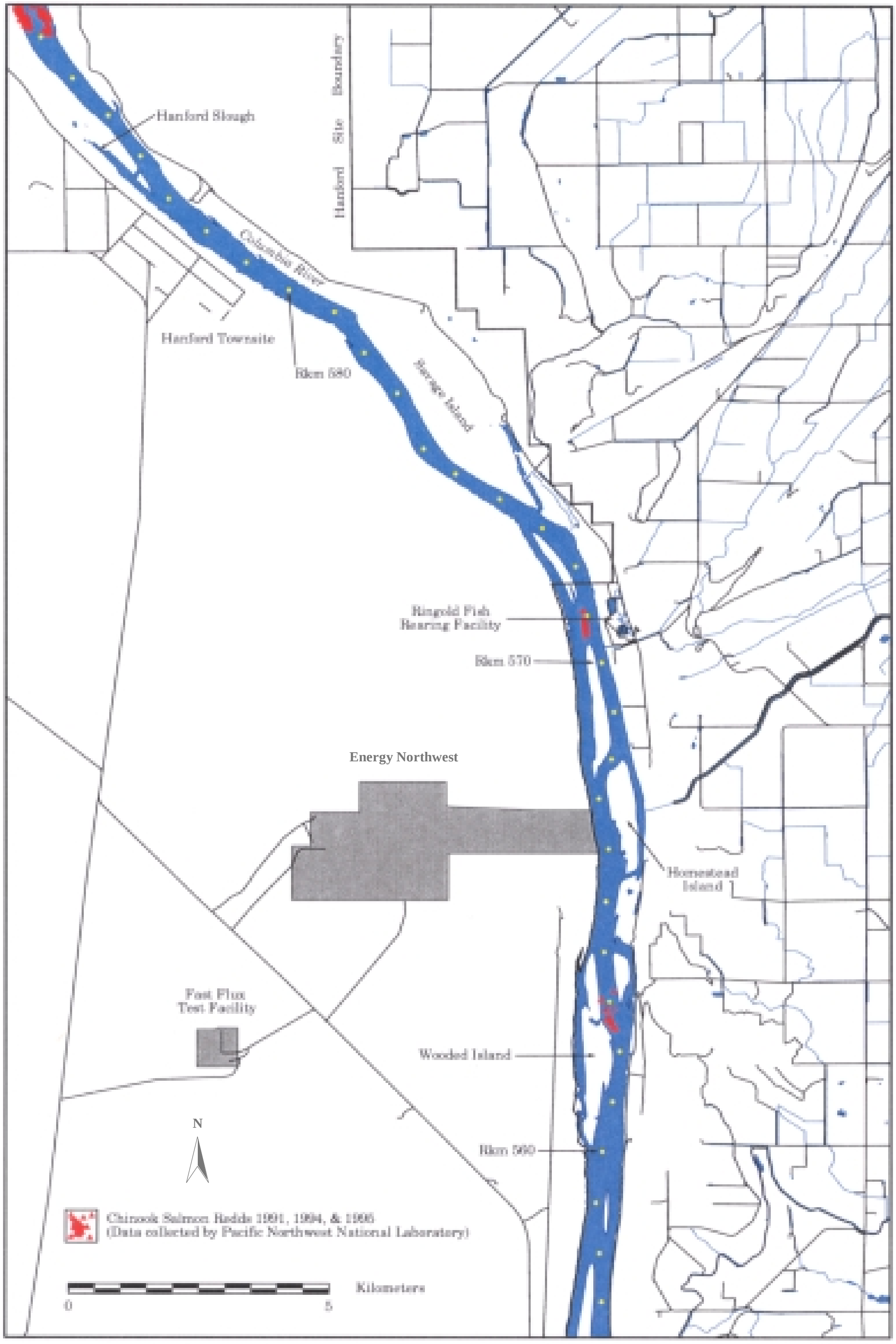


Figure 4. Plan view of Hanford Reach of the Columbia River from Hanford Slough to Richland.

Climate

The Hanford Reach, situated in the rain shadow of the Cascade Mountain Range, receives an annual mean precipitation of 16.1 cm and is considered mid-latitude semi-arid (Glantz et al. 1990). Most of the precipitation falls between October and May (Rickard 1988). Summers are warm and dry with temperatures often exceeding 38^{o}C (Glantz et al.1990). Winters are cool with occasional precipitation and outbreaks of cold artic air that can drop temperatures below –18^{o}C (Glantz et al.1990).

During the juvenile fall chinook salmon emergence and rearing period (March – June) average maximum temperatures range from 14.1^{o}C in March to 28.8^{o}C in June. Average minimum temperatures range from 1.1^{o}C in March to 12.9^{o}C in June. Precipitation averages 4.5 cm during the juvenile fall chinook salmon emergence and rearing period. Large diurnal temperature contrasts can occur during this time period due to low relative humidity in combination with intense solar radiation during the day and radiational cooling at night (Hanford Meteorological Station, PNNL 1998).

River Dynamics

The Hanford Reach is the only un-impounded and last free flowing section of the Columbia River above Bonneville Dam. Priest Rapids Dam, built in 1959, regulates flow discharges and is the major influence of river dynamics on the Hanford Reach. The Hanford Reach has no natural tributaries and receives little additional influent from other sources. Other minimal sources of influent include irrigation runoff and groundwater discharge.

Daily fluctuations in river elevation on the Hanford Reach are the result of discharge changes from Priest Rapids Dam and can vary significantly on an hourly basis. Historically, under normal project operations, tailwater reductions in excess of 7 vertical ft/hr (2.1 m/hr) and 13 vertical ft (4.0 m) within a 24-hr period have occurred during the juvenile fall chinook salmon emergence and rearing period.

Seasonal daily average discharges from Priest Rapids Dam range from about 40 to 250 kcfs (Dauble and Watson 1997). Average seasonal flows from 1990 to 1999 show that spring runoff peaks during mid-June and decreases significantly during the summer with annual minimum flows in September **(Figure 5**). The Federal Energy Commission has established 36 kcfs as a minimum flow from Priest Rapids Dam (Dauble and Watson 1997).

Fluctuations in river elevation downstream of Priest Rapids Dam are dampened by channel configuration and bank storage. Translation time of fluctuations downstream is determined by a variety of factors that may include river configuration, bank storage, and magnitude and duration of the fluctuation. **Figure 6** illustrates the entire flow regime from below Priest Rapids Dam (Rkm 639.0) to the bottom of Wooded Island (Rkm 560.6) over a one-week period during the 1998 juvenile fall chinook salmon emergence and rearing period. Corresponding stranding and entrapment events that occurred during this time period and the number of juvenile fall chinook salmon associated with each event also are represented.

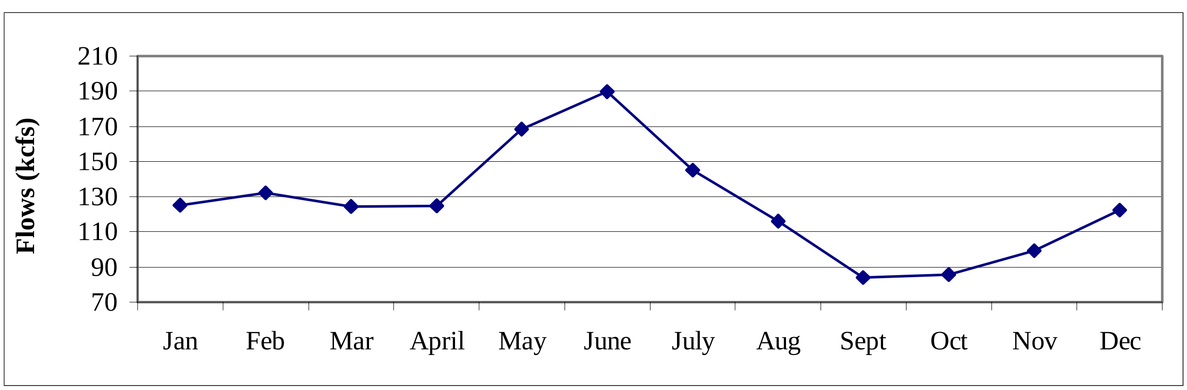
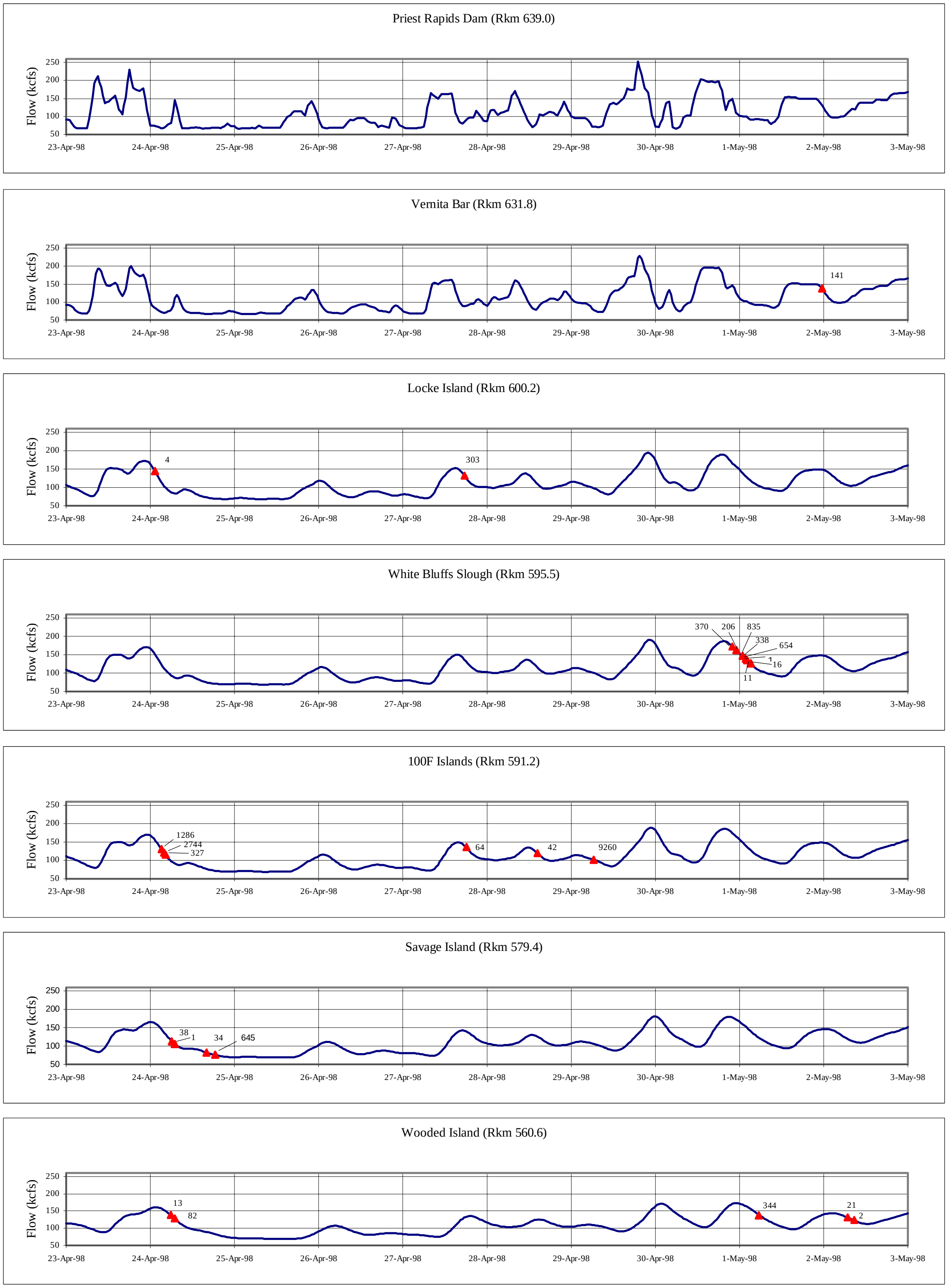


Figure 5. Mean 10-year flows for the Columbia River below Priest Rapids Dam (1990 – 1999).



▲ Stranding or Entrapment Event (number indicates stranded or entrapped juvenile fall chinook salmon)

Figure 6. Columbia River flow regime from Priest Rapids Dam to Wooded Island (April 23 – May 3, 1998).

Summary of Prior Years Evaluations

1997 Juvenile Fall Chinook Salmon Stranding Evaluation

In 1997, WDFW performed pilot fieldwork from May 7 through July 28. The work was performed to aid in the development of a work plan for the 1998 evaluation of juvenile fall chinook salmon stranding on the Hanford Reach.

The Hanford Reach was exposed to exceptionally high river flows in 1997. Annual flows in 1997 averaged 169 kcfs compared to only 114 kcfs (range 91 – 161kcfs) during the previous ten years (1987 – 1996). In addition, June flows in 1997 averaged 323 kcfs compared to 156 kcfs (range 111 – 237 kcfs) for the previous ten years.

High spring river flows in 1997 hampered field activities. Field operations that could not be completed included two controlled river elevation reduction tests and the assessment of stranding in cobble substrate. Investigation work completed included the identification of the primary juvenile fall chinook salmon production areas and the determined feasibility of a benthic macroinvertebrate evaluation. In addition, Pacific Northwest National Laboratory (PNNL) completed work on the Modular Aquatic Simulation System 1D (MASS1), a one-dimensional unsteady flow model for the Hanford Reach (Richmond and Perkins 1998).

Results of the field investigations indicated that despite the high flow year, juvenile fall chinook salmon as well as other fishes were observed stranded and entrapped. Other fishes found stranded and entrapped included sucker (*Catostomus* spp.), northern pikeminnow (*Ptychocheilus oregonensis*), redside shiner (*Richardsonius balteatus*), peamouth (*Mylocheilus caurinus*), smallmouth bass (*Micropterus dolomieui*), threespine stickleback (*Gasterosteus aculeatus*), sculpin (*Cottus* spp.), common carp (*Cyprinus carpio*), and largemouth bass (*Micropterus salmoides*). Field observations indicated stranding and entrapment susceptibility of juvenile fall chinook salmon appeared to decrease with increasing fish size. A size threshold of 81 mm was identified as the end of juvenile fall chinook salmon stranding and entrapment susceptibility. Thermal stress and thermal shock appeared to be the primary sources of juvenile fall chinook salmon mortality in entrapment areas. Juvenile fall chinook salmon and other fishes demonstrated evidence of specific habitat preference and appeared to be somewhat segregated. Some species of fish appeared to be more susceptible as spawning adults while others were most susceptible as newly hatched fry.

1998 Juvenile Fall Chinook Salmon Stranding Evaluation

The 1998 field efforts were performed from March 12 through October 5. These efforts were mainly exploratory because high flows hampered the 1997 pilot year evaluation. The objectives of the 1998 evaluation were to collect basic information on the physical parameters of the Hanford Reach, evaluate the extent of stranding and entrapment of juvenile fall chinook salmon and other fishes, and identify critical habitat zones. The data collected was used to generate a sampling design for 1999. The information is also being used in the development of a model to determine susceptibility of juvenile fall chinook salmon to stranding and entrapment due to river elevation fluctuations. WDFW subcontracted the University if Idaho (U of I) and Steamside Programs Consultation (SPC) to assess the effects of river fluctuations on the benthic macroinvertebrate communities and the United States Geological Survey Biological Resources Division (USGS/BRD) to study the effects of heat stress on the survival, predator avoidance ability, and physiology of juvenile fall chinook salmon. The United States Army Corps of Engineers (COE) also was subcontracted to collect detailed bathymetry data on the Hanford Reach using the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system.

River conditions on the Hanford Reach in 1998 were marked by below average river flows, above normal ambient air temperatures, near normal precipitation, and near average solar radiation levels.

Juvenile fall chinook salmon first appeared in both nearshore and entrapment sites on March 19 and were last encountered in entrapments on June 24 and last sampled in nearshore sites on June 27. Peak numbers of individuals and mortalities were observed between early April and early May. Juvenile fall chinook salmon distribution and mortality was highest at island complex areas. Individuals less than 59 mm in length were most susceptible to entrapment. Juvenile fall chinook salmon appeared to be most vulnerable to reductions in flow at night, in the first 0.9 m of vertical flow reduction, and when reductions occurred between 100 kcfs and 140 kcfs. Juvenile fall chinook salmon were found to be stranded/entrapped by the smallest flow reductions measurable. The majority of stranding mortalities (94.4%) occurred within 24 hours of the entrapment creation time while most thermal mortalities (99.8%) took place within three days. Stranding mortality occurred more often over coarse unembedded substrates while thermal mortality took place more frequently over fine embedded substrates. Juvenile fall chinook salmon were found most regularly in areas absent of vegetation.

Other fishes found stranded and entrapped in 1998 included northern pikeminnow, redside shiner, sucker, peamouth, threespine stickleback, sculpin, smallmouth bass, mountain whitefish (*Prosopium williamsoni*), dace (*Rhinichthys* spp.), common carp, lamprey (*Lampetra* spp.), bullhead (*Ameiurus* spp.), and yellow perch (*Perca flavescens*).

Fluctuations in water levels led to observed desiccation of the macroinvertebrate community during the 1998 investigation. U of I determined sampling parameters and protocols for the 1999 full-scale evaluation. USGS/BRD found that juvenile fall chinook salmon exposed to thermal stressors similar to those found on the Hanford Reach had no increased vulnerability to predation. USACE collected detailed bathymetry on 35.1 km^2 of the Hanford Reach from Rkm 571.3 to Rkm 606.9.

WDFW and the joint fish managers recommended that operations at Priest Rapids Dam create no fluctuations and/or steadily increasing flows on the Hanford Reach of the Columbia River throughout the juvenile fall chinook salmon emergence and rearing period. This recommendation was provided to the power managers who subsequently proposed a protection program to meet the follow criteria: 1) substantially more protection for juvenile fall chinook fry than occurred in 1998, 2) preservation of opportunity for load-following/power peaking operations, 3) allow system coordinated river operations, 4) provide ability to monitor and evaluate in-season and adaptively manage operations to reduce stranding and entrapment. The proposed program set forth the following operating scenarios: 1) limit daily fluctuations to a range of +/-20 kcfs (a range of 40 kcfs) when weekly average flows are less than 170 kcfs, 2) limit daily fluctuations to a range of +/-30 kcfs (a range of 60 kcfs) when weekly average flows are above 170 kcfs, and 3) rewetting of entrapment zones. Further development of the Interim Protection Program was continued in 1999.

1999 Juvenile Fall Chinook Salmon Stranding Evaluation

The 1999 field season began on March 5 and ended September 29. The objectives of the 1999 evaluation were to continue to collect basic information on the physical parameters of the Hanford Reach, evaluate the extent of stranding and entrapment of juvenile fall chinook salmon and other fish species, and identify critical habitat zones and to use the information to develop a model for determining susceptibility of juvenile fall chinook salmon to stranding and entrapment due to flow fluctuations. The assessment of the effects of flow fluctuations on the benthic macroinvertebrate communities by U of I and SPC and the study of the effects of heat stress on the survival, predator avoidance ability, and physiology of juvenile fall chinook salmon by USGS/BRD were scheduled to be completed in 1999.

The Hanford Reach experienced above average river flows, below normal ambient air temperatures, below normal precipitation, and above average solar radiation levels during the 1999 juvenile fall chinook salmon emergence and rearing period (March–July). Priest Rapids Dam (Rkm 639.1) discharges averaged 161.4 kcfs from March 8 through June 30. Hourly discharge ranged from 61.9 to 261.3 kcfs. Mean daily fluctuation during this time period was 42.1 kcfs.

Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system bathymetry data collected by the United States Army Corps of Engineers (COE) in 1998 was processed in 1999. SHOALS data was used in conjunction with the MASS1 to characterize the Hanford Reach at stage discharges from 40-400 kcfs (See section below).

The Hanford Reach produced an estimated 17,194,262 fall chinook salmon fry in 1999. Juvenile fall chinook salmon were first captured in nearshore areas on March 5 and last sampled July 21. Peak abundance was observed between April 28 and June 2 with the largest catch of the season occurring on May 13. Juvenile fall chinook salmon with fork lengths at or below 42 mm (emergent fry) comprised at least 30% of the fish sampled each week until after May 26. Fish with fork length greater than 59 mm (size threshold thought to be less susceptible to stranding or entrapment) began to appear in nearshore samples on May 5 but did not occur in large numbers until June 2.

In 1999, 1,026 juvenile fall chinook salmon were found stranded/entrapped in random plots. Fish were first encountered in random plots on March 20 and last observed June 12. The majority of stranded and entrapped fish were sampled during the weeks of March 21-27, April 4-10, April 11-17, and May 23-29. These time periods coincided with lower flows (<120 kcfs) and large flow fluctuations (>80 kcfs).

Stranded and entrapped juvenile fall chinook salmon had a mean fork length of 45.6 mm and ranged from 36 to 66 mm. Indivduals less than 60 mm comprised 96.9% of the juvenile fall chinook salmon measured. Fish were found throughout the SHOALS defined study area in a variety habitats and flow bands but the highest concentrations were found at the island complex areas of Locke Island (600-605 Rkm) and 100 F Islands (590-595 Rkm) at flows of 80-120 and 120-160 kcfs in random plots with gravel to cobble substrates, low substrate embeddedness, and absent to medium vegetation density.

The estimated total number of juvenile fall chinook salmon stranding and entrapment mortalities in 1999 was calculated to be 125,695 with a 95% confidence interval between 50,724 and 200,666. Juvenile fall chinook salmon placed at risk of mortality due to stranding and entrapment was calculated to be 381,897 with a 95% confidence interval between -347 and 764,141.

Other fish species found stranded and entrapped in 1999 included northern pikeminnow, threespine stickleback, smallmouth bass, sculpin, mountain whitefish, sucker, bluegill (*Lepomis macrochirus*), lamprey, peamouth, dace, and walleye (*Stizostedion vitreum*).

Long-term tests on the effects of fluctuations clearly show that benthic macroinvertebrates within the river fluctuation zone were severely limited in density and biomass compared to the communities on continually inundated areas. Total invertebrate density was approximately 4 times higher on substrates never dewatered than on substrates exposed only 1 to 24 hours. Mean total invertebrate density and biomass were reduced by 59% and 65%, respectively, from substrates exposed up to 24 hours to substrates never dewatered. Effects of short-term exposure scenarios revealed that a dramatic decrease in survival was found with even short duration exposures to air. Artificial exposure tests revealed that survival of macroinvertebrates on substrates exposed to air decreased dramatically with increasing duration of exposure, with only 50% survival after 1 hour of exposure. Changes in discharge and water levels also catastrophically entrained macroinvertebrates into the drift outside of behavioral diel periodicity.

USGS/BRD thermal tolerance tests showed thermally-stressed juvenile fall chinook salmon had little direct mortality and no increased vulnerability to predation. However, these fish showed transient increases in plasma concentrations of cortisol, glucose, and lactate, and a dramatic (25-fold higher than controls) and persistent (lasting 2 weeks) increase in levels of liver hsp70. It is not known what the consequences of exposure to multiple, cumulative stressors may be to the fish.

An emergency management team (EMT) consisting of WDFW and YN personnel was organized in 1999 to monitor primary fall chinook salmon rearing areas to identify flow fluctuation events that pose risks (imminent drainage of entrapments, lethal water temperatures) to large numbers of entrapped juvenile fall chinook salmon. The EMT monitored 119 entrapments from April 17 to June 21. A total of 8,240 juvenile fall chinook salmon were seined from these entrapments. Field crews recorded 166 direct mortalities at the time entrapments were sampled. Projected mortalites were estimated at 428 based on drainage or lethal temperatures monitored in entrapments. Criteria for emergency action were reached on four days (April 17, May 18, May 22, and May 23), only one (May 22) of which GCPUD could not met with additional water.

Based on the results of the 1999 evaluation, the Hanford Policy Group recommended, with the exception of eliminating the rewetting of entrapment zones after large fluctuations, that the operation constraints imposed in 1999 should be repeated in 2000.

Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) Bathymetry Data

COE collected detailed bathymetry data on 35.1 km^2 of the Hanford Reach from Rkm 571.3 to Rkm 606.9 in August 1998 using the SHOALS system (**Figure 7**). The horizontal positional accuracy of the data was +/-3 m and the vertical positional accuracy was +/-15 cm. These data were used in conjunction with MASS1 to provide information on the Hanford Reach at a range of stage discharges. From this information, the extent of area of shoreline exposed by flow fluctuations and the configuration of the river channel could be determined. The area of shoreline exposed for a portion of the Hanford Reach (100 F Islands) during the 2000 juvenile fall chinook salmon emergence and rearing period is illustrated in **Figure 8**. **Figure 9** shows the amount of area of shoreline within each 10 kcfs flow fluctuation zone for the portion of the Hanford Reach defined by the SHOALS data. The area of shoreline exposed by flow fluctuations at lower river elevations (40kcfs – 110 kcfs) is much larger than at higher fluctuation zones (>110 kcfs). However, the amount of shoreline exposed at different flow levels varys with river kilometer (**Figure 10**). The cross-sections in **Figure 11** reveal the steep banks and flood terraces that can occur within the Hanford Reach.

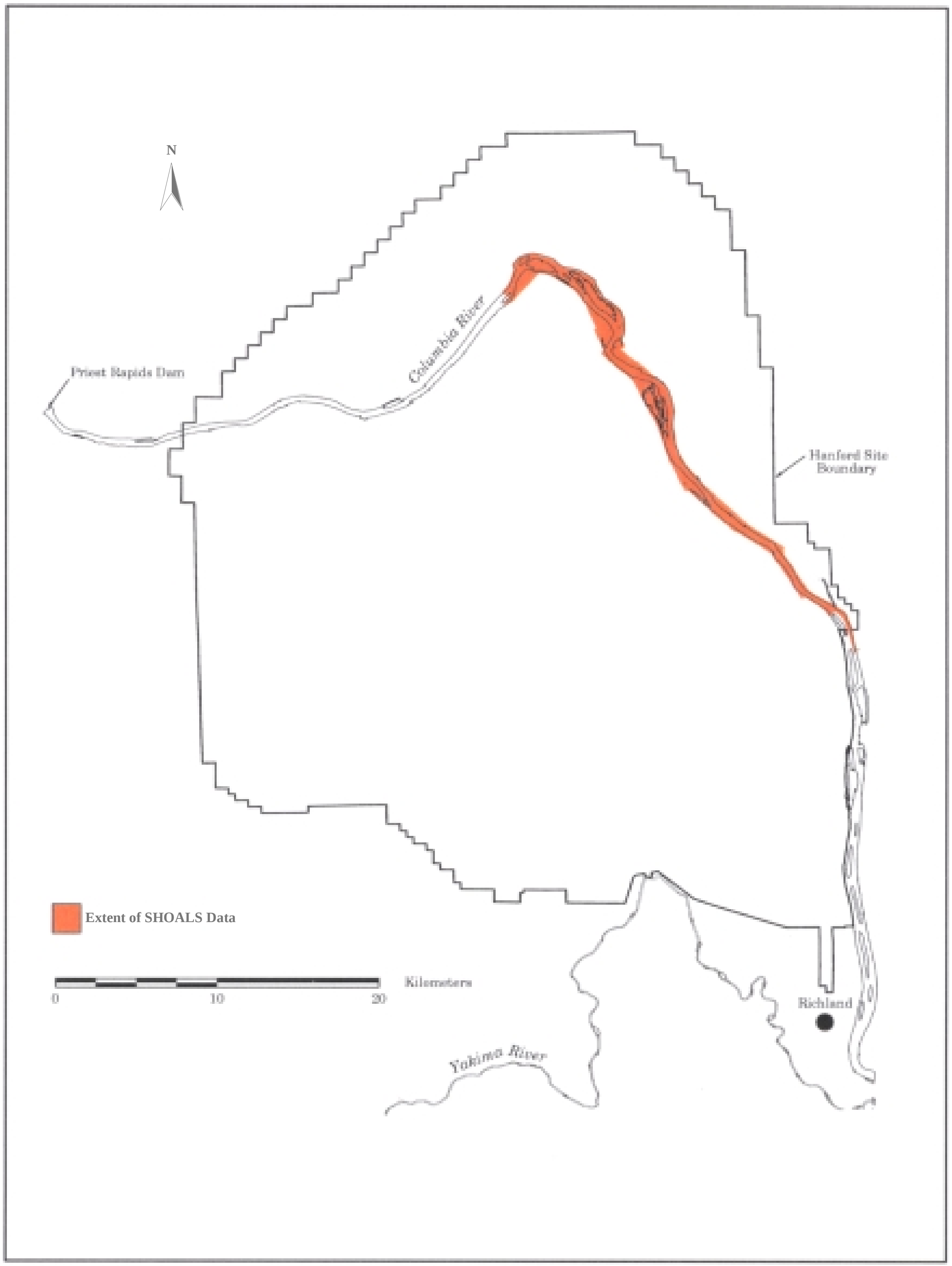


Figure 7. Area of the Hanford Reach of the Columbia River where detailed bathymetry data has been collected using the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS).

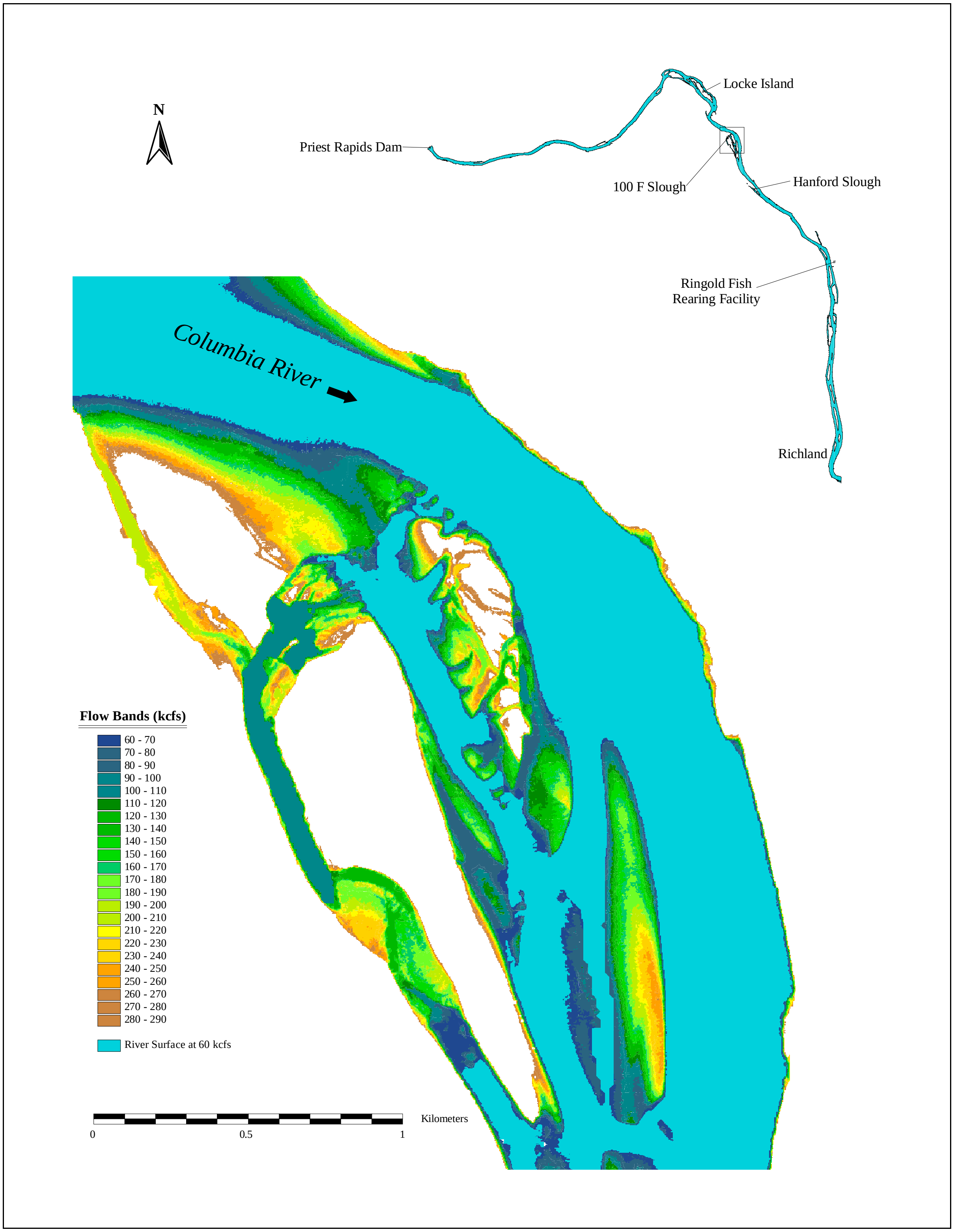


Figure 8. The extent of shoreline exposed in the 100 F Islands area of the Hanford Reach of the Columbia River during the juvenile fall chinook salmon emergence and rearing period in 2000.

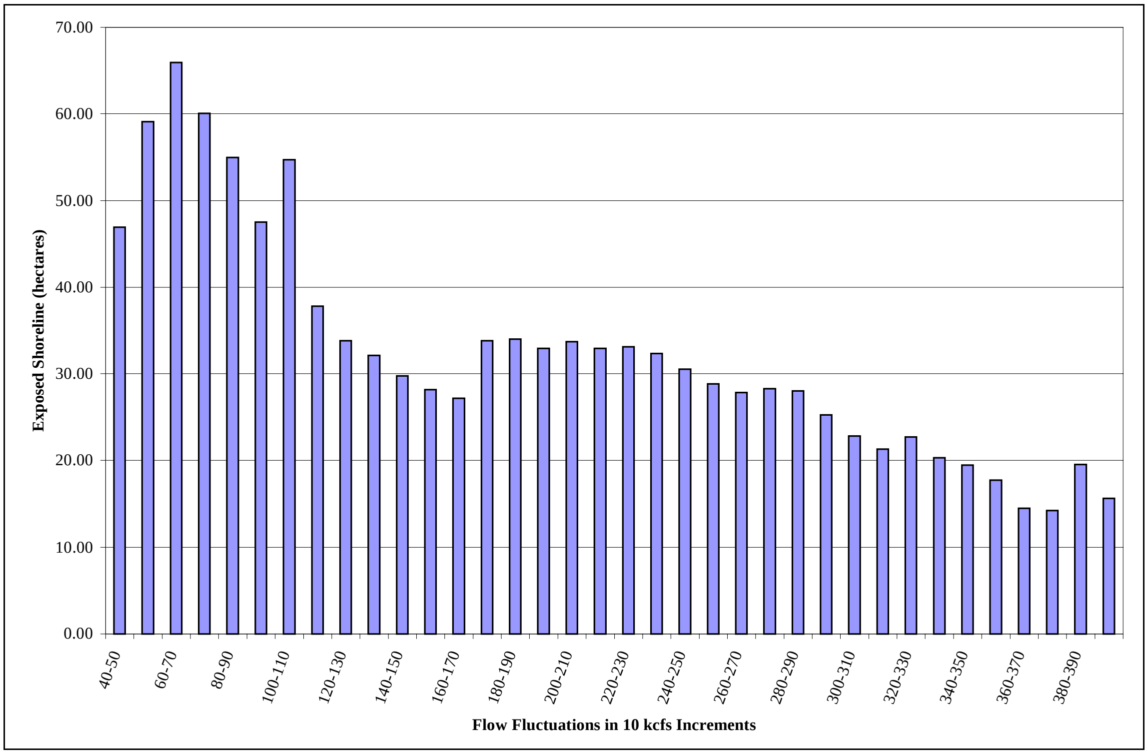


Figure 9. The area of shoreline exposed within each 10 kcfs flow band for the portion of the Hanford Reach of the Columbia River defined by the SHOALS data (Rkm 571.3 to Rkm 606.9).

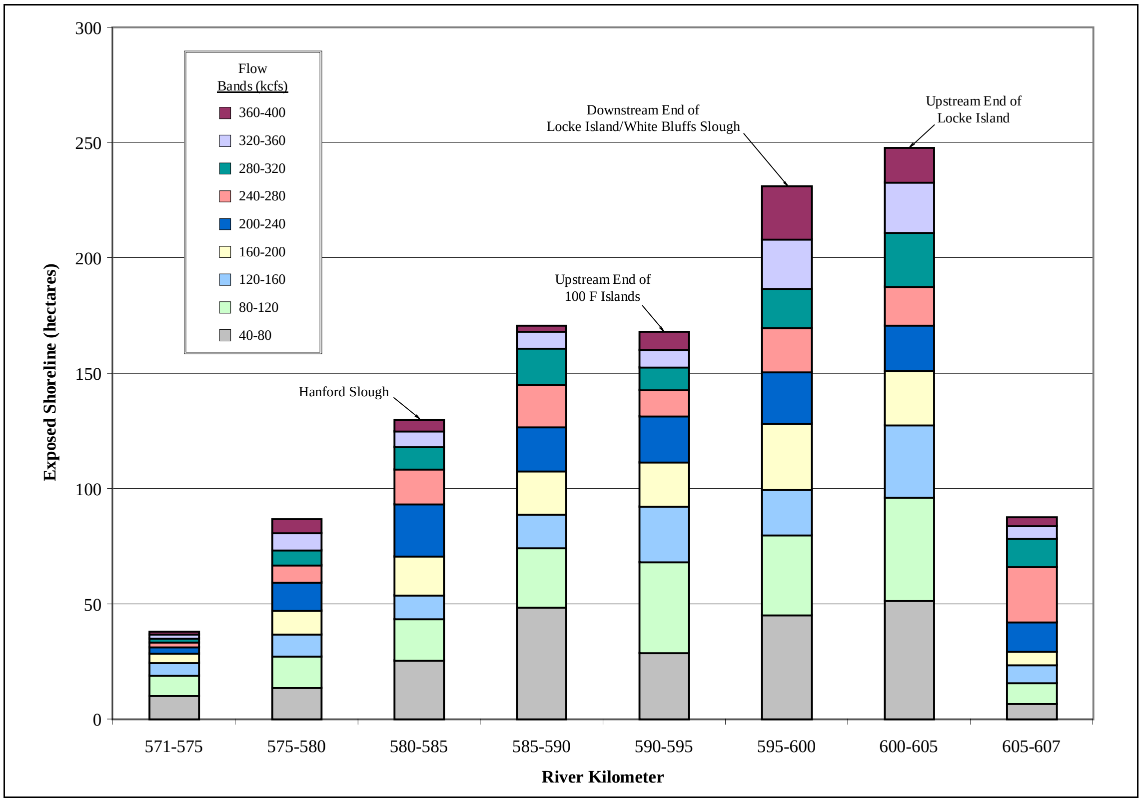


Figure 10. The area of shoreline exposed within 40 kcfs flow band for five kilometer sections of the Hanford Reach of the Columbia River defined by the SHOALS data (Rkm 571.3 to Rkm 606.9).

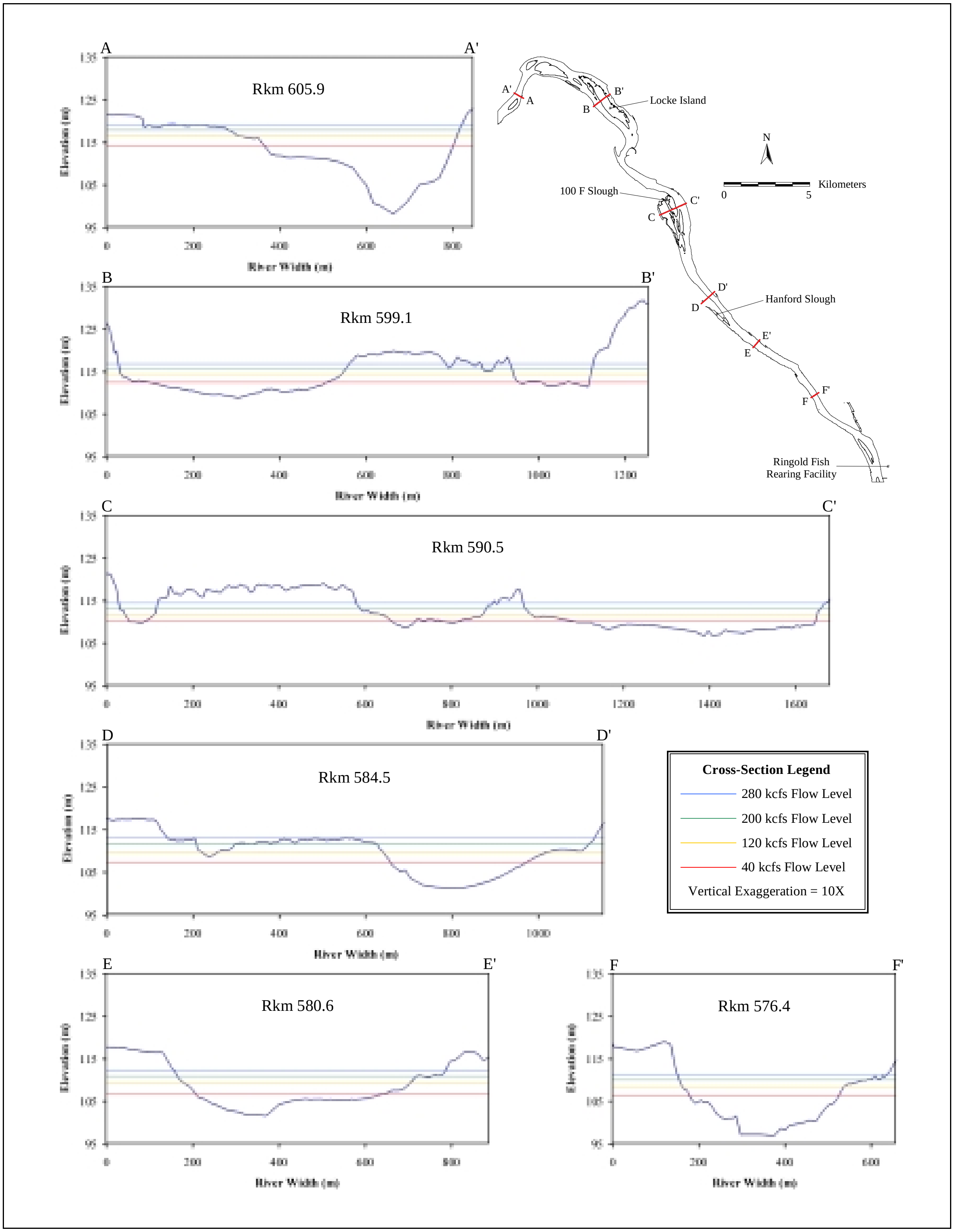


Figure 11. Cross-sectional views of the Hanford Reach of the Columbia River for the portion of the river defined by the SHOALS data (Rkm 571.3 to Rkm 606.9).

The 2000 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program

The 2000 Hanford Reach Juvenile fall Chinook Salmon Interim Protection Program was similar to the protection program conducted in 1999. Operational constraints limited flow fluctuations to a range of 40 kcfs on a daily basis (60 kcfs on a daily basis during flow augmentation for outmigrating juvenile fish under NMFS Biological Opinion) when weekly average flows were less than 170 kcfs at Priest Rapids Dam (NMFS 1995 and 1998). When weekly average flows were greater than 170 kcfs at Priest Rapids Dam, flows were restricted to an hourly minimum of 150 kcfs. These operational constraints were imposed when a daily total of 50 or more subyearling fall chinook salmon were seined from the six established nearshore sampling sites used to assess relative abundance and fish size. The sampling of these sites was begun one week prior to the calculated start of emergence under the Vernita Bar Agreement. Seining was performed every other day to define the beginning of susceptibility then once a week thereafter. Operational constraints were lifted when no more than a total of 50 subyearling fall chinook salmon less than 60 mm were captured in the six nearshore sampling sites or seining catch had declined to 4% or less of the cumulative annual total. The 2000 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program is further detailed in **Appendix A**.

Objectives

The objectives for the 2000 evaluation were as follows:

1) Determine the starting and ending dates of the special operations period.
2) Estimate the total number of juvenile fall chinook salmon killed or placed at risk due to flow fluctuations during the implementation of the 2000 Interim Protection Program.
3) At a pre-determined index site, test the difference in impact on Juvenile fall chinook salmon of two flow conditions ($\pm$20 kcfs versus $\pm$30 kcfs around the daily discharge average) during the special operations period.
4) Determine through daily monitoring the need for emergency re-wetting during the special operations period.
5) Complete resident fish data analysis and reporting.
6) Complete the susceptibility model.

Methods

The methods used to achieve the established objectives included estimating the total number (within the area defined by the SHOALS data) of juvenile fall chinook salmon mortalities and fish at risk due to stranding and entrapment, estimating fry production on the Hanford Reach, surveying to determine relative abundance and size structure of the rearing fall chinook salmon population, surveying the composition, abundance, and growth of other fish species in the nearshore area, and developing a juvenile fall chinook salmon susceptibility model. Objective 3 was determined to be impracticable prior to the start of the 2000 field season (**Appendix B**). To detect a significant difference between two operational strategies ($\pm$20 kcfs versus $\pm$30 kcfs around the daily discharge average) would require an enormous number of samples and it may be impossible to ascertain the flow fluctuations that entrapped the fish.

Estimates of Juvenile Fall Chinook Salmon Stranding and Entrapment

A sampling plan was designed by PNNL and WDFW prior to the 1999 field season to estimate the total number of juvenile fall chinook salmon killed or placed at risk due to flow fluctuations. This same design was used to assess the effectiveness of the 2000 Interim Protection Plan in reducing mortality. The study area was confined to the portion of the Hanford Reach defined by the SHOALS bathymetry data from 40 to 400 kcfs.

The study area was classified into 40 kcfs flow bands and divided into 3600 ft^2 (344.4 m^2) plots or sampling cells. The sample plot size was based on the mean size of entrapments found in 1998. Sample plots that crossed the line between designated 40 kcfs flow bands were included in the flow band that contained at least 50% of the cell. Cells that did not include a majority of one 40 kcfs flow band were removed from consideration. A list of all cells contained within the study area was compiled and cells were randomly selected to use in daily field sampling activities. Daily sampling targeted random sampling locations within wetted flow bands identified in the previous 48-hour flow history.

Initiation of field activities was based upon juvenile fall chinook salmon emergence timing as calculated under the terms of the 1988 Vernita Bar Settlement Agreement. Because fall chinook salmon spawning and subsequent spring emergence may occur earlier than predicted, field operations were initiated approximately one week prior to the calculated start of emergence to ensure maximum protection of newly emergent fall chinook salmon. Implementation of the 2000 Interim Protection Program and field sampling was based on population surveys conducted at six index sites. Detailed information regarding the 2000 Interim Protection Program initiation criteria is included in **Appendix A**.

Two field teams comprised of WDFW, GCPUD, and Yakama Nation (YN) personnel collected data daily during the fall chinook salmon emergence and rearing period when wetted shorelines were visible. The crews chose sample locations in the appropriate flow bands from the list of randomly generated sample plots prior to sampling. A high-performance global positioning system (GPS) with submeter accuracy was used to navigate to the sample locations.

An anchor attached to an incrementally marked wire cable was placed at the center of each sample plot to delineate the circular boundary of the plot. The number of juvenile fall chinook salmon and other species of fish found within the sample plot were counted and classified as alive or dead. If entrapments were encountered, an assessment was made to determine the percentage of the entrapment contained within the sample plot. Entrapments with area of 50% or greater within the circle were sampled in their entirety. Entrapments with area of greater than 50% outside of the circle were not surveyed. In cases where portions of the plot were dry or under water at the river's edge, the marked wire cable was used to measure the amount of wetted shoreline. A scaled drawing was produced to calculate the proportion of the plot contained within the fluctuation zone. Other data recorded at the sites included bird activity (i.e., tracks), entrapment water temperatures, dominant and subdominant substrate size, substrate embeddedness, and vegetation density. Dominant and subdominant substrate size were classified according to a modified Wentworth code (Platts et al. 1983); substrate embeddedness was classified according to Platts et al. (1983); and vegetation density was recorded as absent, sparse, medium, or dense (**Appendix C**). An additional step was taken in 2000 to revisit entrapments the following day to determine the fate of juvenile fall chinook salmon that had been in entrapped (i.e., drainage of entrapment, lethal water temperatures). Methods for calculating the estimated total number of juvenile fall chinook salmon mortalities and at risk due to stranding and entrapment are provided in **Appendix D**.

Fall Chinook Salmon Fry Production Estimate

A coarse estimate of the 2000 fall chinook salmon fry production in the Hanford Reach was calculated to gauge the proportion of the population affected by flow fluctuations. The estimate was based on 1999 adult fall chinook salmon escapement to the Hanford Reach, female composition of the escapement, fecundity, egg retention, and egg to emergence survival. Information on escapement (number and percent female) and egg retention was obtained from the 1999 WDFW Hanford Reach carcass and creel surveys (Watson 2000). The sex composition of Hanford Reach spawners was derived from the sport fishery harvest data collected during these surveys (**Appendix E**). It was assumed that anglers had an equal chance of harvesting a male or female and there was no behavioral characteristics associated with gender that would bias catch. Fecundity rates have not been established for naturally spawning fall chinook salmon on the Hanford Reach but, for this estimate, it was assumed that these rates were similar to rates of fall chinook salmon sampled at Priest Rapids Hatchery. No studies have been conducted on egg to emergence/fry/smolt mortality rates of fall chinook salmon on the Hanford Reach. Healey (1998) reports that, under natural conditions, 30% or less of the potential eggs deposited resulted in emergent fry or fry and fingerling migrants in the systems studied. For purposes of this estimate, an egg to fry survival rate of 30% was used.

Accumulated Temperature Units and Juvenile Fall Chinook Salmon Stranding and Entrapment Susceptibility

The embryonic development and growth of fall chinook salmon is highly dependent on river temperature. Accumulated temperature units (ATU's) can be used to predict the rate of development, hatching, and emergence timing of fall chinook salmon. ATU's are the cumulative total of daily river temperatures. Generally, fall chinook salmon eye at approximately 250^{o}C ATU's after spawning, hatch at around 500^{o}C ATU's and emerge at roughly 1000^{o}C ATU's. The use of ATU's was investigated to determine a logical criterion for lifting operational flow constraints.

Assessment of Juvenile Fall Chinook Salmon Relative Abundance and Fish Size

Juvenile fall chinook salmon were seined from six nearshore sampling sites on the Hanford Reach once a week during the emergence and rearing period to assess relative abundance and fish size. The six sites included three at Locke Island (Rkm 597.0, 599.5, and 600.7), one upstream of 100 F Islands (Rkm 593.1), one at 100 F Islands (Rkm 591.4), and one at the downstream end of Savage Island (Rkm 573.2). Seining techniques were similar to methods described by Key et al. (1994).

A beach seine, 21.3 m x 1.8 m with a 1.8 m^2 bag, 4.8 mm diamond mesh, and 15.2 m leads, was used to collect juvenile fall chinook salmon and other fish species from the six designated nearshore sampling sites. One lead of the seine was cleated to the bow of a 5.5 m boat, the seine was folded and laid on the bow, and the other lead was held by a person on shore. The boat was then backed perpendicular to shore to a distance of 15.2 m and then backed upstream allowing the seine to be fed out parallel to shore. Once the seine was unfurled, the boat was maneuvered back into shore. Both ends of the seine were then simultaneously hauled to shore. The area sampled in this manner was approximately 320 m^2. When samples contained less than 100 juvenile fall chinook salmon, all fish were anesthetized with tricaine methanesulfonate (MS 222), measured, and fork lengths were recorded. Samples containing over 100 juvenile fall chinook salmon were sub-sampled to obtain approximately 100 fish. Fish sub-sampled were anesthetized and fork lengths were recorded; the remaining fish were counted. All fish were released back into the river. Temperature, dominant and subdominant substrate size (modified Wentworth code; Platts et al. 1983), substrate embeddedness (Platts et al. 1983), and vegetation density (absent, sparse, medium, or dense) were recorded for each site (**Appendix C**).

Evaluation of Potential Mortality Events in Primary Fall Chinook Salmon Rearing Areas

An emergency management team (EMT) consisting of WDFW and YN personnel monitored primary fall chinook salmon rearing areas for potential mortality events. The objective of the EMT was to identify flow fluctuation events that posed risks to large numbers of juvenile fall chinook salmon. When such events were identified, a pre-established notification procedure was used to request immediate corrective action.

The EMT inspected one of three sites daily. The sites included Locke Island (Rkm 600.0), 100 F Islands (Rkm 591.0), and Hanford Slough (Rkm 585.0). The EMT alternated through these sites in consecutive order. Observation entrapments were established at each of the sites and used to index conditions throughout the Hanford Reach. Multiple entrapments were identified and marked at each site so that the full range of flow conditions could be indexed. When entrapments containing juvenile fall chinook salmon were observed, all fish were seined, counted, and released into the river. After removal of the fish, water temperatures and drainage rates were monitored in the entrapments throughout the day. If two or more entrapments previously containing juvenile fall chinook salmon reached 24^{o}C or drainage of the entrapments was imminent, the EMT would contact the other field crews to verify that similar detrimental conditions were present in other areas of the Hanford Reach. When conditions warranted, the field crew leader would call the designated GCPUD personnel to request immediate re-wetting or other operational solutions.

Surveys of Other Fish Species

Data pertaining to fish species other than fall chinook salmon were collected during the spring period in concurrence with the evaluation of the 2000 Interim Protection Program. In addition, WDFW field personnel worked in conjunction with USGS/BRD larval fish researchers in sampling nearshore sites (**Appendix F**). Ten nearshore sites were sampled weekly during the summer and early fall. These sites consisted of six main channel and four slough sites. The six main river channel sites included three at Locke Island (Rkm 598.1, 600.5, and 600.5), two at 100 F Islands (Rkm 591.1 and 591.3), and one at the Hanford Townsite (Rkm 582.0). The four slough sites consisted of two in Hanford Slough (Rkm 583.1) and two in White Bluffs Slough (Rkm 595.8).

Nearshore sites were sampled using a small beach seine (15.2 m x 1.2 m with a 1.2 m^2 bag and a mesh size of 0.8 mm), following the methods of Barfoot et al. (1999). To collect fish, the seine was pulled perpendicular to the shore from a depth of one meter or from a distance of 15 meters from the shore whichever was attained first. Fish collected that were large enough to be identified in the field were anesthetized with MS-222, measured, recorded, and released. Larval fish and smaller juvenile fish collected were preserved in 10% buffered formalin and transported to the USGS/BRD laboratory for analysis. In the situation where large numbers of larval fish were collected, volumetric sub-sampling was performed and excess fish were released back into the river. At the laboratory, preserved samples of larval and juvenile fish were sorted, identified to the lowest possible taxa and counted. Larval fish numbers by taxa were estimated using simple extrapolation of the sub-samples. A maximum of 50 specimens of each taxa were randomly selected and measured to the nearest 0.1 mm standard length. Water quality parameters were collected at all index sites during each sample event. Water temperatures were recorded at mid-depth offshore at the most distant point of the seine haul and at a 20 cm depth near shore.

Modeling of Juvenile Fall Chinook Salmon Susceptibility to Stranding and Entrapment

In 2001, PNNL began design of a computer model for predicting the number of juvenile fall chinook salmon that would be placed at risk of mortality due to stranding and entrapment as a result of changes in system operations. Stranding susceptibility is modeled as a function of time dewatered and the characteristics of the dewatered substrate and as a function of the number and size of fish present in areas of interest. The influence of upstream hydrologic inputs on the amount of substrate dewatered was modeled with MASS1. The model provides time-varying water elevation information at a number of locations throughout the potential stranding area. Other inputs include fry production variables, growth variables, and habitat variables. The modeling effort will be completed in early 2002.

Results

2000 Hanford Reach Flows and Meteorological Conditions

The Hanford Reach experienced slightly warmer to near normal air temperatures and wetter than normal conditions during the 2000 juvenile fall chinook salmon emergence and rearing period (March–July) (**Table 1**). Solar radiation levels, a good indication of cloud cover, were above the 20-year mean (1980-1999) each month during this time period with the exception of March. River flows during the juvenile fall chinook salmon emergence and rearing period were below the 10-year mean flows (1990-1999) for each month with the exception April when flows were 30.6 kcfs above the previous 10-year mean.

Table 1. Comparison of 2000 monthly average river flows, air temperatures, precipitation, and solar radiation levels to past years on the Hanford Reach of the Columbia River.

River Flows[1] (kcfs)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2000	150.2	121.6	105.9	155.5	163.8	133.6	125.7	111.5	86.2	77.2	98.2	110.1
Mean (1990-1999)	125.2	132.2	124.6	124.9	168.5	189.9	144.9	116.1	84.1	85.7	99.3	122.4
Departure	+25.0	-10.6	-18.7	+30.6	-4.7	-56.3	-19.2	-4.6	+2.1	-8.5	-1.1	-12.3
Air Temperature[2] (°C)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2000	0.5	3.7	7.1	13.0	16.2	21.1	24.2	23.3	17.6	11.2	1.1	-1.3
Normal (1961-1990)	-0.4	3.3	7.6	11.5	16.3	20.9	24.6	23.9	18.7	11.6	4.6	-0.3
Departure	+0.9	+0.4	-0.5	+1.5	-0.1	+0.2	-0.4	-0.6	-1.1	-0.4	-3.5	-1.0
Precipitation[2] (cm)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2000	2.8	2.8	2.4	1.4	2.0	0.6	1.2	Trace	1.4	1.4	2.7	1.7
Normal (1961-1990)	2.0	1.6	1.2	1.0	1.3	1.0	0.5	0.7	0.8	1.0	2.3	2.6
Departure	+0.8	+1.2	+1.2	+0.4	+0.7	-0.4	+0.7	-0.7	+0.6	+0.4	+0.4	-0.9
Solar Radiation[2] (Langleys)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2000	89.4	157.7	283.4	437.9	520.5	590.0	620.8	549.1	347.2	229.7	106.1	57.3
Mean (1980-1999)	95.8	169.6	300.1	425.0	518.0	575.9	600.5	521.7	389.9	241.9	116.0	76.2
Departure	-6.4	-11.9	-16.7	+12.9	+2.5	+14.1	+20.3	+27.4	-42.7	-12.2	-9.9	-18.9

[1]Data from USGS Gauging Station 12472800 below Priest Rapids Dam

[2] Data from Hanford Meteorological Station, PNNL

Implementation Timing and Operation of the 2000 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program

A working Interim Protection Program was agreed upon by the Hanford Policy Group prior to the calculated start of 2000 fall chinook salmon emergence (**Appendix A**). As a precautionary measure, field activities commenced before estimated emergence of juvenile fall chinook salmon to ensure maximum protection while the implementation criteria were under development.

Emergence of wild juvenile fall chinook salmon in 2000, as calculated under the terms of the 1988 Vernita Bar Settlement Agreement (GCPUD 1988), was estimated to start on March 20. Population index surveys were subsequently initiated on March 13 to account for possible early emergence. Implementation criteria were met on March 19 and the 2000 Interim Protection Program began March 21. Random sampling to assess the effectiveness of the 2000 Interim Protection Program began on March 20 and ended June 25. The protection program continued through June 26.

Priest Rapids Dam (Rkm 639.1) discharges averaged 147.7 kcfs from March 21 through June 26 in 2000. Hourly discharge from the Dam ranged from 62.1 to 293.2 kcfs (**Figure 12**). Mean daily fluctuation during this period was 50.0 kcfs. A 17 kcfs fluctuation in discharge equates to a vertical change in river elevation of approximately one foot (0.3 m) at Vernita Bar (Rkm 632.4). The primary period of susceptibility of juvenile fall chinook salmon to stranding in 2000 based on fish recorded as "mortalities" and "at risk" in random samples and length frequency distribution from index sampling appears to be from the start of emergence to May 21 (200 temperature units Celsius after the estimated end of emergence). Mean daily flow fluctuation from Priest Rapids Dam during the primary period of susceptibility was 46.5 kcfs with 9 days of relatively stable flows (fluctuations < 20 kcfs) and 33 days of flow fluctuations greater than 40 kcfs including 8 days of flow fluctuations greater than 80 kcfs (**Table 2** & **Figure 13**).

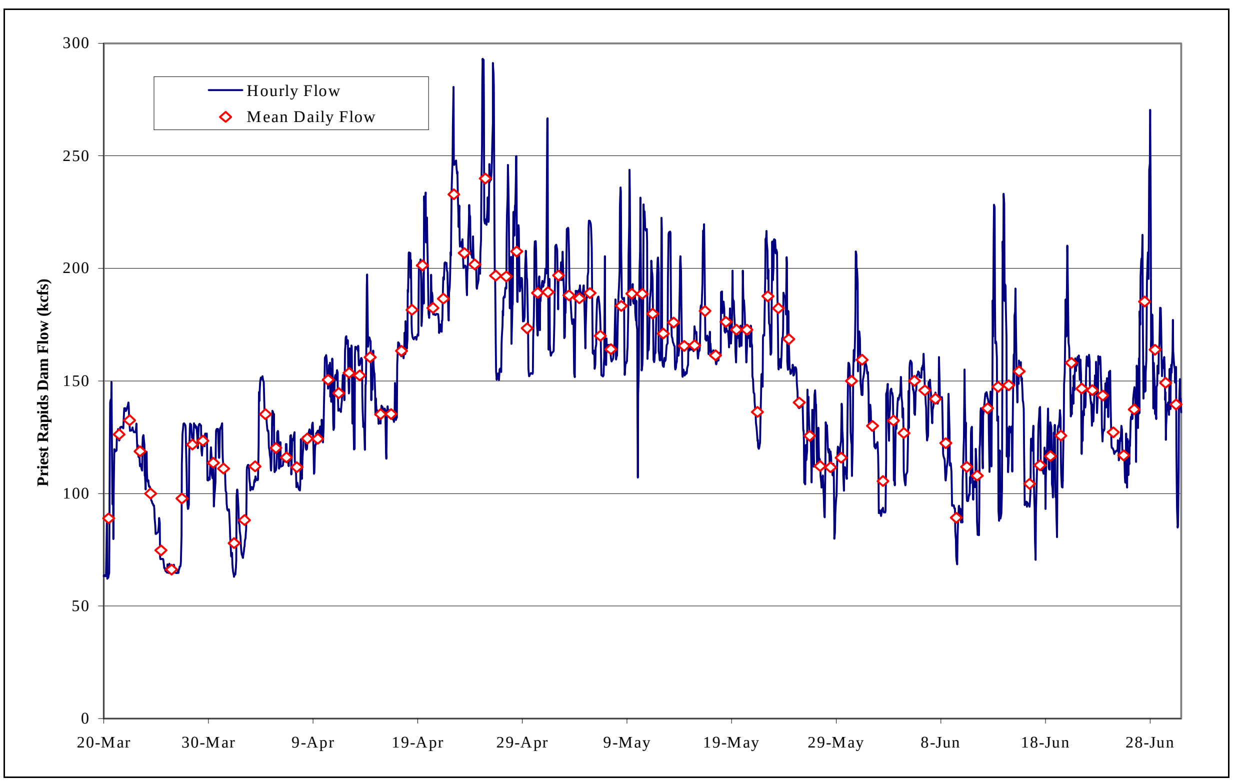


Figure 12. Hourly and mean daily flows from Priest Rapids Dam on the Columbia River (March 20-June 30, 2000).

Table 2. Daily fluctuations in flow from Priest Rapids Dam on the Columbia River (March 8-June 30, 2000).

Date	Mean Flow Fluctuation (kcfs)	Number of Days				
		<20 kcfs (stable)	20-40 kcfs	40-60 kcfs	60-80 kcfs	>80 kcfs
March 21-May 21	46.5	9	20	17	8	8
May 22-June26	55.9	0	10	17	5	4
Total	50.0	9	30	34	13	12

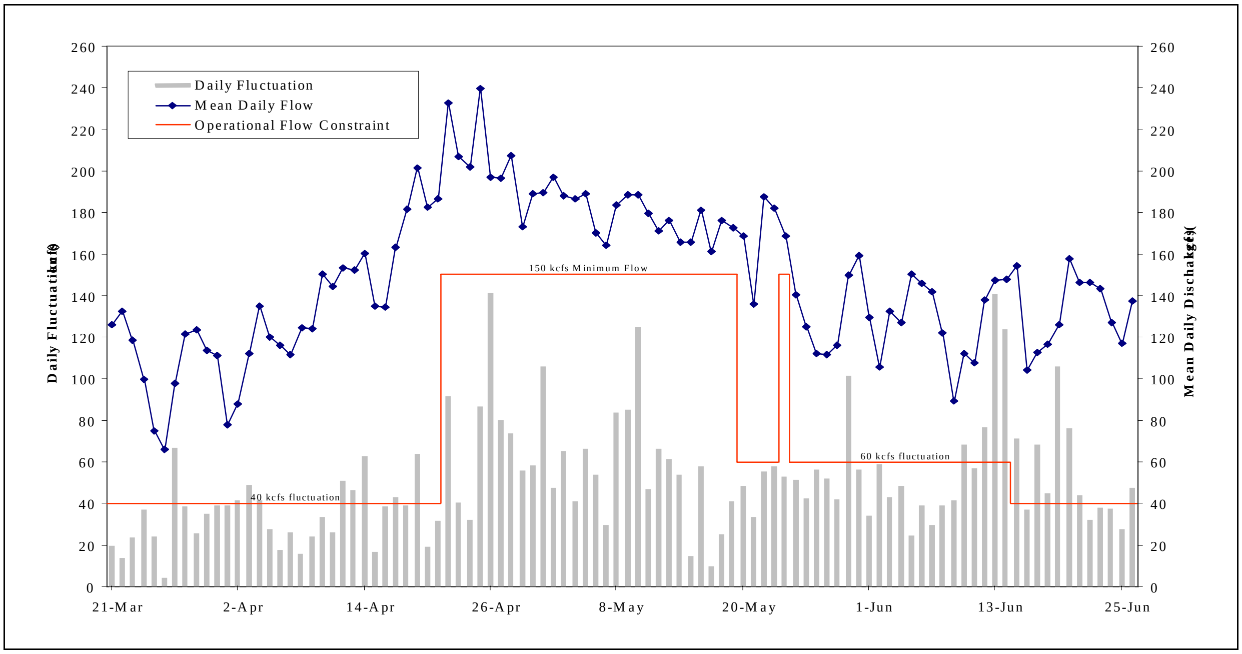


Figure 13. Mean daily flow, daily fluctuation in flow, and operational flow constraints for Priest Rapids Dam on the Columbia River (March 21-June 26, 2000).

Estimates of Juvenile Fall Chinook Salmon Stranding and Entrapment

Numbers of Juvenile Fall Chinook Salmon

A total of 924 random plots encompassing 206,369 m^2 (2,221,411 ft^2) were sampled in 2000. Random sampling was conducted between March 20 and June 25 within six flow bands (60-80 kcfs, 80-120 kcfs, 120-160 kcfs, 160-200 kcfs, and 200-240 kcfs, and 240-270 kcfs). The lower most and upper most 40 kcfs flow bands were truncated because no fluctuations occurred between 40-60 kcfs and 270-280 kcfs within the SHOALS defined study area. Of the total 924 random plots, 797 were used to calculate loss estimates. A decision was made to only include samples through June 9. This decision, which eliminated 127 samples, was made because no juvenile fall chinook salmon were found at risk after June 5 although the 2000 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program and associated field sampling activities continued through June 26.

Random plots contained 709 juvenile fall chinook salmon in 2000, including 138 stranded and 571 entrapped individuals. Field crews recorded 156 direct mortalities consisting of the 138 stranded and 18 thermal induced fatalities (**Table 3**). Random plots with entrapments that contained live chinook were revisited during the following 24 hours to determine the fate of these chinook. Entrapped fish were recorded as mortalities if the entrapments drained or reached lethal temperatures (>24°C). Based on re-visitation of entrapments, 487 of the 571 entrapped chinook were mortalities bringing the total mortality to 625 chinook. Fish were first encountered in random plots on March 24 and last found on June 2. The majority of juvenile fall chinook salmon were sampled during two time periods, March 26-April 15 and April 23-May 6. The first time period (March 26-April 15) was marked by low to moderate flows (66-161 kcfs) and moderate flow fluctuations (41-67 kcfs). The second time period coincided with high flows (240 kcfs) followed by steadily decreasing flows and large flow fluctuations (80-140 kcfs) (**Figure 13**).

The estimated total number of juvenile fall chinook salmon stranding and entrapment mortalities in 2000 was calculated to be 72,362 with a 95% confidence interval between 34,270 and 110,454. The number of mortalities estimated by re-visitation of entrapments was 209,997 with 95% confidence interval between –20,483 and 440,476. It is obvious the lower limit of the 95% confidence interval calculated using the standard error does not have physical meaning and is caused by the high variance in the data. A more reasonable lower limit would be 625, the projected number of mortalities based on re-visitation. Juvenile fall chinook salmon placed at risk of mortality due to stranding and entrapment was calculated to be 255,222 with a 95% confidence interval between 17,743 and 492,701 (**Appendix D**).

These assessments should be considered minimum estimates because the area for which detailed bathymetry data was available is only a portion of the Hanford Reach. In addition, sampling efficiency was assumed to be 100%, but was likely a lesser value that could not be calculated. Potential sources of reduced sampling efficiency included losses of fish from sample locations to scavengers/predators prior to sampling and/or less than 100% efficiency in recovery of fish by surveyors during sampling activities.

Table 3. Weekly numbers of juvenile fall chinook salmon found in random plots on the Hanford Reach of the Columbia River in 2000.

Week	Stranded[1]	Entrapped[2]	Total Mortalities (Stranded + Thermal)	Projected Chinook Mortalitites[3]	Total Chinook at Risk
March 5-11	0	0	0	0	0
March 12-18	0	0	0	0	0
March 19-25	1	0	1	1	1
March 26-April 1	18	16	18	18	34
April 2-8	24	75 (18)	42	63	99
April 9-15	25	83	25	108	108
April 16-22	5	0	5	5	5
April 23-29	17	15	17	17	32
April 30-May 6	16	367	16	381	383
May 7-13	17	2	17	17	19
May 14-20	2	13	2	2	15
May 21-27	8	0	8	8	8
May 28-June 3	5	0	5	5	5
June 4-10	0	0	0	0	0
June 11-17	0	0	0	0	0
June 18-24	0	0	0	0	0
June 27-July 3	0	0	0	0	0
Total	138	571 (18)	156	625	709

[1] All stranded fish were counted as mortalities.

[2] Numbers in ( ) represent thermal mortalities.

[3]Entrapments were revisited the next day to determine if fish would have died from drainage of entrapments or lethal temperatures (>24°C).

Size Susceptibility of Juvenile Fall Chinook Salmon

Juvenile fall chinook salmon collected in random plots had a mean fork length of 41.7 mm and ranged from 33 to 86 mm (**Figure 14**). Individuals less than 60 mm comprised 99.2% of the juvenile fall chinook salmon measured.

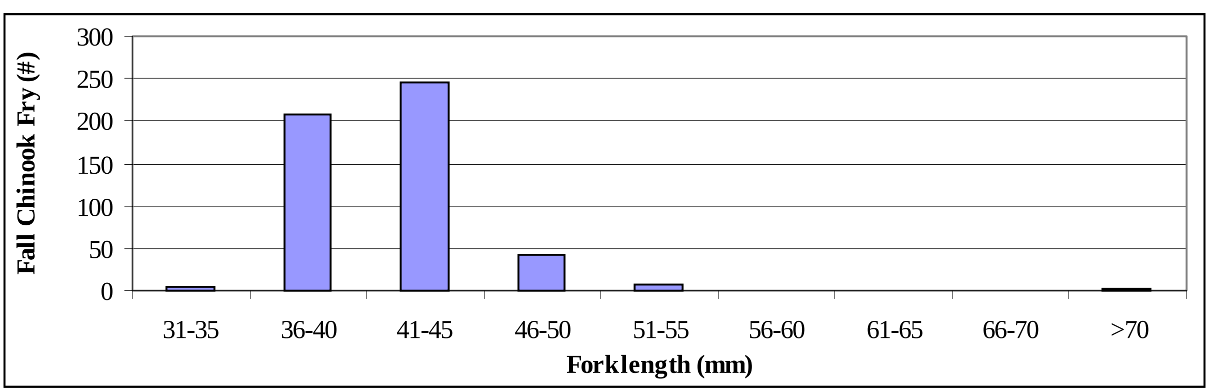


Figure 14. Fork length measurements of juvenile fall chinook salmon collected from random plots on the Hanford Reach of the Columbia River in 2000.

Distribution of Juvenile Fall Chinook Salmon

The portion of the Hanford Reach defined by the SHOALS bathymetry data was divided into eight river sections (~5 Rkm long) and the total amount of shoreline exposed during the juvenile fall chinook salmon emergence and rearing period was calculated for each 40 kcfs flow band within each section to determine the horizontal and vertical distribution of stranding and entrapment (**Figure 15**). The total amount of shoreline exposed was calculated by multiplying the amount of shoreline exposed for each flow band at each river section by the number of flow fluctuations that occurred in that flow band over the entire period. Flow fluctuations were counted at Rkm 588.3, the closest MASS1 transect to the midpoint of the SHOALS data. Juvenile fall chinook salmon were found throughout the SHOALS defined study area at a variety flow bands but the highest concentrations were found at Locke Island (595-605 Rkm) and the downstream end of 100 F Islands (585-590 Rkm) at flows of 120-200 kcfs.

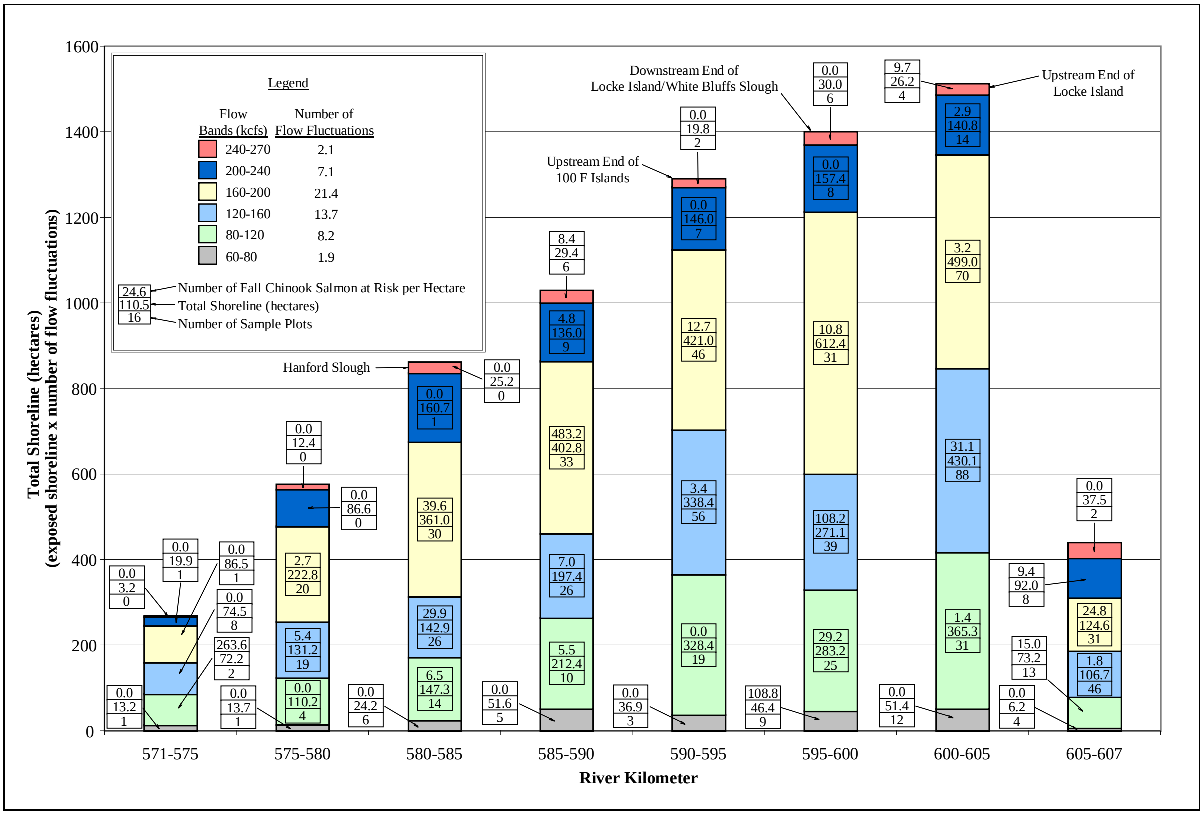


Figure 15. The total area of shoreline exposed during the 2000 juvenile fall chinook salmon emergence and rearing period within 40 kcfs flow band for five kilometer sections of the Hanford Reach of the Columbia River defined by the SHOALS data (Rkm 571.3 to Rkm 606.9). Included in the figure is the number of random plots sampled and the number juvenile fall chinook salmon found per hectare.

Physical Characteristics of Random Sample Plots

Substrate size, substrate embeddedness, and vegetation density in random plots varied between flow bands (**Figure 16**) and between river sections (**Figure 17**). Lower flow bands held more random plots containing gravel to cobble substrates with less substrate embeddedness and absent to medium vegetation density. Higher flow bands contained more random plots with finer substrates, higher substrate embeddedness and higher vegetation density. Juvenile fall chinook salmon were found in random plots with a range of physical characteristics but were most often found in the lower flow bands (**Figure 18**). The majority juvenile fall chinook salmon were located in two sections of the river, Rkm 595-605 (Locke Island) and Rkm 585-590 (downstream end of 100 F Islands) (**Figure 19**).

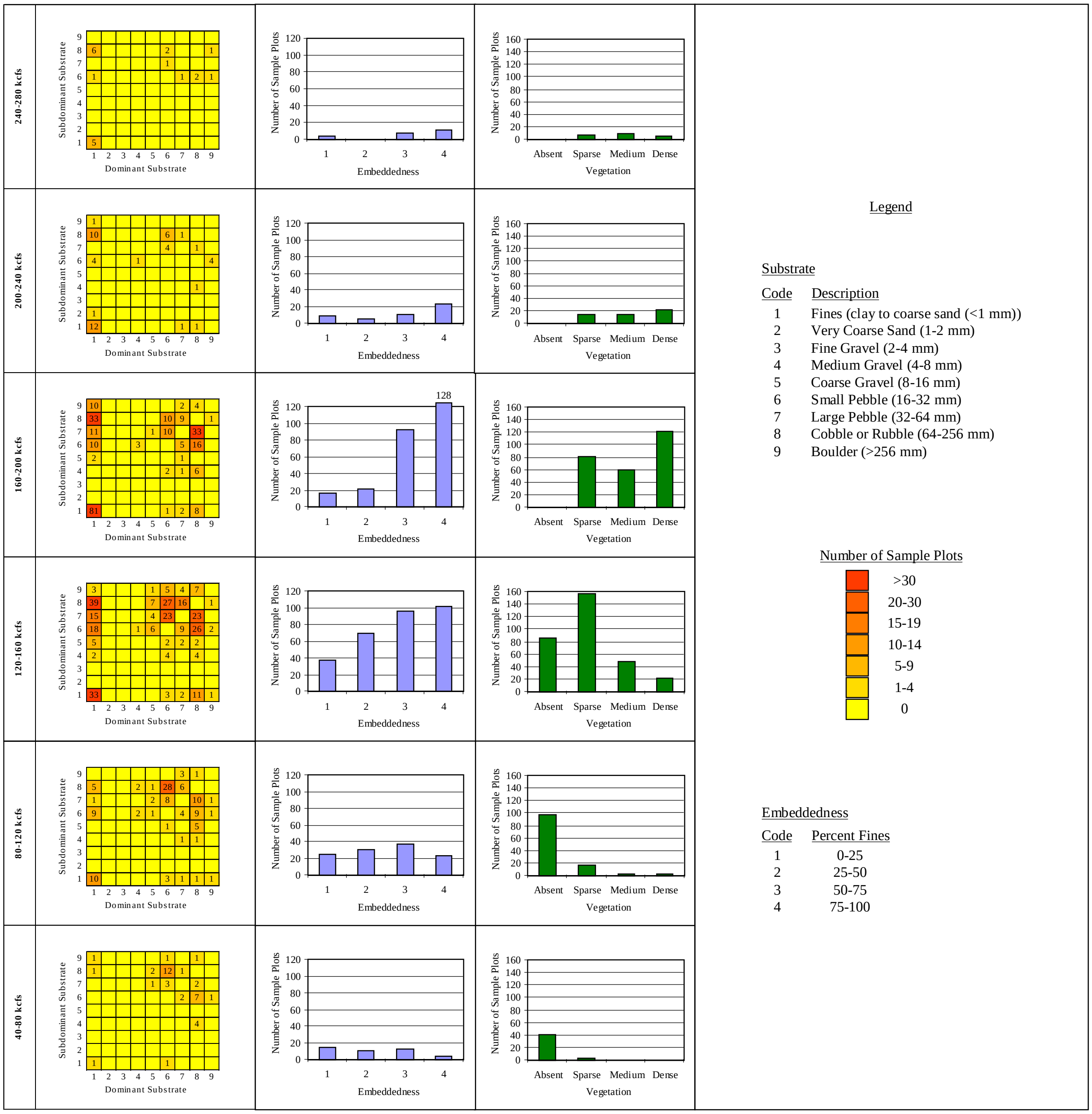


Figure 16. Comparison of substrate size, substrate embeddedness, and vegetation density of random plots between 40 kcfs flow bands on the Hanford Reach of the Columbia River in 2000.

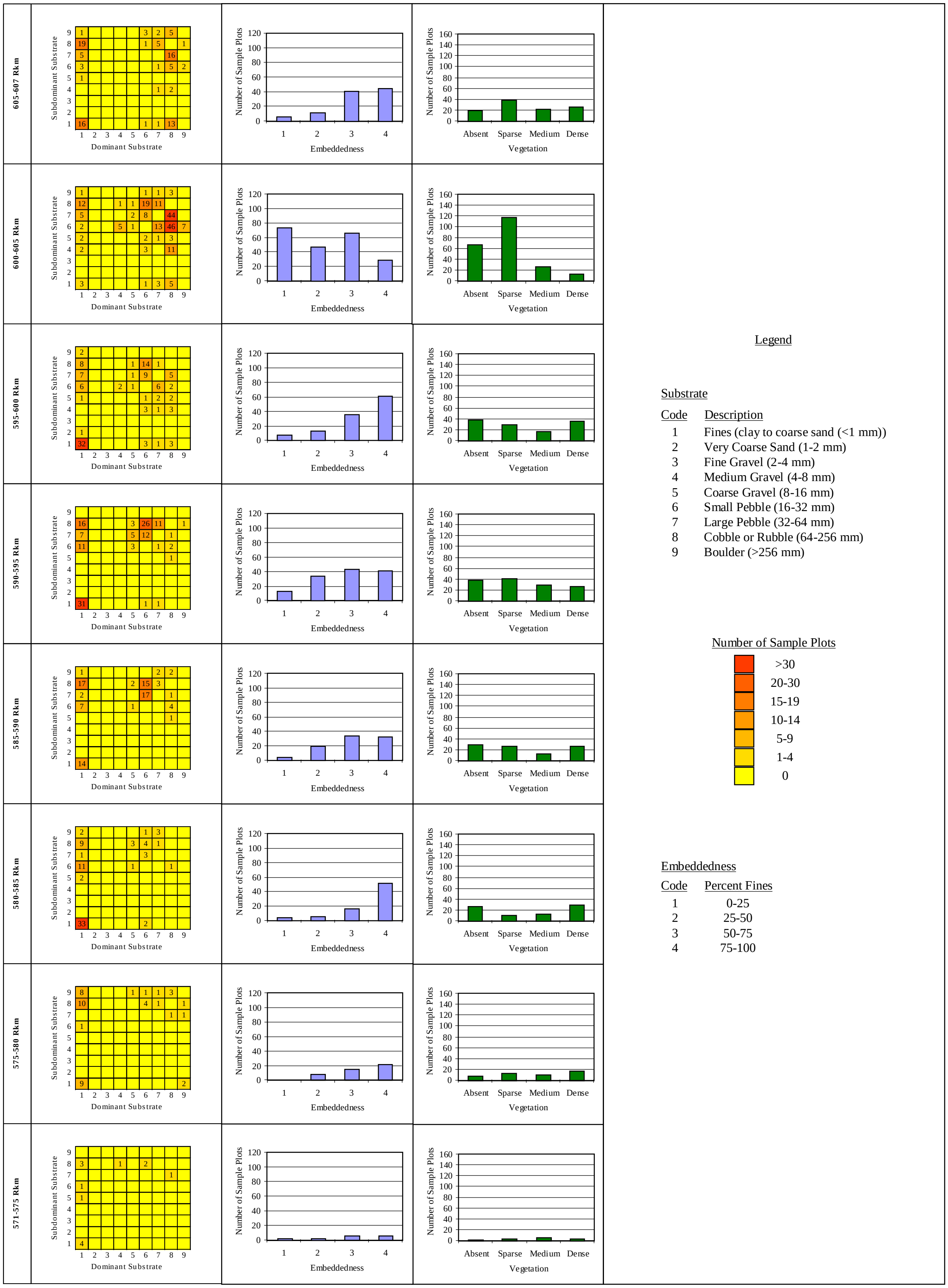


Figure 17. Comparison of substrate size, substrate embeddedness, and vegetation density of random plots between river sections on the Hanford Reach of the Columbia River in 2000.

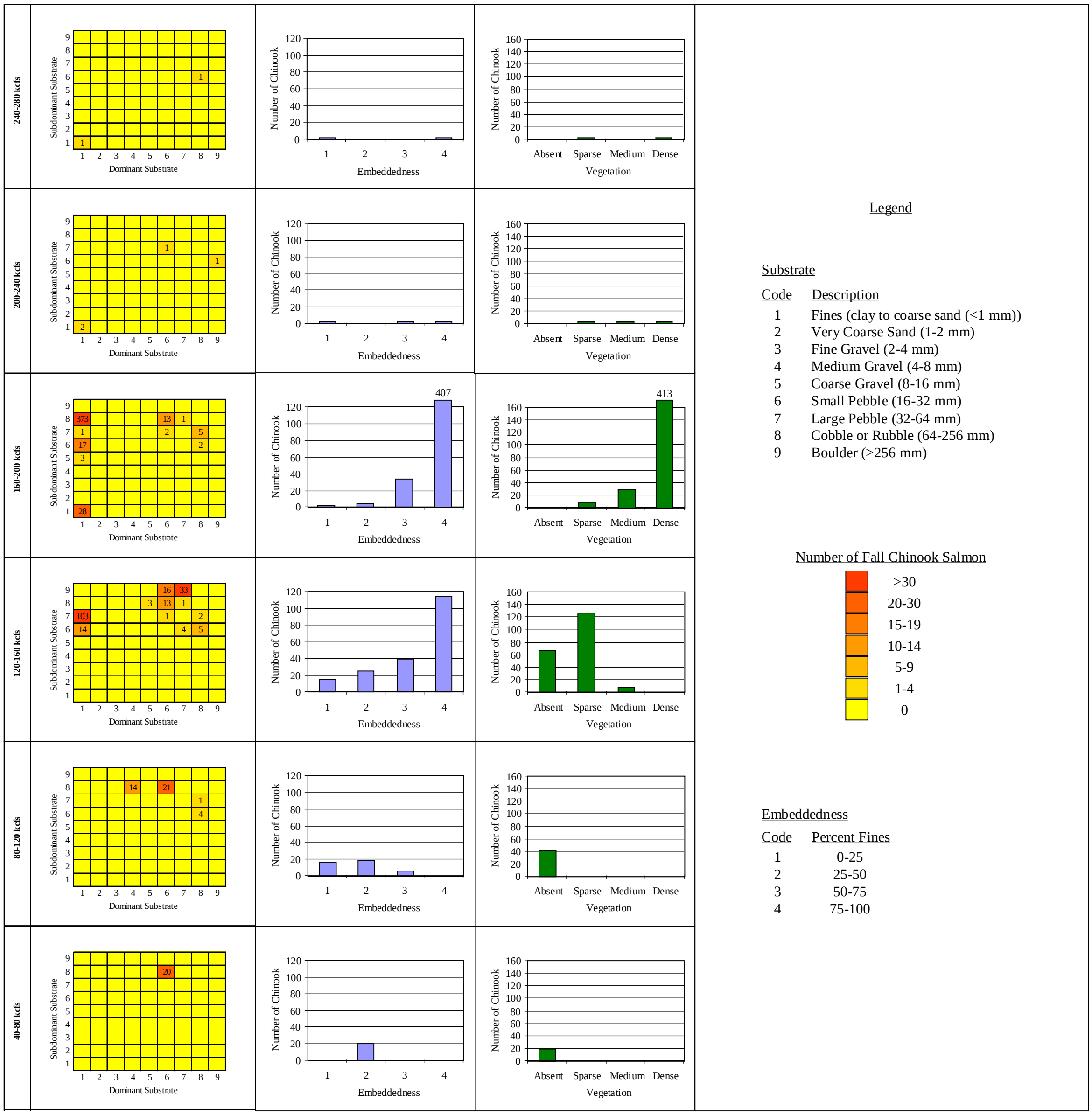
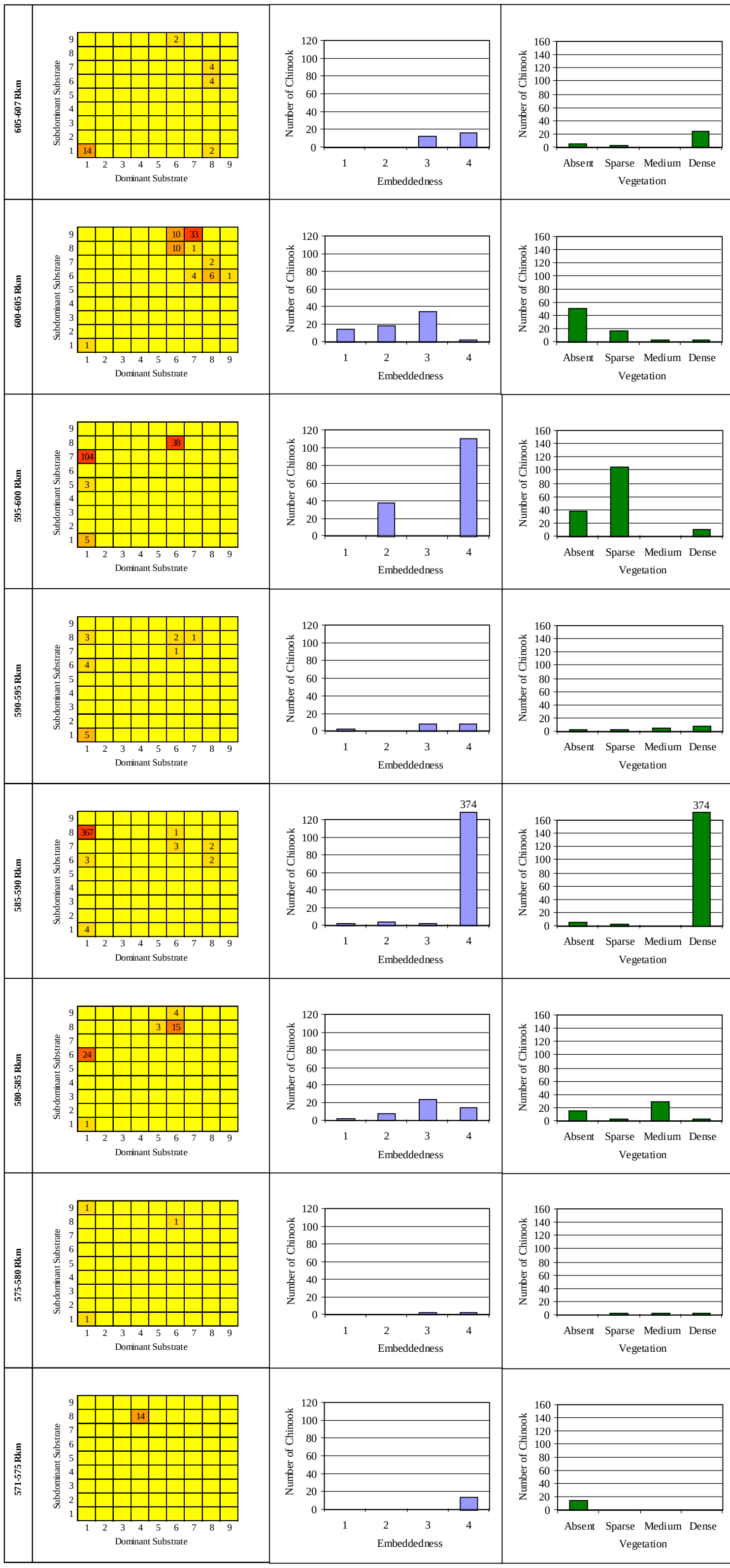


Figure 18. Comparison of numbers of stranded and entrapped juvenile fall chinook salmon and substrate size, substrate embeddedness, and vegetation density of random plots between 40 kcfs flow bands on the Hanford Reach of the Columbia River in 2000.



Legend

Substrate

Code	Description
1	Fines (clay to coarse sand (<1 mm))
2	Very Coarse Sand (1-2 mm)
3	Fine Gravel (2-4 mm)
4	Medium Gravel (4-8 mm)
5	Coarse Gravel (8-16 mm)
6	Small Pebble (16-32 mm)
7	Large Pebble (32-64 mm)
8	Cobble or Rubble (64-256 mm)
9	Boulder (>256 mm)

Number of Fall Chinook Salmon

>30
20-30
15-19
10-14
5-9
1-4
0

Embeddedness

Code	Percent Fines
1	0-25
2	25-50
3	50-75
4	75-100

Figure 19. Comparison of numbers of stranded and entrapped juvenile fall chinook salmon and substrate size, substrate embeddedness, and vegetation density of random plots between river sections on the Hanford Reach of the Columbia River in 2000.

Fall Chinook Salmon Fry Production Estimate

Based on data from Priest Rapids Hatchery, carcass and creel surveys in the Hanford Reach, WDFW Hanford Reach fall chinook escapement estimates, and egg to fry survival rate of 30%, an estimated 16,293,584 fall chinook salmon fry were produced on the Hanford Reach in 2000 (**Table 4**). The Hanford Reach fall chinook salmon escapement estimate for 1999 was 29,812 **(**Watson. 1999)**.** This total included 2,800 jacks which were removed from the calculation. Jacks are generally all male and do not contribute to egg production. Based on sport harvest data, 46.1% of the run was female, 858 of 1,860 fall chinook salmon harvested on the Hanford Reach in 1999 (**Appendix E**). It was assumed that anglers had an equal chance of harvesting a male or female and there was no behavioral characteristics associated with gender that would bias catch. Fecundity rates have not been established for naturally spawning fall chinook salmon on the Hanford Reach but, for this estimate, it was assumed that these rates were similar to rates of fall chinook salmon sampled at Priest Rapids Hatchery. Average fecundity for fall chinook salmon at Priest Rapids Hatchery in 1999 was 4,371 eggs per female (Carlson 2000). Egg retention of natural spawners on the Hanford Reach is typically near zero as was the case in 1999 (Watson 2000). No studies have been conducted on egg to emergence mortality rates of fall chinook salmon on the Hanford Reach. Healey (1998) reports that, under natural conditions, 30% or less of the potential eggs deposited resulted in emergent fry or fry and fingerling migrants in the systems studied. For purposes of this estimate an egg to fry survival rate of 30% was used.

Table 4. Calculation of the 2000 fall chinook salmon fry production estimate for the Hanford Reach.

2000 Adult Escapement	27,012	Hanford Reach Carcass Survey,Watson 2000
Female (%)	46%	Hanford Reach Sport Fishery, Watson 2000
Fecundity	4,371	Priest Rapids Hatchery, Carlson 2000
# of females	12,426	
Potential eggs	54,311,948	
Egg retention	0	Hanford Reach Carcass Survey, Watson 2000
Total eggs deposited	54,311,948	
Est. survival (egg to fry)	30%	M.C. Healy, Pacific Salmon Life Histories
Estimated Fry at Emergence	**16,293,584**	

Accumulated Temperature Units and Juvenile Fall Chinook Salmon Stranding and Entrapment Susceptibility

All stranded and entrapped juvenile fall chinook salmon collected from random plots in 1999 and 2000 were found between the start of emergence (1000^{o}C ATU's from initiation of spawning) and 1400^{o}C ATU's from the end of spawning (**Figure 20**). The last juvenile fall chinook salmon found in a random plot in 1999 was located on June 12 at 1379^{o}C ATU's past the end of spawning and on June 2 in 2000 at 1363^{o}C ATU's.

Assessment of Juvenile Fall Chinook Salmon Relative Abundance and Fish Size

Sampling to assess juvenile fall chinook salmon abundance and fish size began on March 13, just prior to the estimated start of emergence on March 20 (Carlson 2000), and ended on June 26 (**Figure 21**). A total of 5,624 juvenile fall chinook salmon were seined during this period. Juvenile fall chinook salmon were collected from six index locations once per week during this period. Peak abundance was observed from April 24 to May 29. The largest catch of the season was obtained on May 29 when 870 individuals were sampled.

Some juvenile fall chinook salmon collected on the Hanford Reach possessed ventral slits (unbuttoned), a physical characteristic of the late stage of yolk sac absorption in newly emergent fry. Fork lengths of these unbuttoned fall chinook salmon ranged up to 44 mm but were most often at or below 42 mm. Juvenile fall chinook salmon with fork lengths at or below 42 mm made up at least 30% of the fish seined in the Hanford Reach until after May 15 and fish of this size remained in the samples until after June 19. Juvenile fall chinook salmon with fork lengths greater than 59 mm, the size threshold that individuals are thought to become less susceptible to entrapment (Nugent et al. 2001a and 2001b), began to appear in the samples on April 24 but were not collected in considerable numbers until May 23. Priest Rapids Hatchery released 6,856,000 sub-yearling fall chinook salmon between June 14 and June 27 which caused an increase in the number and size of fish collected on the Hanford Reach at that time.

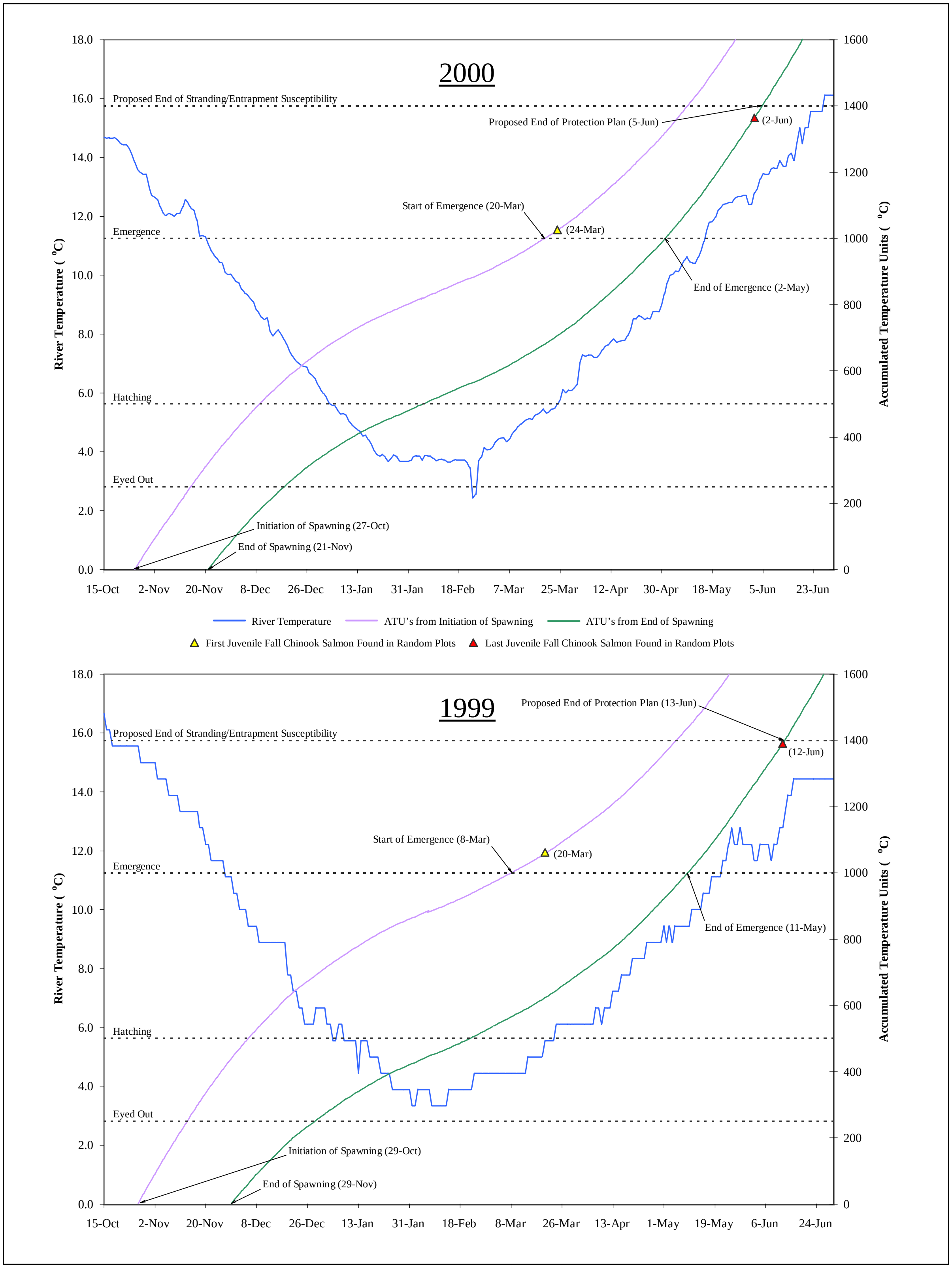


Figure 20. Mean daily river temperatures on the Hanford Reach of the Columbia River in 1999 and 2000 and estimated timing of fall chinook salmon development, hatching, emergence, and end of stranding and entrapment susceptibility based on accumulated temperature units (ATU's).

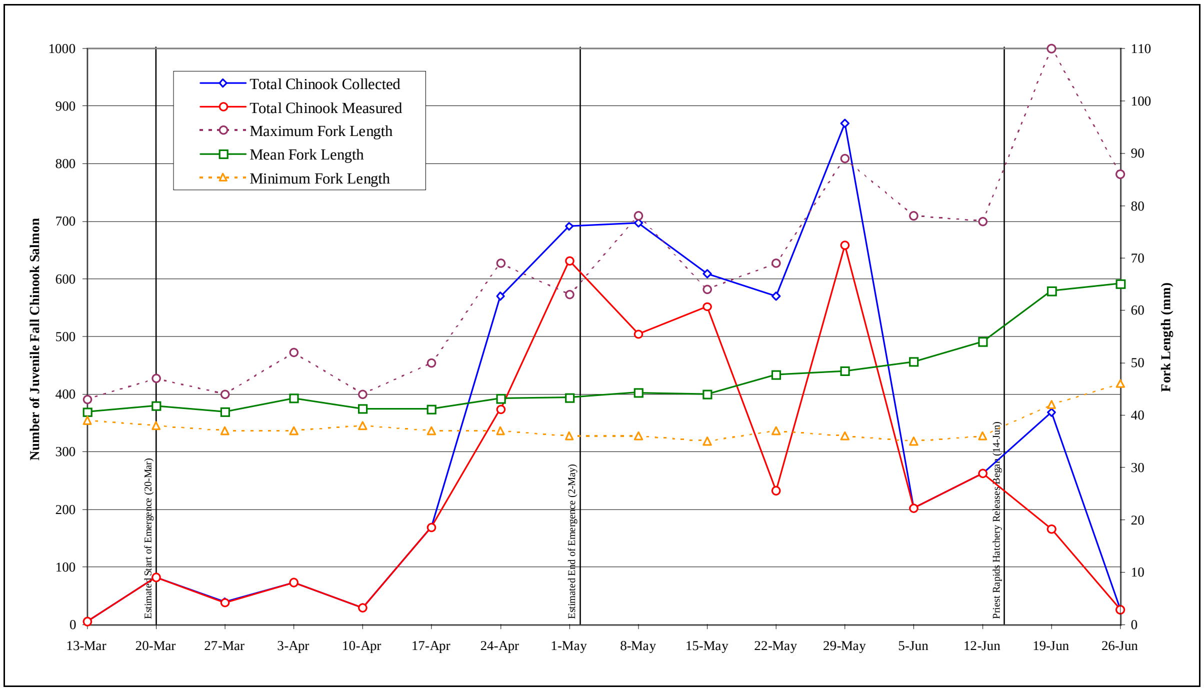


Figure 21. Relative abundance and fork length measurements of juvenile fall chinook salmon collected from nearshore sites on the Hanford Reach of the Columbia River in 2000.

Evaluation of Potential Mortality Events in Primary Fall Chinook Salmon Rearing Areas

The EMT monitored entrapments in primary fall chinook salmon rearing areas from March 20 to June 24. A total of 10,705 juvenile fall chinook salmon were seined from 158 entrapments (including many of the same entrapments sampled on multiple days) during this time period (**Table 5**). Field crews recorded 311 direct mortalities at the time entrapments were sampled. Projected mortalites were estimated at 4,451 based on drainage or lethal temperatures monitored in entrapments. Criteria for emergency action were reached on 10 days (March 27, April 2, April 6, April 15, April 27, April 30, May 2, May 6, May 26, and June 9) in 2000. GCPUD provided additional water to re-inundate (or increase river elevations) entrapments on six of these days (March 27, April 2, April 6, April 15, April 27, and June 9).

Surveys of Other Fish Species

Spring and Early Summer

Minimum numbers of fish other than fall chinook salmon were sampled during the implementation and evaluation of the Interim Protection Program in 2000 (March 13-June 26). Spring chinook salmon (*Oncorhynchus tshawytscha*) and at least 10 other species of fish were collected in nearshore sites and random plots during the spring and early summer sampling period (**Table 6**). Yearling chinook salmon were distinguished from subyearling chinook based upon size and morphological characteristics. Spring chinook salmon naturally outmigrate during the second year of life as yearlings in the mid and upper Columbia and therefore most of the yearling chinook salmon sampled were believed to be spring chinook. Resident species found consisted of mountain whitefish, northern pikemoinnow, peamouth, redside shiner, sculpin, smallmouth bass, sucker, threespine stickleback, dace, and yellow perch. Spring chinook salmon, peamouth, smallmouth bass, dace, and yellow perch were not represented in random plots.

Table 5. Weekly numbers of juvenile fall chinook salmon found by emergency management teams in primary rearing areas on the Hanford Reach of the Columbia River in 2000.

Week	Number of Entrapments	Total Number of Chinook	Chinook Mortalities at Time of Sampling	Projected Chinook Mortalities[1]
March 19-25	30	57	10	15
March 26-April 1	36	791	161	271
April 2-8	24	3,353	57	1,081
April 9-15	4	140	0	126
April 16-22	7	308	2	4
April 23-29	8	1,927	28	1,901
April 30-May 6	12	1,445	30	533
May 7-13	9	939	11	197
May 14-20	4	315	0	0
May 21-27	11	880	1	133
May 28-June 3	4	232	4	10
June 4-10	5	259	6	122
June 11-17	3	59	1	58
June 18-24	1	0	0	0
Total	158	10,705	311	4,451

[1]Projected chinook mortalities were based on if entrapments drained or reached lethal temperatures (>24°C).

Table 6. Total number of fish other than fall chinook salmon sampled on the Hanford Reach of the Columbia River during the spring and early summer sampling period (March 13-June 26, 2000).

Common Name	Scientific Name	Nearshore	Stranded[1]	Entrapped[2]	Total Fish
Spring Chinook Salmon	*Oncorhynchus tshawytscha*	13	0	0	13
Mountain Whitefish	*Prosopium williamsoni*	300	36	0	336
Northern Pikeminnow	*Ptychocheilus oregonensis*	614	2	0	616
Peamouth	*Mylocheilus caurinus*	103	0	0	103
Redside Shiner	*Richardsonius balteatus*	133	1	0	134
Sculpin	*Cottus* spp.	47	6	2	55
Smallmouth Bass	*Micropterus dolomieui*	1	0	0	1
Sucker	*Catostomus* spp.	75	1	0	76
Threespine Stickleback	*Gasterosteus aculeatus*	21	1	0	22
Dace	*Rhinichthys* spp.	2	0	0	2
Yellow Perch	*Perca flavescens*	2	0	0	2
Total		1,311	47	2	1,360

[1] All stranded fish were counted as mortalities.

[2] No entrapped fish were found dead.

Summer and Early Fall

In 2000, the summer and early fall sampling program began on July 11 and ended August 28. Species collected in nearshore sites during this time period consisted of American shad (*Alosa sapidissima*), common carp, peamouth, northern pikeminnow, dace, redside shiner, undetermined minnow species, sucker, threespine sickleback, bluegill, smallmouth bass, undetermined bass species, and sculpin. A complete analysis of the summer and early fall sampling program from 1998 to 2000 is provided in **Appendix F**.

Conclusions

Juvenile Fall Chinook Salmon

Upon emergence, juvenile fall chinook salmon swim or are displaced downstream (Healey 1998) and move to the margins of the river in areas of reduced current velocity (Dauble et al. 1989). Juvenile fall chinook salmon are most susceptible to stranding and entrapment between emergence and approximately 60 mm in fork length. Juvenile fall chinook salmon are most abundant in areas where substrate particle size is small, velocity is low, and depth is shallow (Chapman and Bjornn 1969 and Everest and Chapman 1972). Consequently, as discharge from Priest Rapids changes fry are forced to move with the shifting shoreline and are found stranded and entrapped in a range of habitat types, flow bands, and river sections. However, some habitat types, flow bands, and river sections, whether selected for or not, seem to be more hazardous to stranding and entrapment than others. In 1999, juvenile fall chinook salmon were found stranded and entrapped most frequently at flows of 80-120 and 120-160 kcfs in areas with gravel to cobble substrates, low substrate embeddedness, and absent to medium vegetation density. Highest concentrations of juvenile fall chinook salmon were found at the island complex areas of Locke Island (Rkm 600-605) and 100 F Islands (Rkm 590-595). These island complex areas with their large and varied shorelines and diverse shallow water areas appear to provide excellent rearing habitat as well as high stranding and entrapment potential. Large flats or flood terraces are present in these areas at those flow levels. Flood terraces may also be a concern at other river sections and at other flow levels.

Other Fish Species

Low numbers of fish other than fall chinook salmon were found stranded and entrapped on the Hanford Reach in 1999. Eleven genera were identified including northern pikeminnow, threespine stickleback, smallmouth bass, sculpin, mountain whitefish, sucker, bluegill, lamprey, peamouth, dace, and walleye.

Recommendations

The joint fish managers, consisting of WDFW, the Columbia River Intertribal Fish Commission, the Tribes of the Columbia River Basin, the Oregon Department of Fish and Wildlife, NMFS, and USFWS, continue to recommend that the best operational program to reduce stranding and entrapment of juvenile fall chinook salmon on the Hanford Reach is for Priest Rapids Dam to create no fluctuations (flat loading) and/or steadily increasing flows throughout the emergence and rearing period. The power managers, consisting GCPUD, BPA, the United States Bureau of Reclamation, and the Mid-Columbia Public Utility Districts (Chelan and Douglas Counties), continue to maintain that this option is infeasible. Based on the low estimated loss of juvenile fall chinook salmon in 1999 and 2000, the power managers recommended and the Hanford Policy Group approved a more flexible operational program for the 2001 juvenile fall chinook salmon emergence and rearing period.

1) When weekly average flows are less than or equal to 170 kcfs at Priest Rapids Dam, the following constraints will be imposed:

   Limit flow fluctuations from Priest Rapids Dam to a range of 60 kcfs on a daily basis during the first week of program implementation.

   Limit flow fluctuations from Priest Rapids Dam to a range of 40 kcfs on a daily basis during the following four weeks of program implementation.

   Limit flow fluctuations from Priest Rapids Dam to a range of 60 kcfs on a daily basis during the sixth week of program implementation.

Following the sixth week of program implementation, if the 85% upper confidence limit for the total impact at week six is less than the average of the estimated total impact after six weeks in 1999 and 2000, then daily flow fluctuations below Priest Rapids Dam will be limited to no more than 80 kcfs for the seventh and eighth weeks of the program. If the 85% upper confidence limit for the total impact at week six is greater than the average of the estimated total impact after six weeks in 1999 and 2000, then daily flow fluctuations below Priest Rapids Dam will be limited to no more than 60 kcfs for the seventh and eighth weeks of the program. The 85% upper confidence for the total impact at week six will be calculated as the estimate of cumulative fish at risk through the first six weeks plus 1.036 times the standard error of the estimate. If the total impact at six weeks cannot be calculated prior to the start of the seventh week, then the comparison will be made based on the average fish at risk per standard plot (3600 ft^2). If the 85% upper confidence limit of the average number of fish at risk per standard plot is less than or equal to 1.0 (the mean of the six week averages in 1999 and 2000), then daily flow fluctuations below Priest Rapids Dam will be limited to no more than 80 kcfs for the seventh and eighth weeks of the program. If the 85% upper confidence limit of the average number of fish at risk per standard plot is greater than 1.0, then daily flow fluctuations below Priest Rapids Dam will be limited to no more than 60 kcfs for the seventh and eighth weeks of the program. The 85% upper confidence for the average will be calculated as the average fish at risk per standard plot plus 1.036 times the standard error of the estimate.

Limit flow fluctuations from Priest Rapids Dam to a range of 80 kcfs on a daily basis from the ninth week until the end of program implementation.

2) Restrict flows to an hourly minimum of 150 kcfs when weekly average flows are greater than 170 kcfs at Priest Rapids Dam.

These operational constraints will be imposed when a daily total of 50 or more subyearling fall chinook salmon are seined from the six established nearshore sampling sites used to assess relative abundance and fish size. The sampling of these sites will begin one week prior to the calculated start of emergence under the Vernita Bar Agreement. Seining will be conducted every other day to define the beginning of susceptibility then once a week thereafter. Operational constraints will be lifted after 1400 ^{o}C ATU's following the end of spawning under the Vernita Bar Agreement.

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Appendix A

2000 Hanford Reach Juvenile Fall Chinook Protection Program

Hanford Reach Juvenile Fall Chinook Protection Program

March 8, 2000

The criteria for development of this program as proposed by the seven mid-Columbia hydroelectric projects are:

1. Provide a high level of protection for rearing fall chinook fry;
2. Maintain reasonable load following capability at all 7 projects;
3. Monitoring and evaluation that allows evaluation of the program relative to its effect on entrapment and stranding; and
4. A monitoring program that allows in-season changes of operations if substantial mortality is detected.

2000 Program Elements

Starting Program Operating Constraints

1. Begin index seining (6 standard beach seine hauls at pre-determined locations) one week prior to the calculated start of emergence under the Vernita Bar Agreement. Index seining will be conducted every other day to define the beginning of susceptibility.

2. Start operational constraints of 2000 program when a daily total of 50 or more sub-yearling chinook are sampled from the 6 index seining stations.

When PRD average weekly discharge is *greater* than 170 kcfs:

1. When average weekly discharge at Priest Rapids is greater than 170 kcfs, the mid-Columbia projects[1] will maintain a 150 kcfs minimum hourly discharge at Priest Rapids.

When PRD average weekly discharge is *less than or equal to* 170 kcfs:

1. For the period starting when stranding susceptibility begins until implementation of BO flow targets[2] (approx. April 10):

   A. Within the requirements of flood control, project operating constraints, and the BO, the GCL weekly average discharge will steadily increase.

   B. The mid-Columbia projects will limit flow fluctuations below Priest Rapids to no more than +20 kcfs and –20 kcfs on a daily basis.

2. For the period from implementation of BO flow targets (April 10) until the end of stranding susceptibility:

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[1] The term "mid-Columbia projects", wherever used, includes Priest Rapids, Wanapum, Rock Island, Rocky Reach, Wells, Chief Joseph, and Grand Coulee dams operated under the hourly coordination agreement.
[2] PRD flows are expected to be less than 170 kcfs during this period.

A. Within the requirements of flood control, project operating requirements, and the BO, GCL will operate to produce average weekly flows of at least 135 kcfs at Priest Rapids.

B. The mid-Columbia projects will limit flow fluctuations below Priest Rapids to no more than +30 kcfs and –30 kcfs on a daily basis when the fish spill program is in effect at Priest Rapids. When fish spill is not occurring, flow fluctuations will be limited to no more than +20 kcfs and –20 kcfs on a daily basis.

Ending Program Operating Constraints

1. During each index seining sample, sub-yearling fork length will be reported. After program is initiated, decrease index seining to one time per week. When no more than 50 subyearling chinook are less than 60 mm, or the index seining catch has declined to 4% or less of the cumulative annual total the program will end.

Monitoring, Evaluation and Adaptive Management

1. Monitoring under the program in 2000 will consist of random sampling by 2 full-time crews on a 7 day a week basis within a 17-mile section of the Hanford Reach to determine the overall impact of the program on juvenile fall chinook mortality. A 3rd crew will monitor index sites identified in 1999 and will also contribute to random sampling. This effort will be led by the WDFW and coordinated with the Yakama Nation and Grant PUD. WDFW will deliver a summary of the previous Monday through Sunday sampling effort to Grant PUD no later than 5:00 pm on Monday.

2. Until stranding susceptibility ends, a weekly report for the Monday through Sunday time period will be produced by Grant County PUD and the WDFW. This report will be available on the Technical Management Team (TMT) website at the following URL
   < www.nwd-wc.usace.army.mil/cgi-bin/proposal.cgi?type=index>
   and will be presented at the weekly TMT meetings. This report will also be distributed to the Hanford Reach Stranding Policy Group each Tuesday morning by e-mail. The TMT will serve as a forum for information exchange and will not be involved in decision making under this Program. It is anticipated that TMT decisions will facilitate, support and not impede activities under this Program. The authority for implementing any changes under this Program rests with the mid-Columbia projects and any disputes will be handled through meetings of the Hanford Reach Stranding Policy Group.

   A. This report will include the following operational information for each day: minimum hourly discharge from Priest Rapids Dam (PRD), maximum hourly discharge from PRD, day average discharge at PRD and whether or not fish spill was occurring. The report will also provide weekly average discharge at PRD.

   B. The weekly reports will also include the following field monitoring information for each day: number of samples taken, number of stranded or entrapped chinook fry and number of chinook mortalities. The weekly report will also include the number of chinook fry sampled from standard index sites which will be used to determine when susceptibility to stranding and entrapment ends.

3. If high levels of chinook entrapment likely to result in mortality are observed, the mid-Columbia operators will evaluate whether to implement operational changes to reduce the level of mortality. At the weekly TMT meeting, the mid-Columbia operators will explain the problem and propose operational changes to resolve it. If there are no significant objections from the Hanford Reach Stranding Policy Group, the operator's proposal will be implemented as soon as practicable.

4. If high levels of chinook entrapment likely to result in mortality are observed and there is significant objection to the mid-Columbia operators' proposal to resolve the problem, the Hanford Reach Stranding Policy Group will meet or hold a conference call within 3 days to resolve the conflict.

5. If the field monitoring crew observe that a significant fall chinook mortality event is occurring or imminent, they will immediately notify the designated representative of the Washington Department of Fish and Wildlife (WDFW) and explain the situation. The WDFW representative will confirm whether a significant fall chinook mortality event is occurring or imminent and decide whether to request a modification of operations. If alteration of operations appears appropriate, the WDFW representative will notify Grant County PUD immediately to discuss a remedy. If Grant County PUD concurs that a significant fall chinook mortality event is occurring or imminent, it will consult, as necessary, with other operators and an operational remedy will be implemented expeditiously.[3]

6. An e-mail explaining the event and describing the remedy taken will be sent to the Hanford Reach Stranding Policy Group by Grant County PUD no later than the next business day following the event.

2001 Program Elements

In 2001, this program will be revised to enable a controlled study to determine the relative effectiveness of the operational restriction parameters. At this point in time the exact nature of this effort cannot be determined, however the parties anticipate that this effort will 1) focus on detailed study of index areas in lieu of an evaluation of overall impact and 2) contain a 2-condition controlled test.. The exact nature of this effort will be determined in discussions of the Hanford Reach Policy and Technical groups following completion and analysis of the 2000 program.

[3] It is anticipated that the parties involved will implement this process in no more than a few hours from initial notification to implementation of remedy, day or night.

Appendix B

Calculation of Number of Samples Required to Detect a Difference between Two Operational Strategies

January 6, 2000

To: Paul Wagner, WDFW
From: Chris Murray, PNNL
Cc: D. Geist and G. McMichael, PNNL

Subject: Calculation of Number of Samples Required to Detect a Difference between Two Operational Strategies.

As requested, I determined the number of samples required to detect a significant difference between two operational strategies in the year 2000. The two operational strategies considered for the proposed hypothesis testing are ±30 kcfs vs. ±20 kcfs on odd and even days.

For the calculations, I used two different assumptions for the mean and variance. Both were derived from the 1999 random sampling data, because I believe that is the most representative data set currently available. For one case, I did not use samples collected on days where the river flows exceeded 150 kcfs at transect 85, because it is my understanding that, under those flow conditions, the ± 20 kcfs fluctuation constraint did not apply (prior to 4/20), nor the ± 30 kcfs constraint (after April 20). For that case, I included 270 of the 772 samples taken during 1999 prior to June 13 for which we have a valid location and flow band determination. For that case, I calculated a mean of 1.2 chinook salmon moralities per sample plot with a variance of 90.6. I also calculated the mean variance for all 772 samples as a second case, which yielded a mean of 0.63 mortalities per plot and a variance of 37.2.

For each case, I used a one-tailed test design to calculate the number of samples needed assuming that we are only interested if mortality for ± 30 kcfs is significantly higher than mortality for ± 20kcfs. The calculations of the number of samples required are based on equations from Snedecor and Cochran, and I used a wide range of potential differences to be detected, as well as differences in alpha levels, and in the power of the test. For each case, three different scenarios were tested and the results are shown in Tables 1 and 2. The first scenario in each table is for alpha = 5% and a power of 80% (the scenario you mentioned in our meeting on 12/16/99, i.e., the "classic" parameters for a hypothesis test). I also examined scenarios where alpha was 10% and the power was 80% (scenario 2), and where alpha = 10% and a power of 70% (scenario 3).

The number of samples required is highly dependent on both the absolute and relative size of the difference that we want to be able to detect (even more than the desired alpha level or power of the test), and on the assumed variance of the data. An increase in the variance increases the number of samples that must be taken by the square of the increase. An increase in the relative difference to be detected (e.g., 10% difference vs. 100% difference) greatly increases the number of samples required. In addition, the absolute size of the difference to be affected (which depends on the value of the mean chinook mortality per plot that is assumed) greatly affects the number of samples, even for the same relative difference. That is, the number of samples required detecting a 10% difference when the mean is 0.6 is much higher than the number required for a 10% difference when the mean is 1.2 (in fact, it is 4 times higher).

From Tables 1 and 2, the number of samples required to detect a significant difference between the proposed operational strategies appears to be extremely high for small relative differences, but remains large even for much larger relative differences. For example, we would need 2-3 times as many samples as were taken in 1999 to detect a 100% difference between operations (i.e., at least twice as many fish killed for an operational strategy off allowing ± 30 kcfs vs. ± 20 kcfs), with alpha level of 5% and a power of 80%. By allowing greater uncertainty in the test, and using, for example, an alpha of 10% and a power of 70% (scenario 3), we could drop the number of samples required to detect a difference of 100% to 800-1200 samples. This represents an average 20% increase from the number of samples taken this year, which might be feasible. However, even that number of samples would only be able to detect large differences between the two operational strategies, but given the small number of mortalities estimated for 1999, the ability to detect only large differences between the proposed strategies might be acceptable.

Note: that one factor that could strongly confound any proposed hypothesis test would be the inability to ensure that fish detected during sampling trips were entrapped during the flow fluctuations that trip was supposed to represent and not from a flow fluctuation that occurred prior to that. If significant potential exists for stranded fish to remain accessible for sampling for more than a day, then the odd/even day approach would be unlikely to detect a significant difference between the two operational strategies, even if one existed.

Table 1. Case 1- Assumptions of mean and variance based on data for flows less than 150 KCFS. Three different scenarios and the number of samples needed to detect differences between flow fluctuations of $\pm$ 20 kcfs and $\pm$ 30 kcfs. There were 772 samples collected during the relevant period in 1999.

Difference	Scenario 1: Alpha = 5% Power= 80%	Scenario 2: Alpha = 5% Power= 80%	Scenario 3: Alpha = 5% Power= 80%
10%	155594	113448	82080
20%	38899	28362	20520
30%	17288	12605	9120
40%	9725	7090	5130
50%	6224	4538	3283
60%	4322	3151	2280
70%	3175	2315	1675
80%	2431	1773	1283
90%	1921	1401	1013
100%	1556	1134	821

Table 2. Case 2- All data included in estimating mean and variance. Three different scenarios and the number of samples needed to detect differences between flow fluctuation of $\pm$ 20 kcfs and $\pm$ 30 kcfs. There were 772 samples collected during the relevant period in 1999.

Difference	Scenario 1: Alpha = 5% Power= 80%	Scenario 2: Alpha = 10% Power= 80%	Scenario 3: Alpha = 10% Power= 70%
10%	231787	169002	122274
20%	57947	42251	30569
30%	25754	18778	13586
40%	14487	10563	7642
50%	9271	6760	4891
60%	6439	4695	3397
70%	4730	3449	2495
80%	3622	2641	1911
90%	2862	2086	1510
100%	2318	1690	1223

Appendix C

Substrate Size, Substrate Embeddedness, and Vegetation Codes

Substrate Codes

Dominant substrate is most common to the sample area and subdominant is the next most common substrate class.

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

Substrate Embeddedness Codes

The substrate embeddedness is estimated visually. Substrate embeddedness refers to the degree that the interstices between the larger particles are filled by sand, silt or clay.

Code	% Fines	Description
1	0-25	Openings between dominant sized particles are 1/3 to 1/2 the size of the particles. Few fines in between. Edges are clearly discernable.
2	25-50	Openings are apparent but <1/4 the size of the particles. Edges are discernable but up to half obscured.
3	50-75	Openings are completely filled but half of edges are still discernable.
4	75-100	All openings are obscured. Only one or two edges discernable and size cannot be determined without removal.

Vegetation Codes

Vegetation is assessed visually to estimate the percent of ground coverage.

Code	Description
1	No vegetation present.
2	Sparse vegetation, substrate is completely evident.
3	Medium vegetation, substrate is only partially obscured.
4	Dense vegetation, substrate is nearly or completely obscured by the vegetation.

Appendix D

Estimation of Total Number of Entrapped and Dead Juvenile Fall Chinook Salmon Due to River Flow Fluctuations - 2000 Field Season

Estimation of Total Number of Entrapped and Dead Juvenile Fall Chinook Salmon Due to River Flow Fluctuations - 2000 Field Season

The total number of juvenile fall chinook salmon mortalities due to stranding/entrapment was estimated for a portion of the Hanford Reach during the sampling period from March 20 to June 9, 2000. The estimate was based on 797 sample measurements taken in six flow bands of the Hanford Reach: 60-80, 80-120, 120-160, 160-200, 200-240, and 240-270 thousand cubic feet per second (kcfs). Note that the lowermost and uppermost 40 KCFS bands were truncated because no fluctuations occurred in the range from 40-60 KCFS or in the range from 270-280 KCFS, so their area was truncated to equal the range over which fluctuations occurred. The samples were collected randomly within each flow band within the area in which the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) topographic/bathymetric data was available. As such, the estimate is only representative of a portion of the entire Hanford Reach, and must be considered a minimum estimate. The six flow bands that were sampled in the study area can be considered as six strata, so estimation of the total number of stranded/entrapped juvenile fall chinook salmon was performed using a stratified random sampling algorithm.

The number of samples used in the estimate is smaller than the total number of samples taken during the entire random sampling campaign (924), which began on March 20 and ended on June 25. A decision was made to only include samples collected through the end of June 9th. This decision, which eliminated 127 samples from the estimate, was made because no juvenile fall chinook salmon were found to be at risk after June 2nd by the random sampling effort. This is similar to the reasoning used to truncate the estimate for the previous year on June 13th of 1999.

A sampling plan was designed by Pacific Northwest National Laboratory (PNNL) and Washington Department of Fish and Wildlife (WDFW) prior to the field season that identified all potential sampling locations in the study area and determined which flow band they fell in using the SHOALS data and the Modular Aquatic Simulation System 1D (MASS1) flow model. The sample plot size used in the study was approximately 3600 sq ft. Samples were then selected randomly from the population of potential samples within each flow band, with the number of random samples selected being proportional to the size of the flow band. A list of random samples, with location coordinates and the flow band to which they belonged, was provided to the WDFW. Each morning, the flow band to target for sampling was identified based on the flow fluctuations in the previous 48 hr period. A list of samples would then be drawn from the list of random samples for sampling that day. Each sampling crew would use a high-resolution global positioning system (GPS) to navigate to the sample locations on the days' list. An anchor weight was placed at the center of each sample plot, and a wire cable was used to determine the boundary of the circular sampling plot. In many cases, the entire area of the plot could not be sampled, because portions of the plot were still under water at the rivers edge, or were above the wetted shoreline. In those cases, a sketch was made that was later used to estimate the proportion of the plot that could actually be sampled. The number of juvenile fall chinook salmon at risk, dead, or likely to die due to stranding or thermal stress in an entrapment (i.e., due to imminent drainage of the entrapment or high temperature) were counted for each sample plot. Other data were also recorded, including the substrate type, embeddedness, and vegetation density. In 2000, an additional step was taken, to revisit entrapments the following day and determine the fate of juvenile fall chinook salmon that had been entrapped.

The first step in the calculation of the total number of dead juvenile fall chinook salmon was to calculate the number of dead juvenile fall chinook salmon per sample plot. If the entire plot could not be sampled, then the number of juvenile fall chinook salmon that would be found in a full size sample plot was estimated by dividing the number of juvenile fall chinook salmon found by the proportion of the area of the plot that was sampled to the standard plot size. The average number of juvenile fall chinook salmon per plot in each flow band, $\bar{x}_h$, was calculated as the sample mean of the number of stranded/entrapped juvenile fall chinook salmon for all samples collected within a flow band *h*, where samples are denoted as x_{hi}, with $h = 1, 2, 3, 4,5,6$ and $i = 1\ldots n_h$. Here *h* is the index of the flow band and n_h is the number of samples taken within a flow band *h*. The equation for estimating the stratified average number of dead juvenile fall chinook salmon per sample plot is:

$$\bar{x}_{st} = \sum_{h=1}^{6} W_h \bar{x}_h \qquad [1]$$

where W_h is the weight of a flow band *h*. The weights for each flow band are found by calculating the total number of plots in a flow band, N_h, and dividing by the total number of potentially impacted plots in all six flow bands. Note that N_h also accounts for the number of fluctuations of flow over the area of a flow band *h*, that is, the total number of potentially impacted plots N_h is the number of plots in a flow band *h* multiplied by the number of fluctuations affecting that flow band (given below). In equation 1, $\bar{x}_h$ is the sample mean of the number of stranded/entrapped juvenile fall chinook salmon per sample plot within a flow band *h*.

The numbers of fluctuations occurring during the study period in each of the 6 flow bands were counted by WDFW personnel using hourly discharge data from Priest Rapids Dam that had been processed using the MASS1 model. The processing was done to account for attenuation of the amplitude of the fluctuations in river flows as recorded at the project as the flows move down through the Hanford Reach. This attenuation causes a reduction in the number of fluctuations that would be counted at areas downstream of the project. For the estimate, the decision was made to use the number of fluctuations calculated for the middle cross-section in the study area (Transect #85) for the time period covered by the random sampling data (March 20 – June 9, 2000). This is the same procedure followed in 1999. The numbers of fluctuations found for each of the 6 flow bands included in the 2000 estimate (60-80, 80-120, 120-160, 160-200, 200-240, and 240-270 kcfs) are 1.9, 8.2, 13.7, 21.4, 7.1, and 1.6, respectively.

The unbiased estimate of the variance of the stratified average (Var ($\bar{x}_{st}$)) is estimated by the weighted sample variance using Eq.[2]:

$$s^2\left(\bar{x}_{st}\right) = \sum_{h=1}^{6} W_h^2 \frac{s_h^2}{n_h} \qquad [2]$$

where the variance of the number of dead juvenile fall chinook salmon per sample plot for each flow band is calculated by

$$s_h^2 = \frac{1}{n_h} \sum_{i=1}^{n_h} \left(x_{hi} - \bar{x}_h\right)^2 \qquad [3]$$

The total number of dead juvenile fall chinook salmon, $\hat{I}$, over the entire area of the six flow bands is estimated by Eq.[4]:

$$\hat{I} = \sum_{h=1}^{6} N_h \overline{x}_h = N\overline{x}_{st} \qquad [4]$$

The estimate of the variance of $\hat{I}$ is also used to estimate the standard error and was obtained from Eq.[5]:

$$s^2\left(\hat{I}\right) = N^2 s^2\left(\overline{x}_{st}\right) \qquad [5]$$

The 95% confidence interval of the estimated total number of juvenile fall chinook salmon mortalities is determined by Eq.[6]:

$$\hat{I} \pm 1.96 * s\left(\hat{I}\right) \qquad [6]$$

assuming a normal distribution.

The results of the computation of the number of juvenile fall chinook salmon mortalities due to stranding and those at risk are listed in the first table at the end of this memo. For comparison, the results from the 1999 field season are included in a separate table. The number of Morts given in the first table is the number of dead juvenile fall chinook salmon estimated using the same procedure followed in 1999. The number in the 2000 table denoted Rev Morts indicates the number of dead juvenile fall chinook salmon based on revisiting the sites of randomly sampled entrapments to determine the number of juvenile fall chinook salmon at risk that died over the next 24 hours due to drainage of the entrapment, high temperatures, etc.

The estimate for the total number of juvenile fall chinook salmon that died within the study area during the period from March 20 – June 9, 2000 is 72,362 (see table below) and a 95% confidence interval for that estimate is [34,270 - 110,454]. The number of mortalities estimated by revisiting the site was 209,997, and the estimated number of juvenile fall chinook salmon at risk was 255,222. The number of dead juvenile fall chinook salmon identified in 2000 is 57.6% the number estimated for 1999 (125,695). Several factors appear to contribute to the lower estimate, including a decrease in the number of fluctuations for several of the flow bands, and a decrease in the mean number of juvenile fall chinook salmon mortalities per plot. The ratio of Rev Morts to juvenile fall chinook salmon at risk for the year 2000 is about 0.82. The estimate of the number of juvenile fall chinook salmon at risk as of 6/13/99 was 381,897, suggesting that the Rev Morts for 1999 would be about 314,225 dead juvenile fall chinook salmon, assuming the same ratio for 1999. The estimated number of juvenile fall chinook salmon at risk for 1999 was about 1.5 times the estimate for this year.

Note that these estimates are all minimum estimates, because the random sampling program only sampled a portion of the Hanford Reach, and we assume 100% efficiency during the sampling, i.e., that no dead juvenile fall chinook salmon were missed during the sampling of each random plot.

2000 Field Season

	Mean	Mean – 1.96 S.E.	Mean + 1.96 S.E.
Morts	72,362	34,270	110,454
Rev Morts	209,997	-20,483	440,476
At Risk	255,222	17,743	492,701

1999 Field Season

	Mean	Mean – 1.96 S.E.	Mean + 1.96 S.E.
Morts	125,695	50,724	200,666
At Risk	381,897	-347	764,141

Chris Murray

Pacific Northwest National Laboratory
September 2000

Appendix E

Data used in Hanford Reach Fall Chinook Salmon Fry Production Estimate

1999 Hanford Reach Fall Chinook Salmon Sport Harvest (Watson 2000)

Week	Male	Female	Jack	Total Adults	Percent Female
August 23-29	0	0	0	0	-
August 30-September 5	3	0	0	3	0.0
September 6-12	11	11	3	22	50.0
September 13-19	54	48	2	102	47.1
September 20-26	79	75	18	154	48.7
September 27-October 3	215	182	31	397	45.8
October 4-10	316	267	48	583	45.8
October 11-17	215	156	39	371	42.0
October 18-24	94	106	14	200	53.0
October 25-31	15	13	1	28	46.4
Total	1002	858	156	1,860	46.1

Published estimates of mortality (%) of chinook to various development stages in fresh water
(mean of ranges in Parentheses)

River system	Eggs not spawned	Losses at spawning	Spawning to eyed stage	Spawning to alevin	Spawning to emergence	Spawning to fry/smolt	Remarks
Mill Cr. (CA)					85-100 (96)		Planted eggs, flooding channel
					40		Planted eggs, controlled flow
Fall Cr. (CA)					68-93 (85)		Natural spawning
Prairie Cr. (CA)		1.0	0-25.5 (10)	14-25 (18)			Natural spawning redd sampling
Yakima (WA)	1.0					84-95 (89)	Stream-type, weir counts of smolts
Lemhi (ID)				27	58		Emergence trap over one redd
Cowichan (BC)						84-91 (87)	Ratio of fry/smolt migrants to eggs
Nanaimo (BC)						80-88 (84)	Ratio of fry/smolt migrants to eggs
Big Qualicum (BC)	12					93-100	Before flow control
						80-88	After flow control
Skeena System							
Bear R. (BC)	25						
Morice R. (BC)	1						
Babine R (BC)	20						
Kamchatka (USSR)	1	88		1-6 (3)			Redd Sampling

Table taken from Groot and Margolis 1998.

Appendix F

Effects of water-level fluctuations on resident fish larvae and age-0 juveniles in the Hanford Reach of the Columbia River during July-September 1998-2000

Effects of water-level fluctuations on resident fish larvae and age-0 juveniles in the Hanford Reach of the Columbia River during July-September 1998-2000

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Abstract

Species composition, abundance, and growth of young-of-the-year (YOY) resident fishes in shorelines of the Hanford Reach, Columbia River, during July-September 1998, 1999, and 2000, were evaluated with regards to environmental conditions during these years. In all three years, the four most abundant taxa collected in beach seine hauls were peamouth, northern pikeminnow, redside shiner, and suckers. During 1999, flow was higher than in 1998 and 2000, and daily water level fluctuations were lower. Shoreline summer water temperatures were highest in 1998 (about 20-30^{o}C) versus 1999 and 2000 (18-24 ^{o}C). Catches of larval and juvenile fishes in all years were highly variable, likely due in part to the high water level fluctuations in this area. Highest overall catches were in the Hanford Slough in 1999, perhaps partially due to less flow fluctuations during this year, although the main channel did not show a similar trend. Growth of the four most abundant taxa was greater in 1998, coinciding with high water temperatures. We examined growth and mortality of age-0 northern pikeminnow in greater detail and in comparison with a past study in the John Day Reservoir of the Columbia River. Growth of northern pikeminnow was lower in the Hanford Reach, which could decrease over-winter survival rates. However, summer mortality rates were also lower and overall abundances of age-0 northern pikeminnow were much higher in the Hanford Reach than in the lower Columbia River, which may mitigate for slow growth. Catches of age-0 peamouth, redside shiner, and suckers were also very high in the Hanford Reach compared to Columbia River reservoirs, possibly due to more spawning habitat in this structurally complex area. In conclusion, although we found evidence of slower growth of resident larval and juvenile fishes in the Hanford Reach, overall abundances of YOY fishes were very high compared to other areas of the Columbia River indicating good spawning conditions and adequate larval and juvenile rearing habitat.

Introduction

The Hanford Reach is one of the few remaining riverine sections of the Columbia River. Because of the variable flow regime in this area, a study was initiated to examine the effects of flow fluctuations on stranding and entrapment of juvenile fall chinook salmon *Oncorhynchus tshawytscha*. However, little is known about the impact of water-level changes on larvae and juveniles of resident fishes in this area. Since for many fish species, year-class strength is determined by survival of larvae and juveniles, factors affecting these stages are important to understand. Larvae and juveniles of many resident fishes rear in very shallow shoreline areas during their first growing season, where they may be particularly vulnerable to both daily and seasonal water-level fluctuations. Water-level fluctuations may strand fish in shoreline pools, resulting in mortality due to reduced water quality (i.e., high temperatures), or ultimately, desiccation. Lowering of water levels results in exposure and loss of submergent vegetation, and other changes in habitat structure which may be detrimental to age-0 fish growth and survival in shoreline nursery areas (Sheidegger and Bain 1995). Highly variable flow regimes have been found to result in unstable habitats which deter the formation of persistent species associations (Cushman 1985; Bain et al. 1988; Gelwick and Matthews 1990).

A first basic objective of our study was to describe the species composition, distribution, and abundance of age-0 resident fishes in shoreline habitats of the Hanford Reach. Secondly, we evaluated and compared abundances and growth of larvae and early juveniles of the dominant resident species (peamouth *Mylocheilus caurinus,* northern pikeminnow *Ptychocheilus oregonensis,* redside shiner *Richardsonius balteatus*, and suckers *Catostomus* spp.) in the Hanford Reach during 1998,1999, and 2000 with regards to environmental conditions during these years. An additional objective was to compare overall catch-per-unit-effort of abundant taxa, and growth and mortality rates of northern pikeminnow, between the Hanford Reach and the John Day Reservoir of the Columbia River (Barfoot et al. 1999; Gadomski, unpublished data) to determine the relative impact of highly variable flow regimes on early stages of resident fishes.

Methods

Age-0 fishes in the Hanford Reach (rkm 582.0-600.5) were collected at ten sites in the main channel and two sloughs (Figure 1). All sites were sampled in all years, except for White Bluffs Slough in 1999, which had limited access due to endangered species in the area. Some sites could not be sampled during some weeks because of high or low water levels. However, fishes were generally sampled weekly during daytime from mid-July through late September in 1998 and 1999, and from mid-July through late August in 2000. The sample sites were shallow ($\leq$ 1.0 m), with little or no water velocity, and a mixture of sand, fine sediment, and gravel/cobble substrate. Vegetation at the sites varied seasonally and with water level fluctuations, and consisted primarily of algal accumulations in shoreline margins and aquatic macrophytes (predominately *Myriophyllum* spp.).

Fishes were collected using a small beach seine (15.2 m x 1.2 m with 2.0 mm mesh and a 1.2 m^2 bag with 0.8 mm mesh), following methods of Barfoot et al. (1999). Following capture, larval and juvenile fishes were preserved in 10% formalin buffered with sodium borate. In some instances due to large catches, fishes were subsampled in the field before preservation. Mid-depth water temperatures were measured offshore at the start of the seine haul (15 m from shore) and near shore in a water depth of 20 cm.

Fishes were sorted from the preserved samples, measured to the nearest 0.1 mm standard length (SL), and grouped into 1-mm length intervals for analysis. In each sample, a maximum of 100 northern pikeminnow and 50 specimens of other taxa were measured and used for extrapolation of size distributions.

We estimated growth and mortality rates of age-0 northern pikeminnow and suckers (the two most abundant taxa) using a length-based ageing method developed by Hackney and Webb (1978). To apply this method, we first computed the mean relative age of each 1-mm length class. The weekly catch of each 1-mm length class from a site was multiplied by a consecutive day of the year corresponding to the date of capture (Dew and Hecht 1994). The sum of the resulting values for each length group was then divided by the total seasonal catch of fish within that group to obtain the mean date of abundance (Hackney and Webb 1978; DeAngelis et al. 1980; Dew and Hecht

1994). For each length class, we estimated the mean relative age in days by subtracting the approximate mean date of hatching from the mean date of abundance values. Based on laboratory growth data (Gadomski et al. 2001), the mean day of hatching of northern pikemininow was assumed to be 10 d prior to the mean date of abundance of larvae in the 10 mm SL interval. This value was also used for suckers.

Growth rates were then estimated with the equation:

$$\ln SL = a + G\ (Age),$$

where SL is the length interval of concern, a is the regression intercept, G is the instantaneous growth rate, and "Age" is the age in days after hatching (Dew and Hecht 1994). Instantaneous mortality rates (Z) were estimated as the negative slope of the $\log_e$ cumulative catches of each 1-mm length group regressed against estimated length class ages. Only length classes for which catch distributions appeared to be completely characterized were included in growth and mortality analyses. To allow inter-annual comparisons, we only present results of sites where growth and mortality rates could be estimated for two of the three study years

Results

Overview

We collected 81,304 age-0 resident fishes in 1998, 114,820 fishes in 1999, and 97,952 fishes in 2000, with mean catch-per-unit-effort (CPUE) ranging from 675 to 5,789 (Table 1). In all years, hauls were dominated by four taxa--peamouth *Mylocheilus caurinus,* northern pikeminnow *Ptychocheilus oregonensis,* redside shiner *Richardsonius balteatus*, and suckers *Catostomus* spp. (which cannot be identified to species when larvae or early juveniles). CPUE varied greatly between weeks and years, and between sample sites (Table 1, Figures 2-10). However, northern pikeminnow and suckers were generally abundant at all sample locations, while peamouth and redside shiner had a more patchy distribution. Highest CPUE of peamouth, northern pikeminnow, and suckers were in the Hanford Slough in 1999, while highest catches of redside shiner were in the main channel in 1998 and 2000, and the Hanford Slough in 1999 (Table 1).

Catches of resident larval and juvenile fishes in the Hanford Reach were much higher than catches in the lower Columbia River during an earlier study (1995-1996) conducted by Gadomski (unpublished data) and Barfoot et al. (1999) using the same gear and methods (Table 2). Almost no redside shiners were collected in the lower Columbia River. Catches of peamouth, northern pikeminnow, and suckers were relatively low below Bonneville Dam, and in most locations of the John Day Reservoir. Higher abundances of age-0 northern pikeminnow were only consistently encountered in the upper John Day Reservoir (Table 2; Barfoot et al. 1999).

At the end of the summer rearing season (late August), mean standard lengths (SL) of northern pikeminnow in the Hanford Reach ranged from 17 to 25 mm, which was similar to mean lengths of redside shiner (Table 3). Suckers were somewhat larger, 27-38 mm SL, and peamouth, which spawn earliest, were the largest age-0 fish collected at mean sizes of 35-46 mm SL. All four dominant taxa were generally larger in main channel versus slough areas (Table 3). Additionally, all four taxa were larger in main-channel sites in 1998 versus 1999 and 2000, and all taxa but peamouth were larger in slough sites in 1998.

Northern pikeminnow

During all years, northern pikeminnow larvae were first collected in shorelines during mid through late July at main-channel and slough sample sites (Figures 2-7). The size of the smallest larvae we collected, 9-10 mm SL, is the size at emergence (Gadomski et al. 2001). We continued to collect small northern pikeminnow through late August at some sites (i.e., F Islands, Locke Island, and White Bluffs Slough during 1998; the Hanford Slough and F Islands in 1999; F Islands, Locke Island, and both sloughs during 2000), indicating protracted spawning and recruitment were occurring at these locations.

Because catch variability was high at many sites and we observed multiple cohorts due to continued recruitment, growth and mortality rates could only be estimated at limited locations; we additionally only present sites where rates could be calculated for at least two years (Figure 11). As examples, growth and mortality curves are presented for one site during each year, the Hanford Townsite in 1998 (Figure 3), and Locke Island in 1999 and 2000 (Figures 5 and 7). Instantaneous growth rates (G) ranged between 0.014 and 0.038, and except for the Hanford Townsite in 1998, were lower than growth rates in the John Day Reservoir in 1994 and 1996 (Figure 11). Instantaneous mortality rates (Z) ranged between 0.059 and 0.151, and were generally lower than the John Day Reservoir in 1996. In the Hanford Reach, growth and mortality rates were both higher at the Hanford Townsite compared to other locations. Similarly, at Hanford Slough and Locke Island, growth and mortality rates were both higher in 2000 than in 1999.

Suckers

Suckers were the most abundant age-0 fish in shorelines of the Hanford Reach during our study, with CPUE high in both main channel and slough areas in all three years (Figures 8-10). Sucker abundances were particularly high in the Hanford Slough in 1999, with a mean CPUE of 13,025 in mid-July (Figure 9).

Instantaneous growth rates (G) for suckers ranged between 0.010 and 0.026) (Figure 12). Growth was highest in 1998 at Locke Island Rkm 598.1, but did not show consistent trends in 1999 and 2000. Instantaneous mortality rates (Z) ranged between 0.041 and 0.239, with the highest rate in 1999 at Locke Island Rkm 598.1.

Peamouth

In all years, peamouth were relatively large when first collected in mid-July, with a mean size of about 20 mm SL (Figures 8-10). This is due to the earlier spawning season of this species (Gadomski and Barfoot 1998), since newly-hatched larvae of peamouth are similarly-sized to northern pikeminnow. Peamouth were particularly abundant in 1999 in the Hanford Slough, with a maximum CPUE of 1490 in late July (Figure 9).

Redside shiner

Redside shiner hatch at a smaller size than other cyprinids in the Hanford Reach, first appearing in shorelines at about 8 mm SL (Figures 8-10). Redside shiner distributions in the Hanford Reach were somewhat patchy, with highest CPUE in the main channel (primarily a protected area of the F Islands at rkm 591.3) in 1998 and 2000, and in Hanford Slough in 1999.

Environmental conditions

In all three years, water temperatures were higher in the sloughs than main-channel locations, and higher nearshore than offshore (Figure 13). Water temperatures during July-August were highest in 1998 (about 20-30^{o}C) versus 1999 and 2000 (18-24 ^{o}C).

Flow downstream of Priest Rapids Dam (the upper segment of the Hanford Reach) was used as an indicator of water level fluctuations (Tiffan et al. unpublished manuscript). Mean daily flow was higher in 1999 than in 1998 and 2000 during the entire months of July and August, ranging from 130 to 230 kcfs (1000 ft^3/sec) (Figure 14). Mean daily flow during 1998 and 2000 ranged from about 60 to 170 kcfs. We used the daily coefficient of variation (CV) of hourly flow as an indicator of daily water level fluctuations in the Hanford Reach (Figure 14). Coefficients of variation were lower in 1999 than 1998 and 2000, indicating lower daily variations in water levels during 1999.

Discussion

Instantaneous mortality rates of northern pikeminnow in the Hanford Reach were lower or similar to rates presented by Barfoot et al. (1999) for northern pikeminnow in the upper John Day Reservoir (Figure 11), an area with very little shoreline water level fluctuations. Also, overall abundances of age-0 fish in the Hanford Reach were much higher than those observed in past studies in Columbia River reservoirs and below Bonneville Dam (Tables 1 and 2). This indicates that although shoreline water level fluctuations are greater in the Reach than Columbia River reservoirs, spawning conditions and larval and juvenile rearing habitat are still adequate. High densities of larvae in shorelines of the Hanford Reach relative to reservoir areas may be largely due to an abundance of optimal spawning habitat in the Reach. Environmental conditions considered optimal for northern pikeminnow spawning are rubble/cobble substrate with enough water velocity to keep spawning areas clean of sediment, but with some protection from currents so that spawning fish can maintain position (Beamesderfer 1992; Gadomski 2001). A riverine environment with island complexes such as the Hanford Reach would have many such locations, in contrast to a more lentic-like reservoir. Similarly, the two species of suckers found in the Reach, largescale sucker *Catostomus macrocheilus* and bridgelip sucker *Catostomus columbianus* (Dauble 1980), spawn on gravel substrate with moderate current.

Although overall larval fish abundances in the Hanford Reach were high, our results suggest that years with low flows combined with high water level fluctuations may cause decreased survival of resident fish larvae and juveniles in shoreline areas. Highest catches of the four dominant taxa in this area, peamouth, northern pikeminnow, redside shiner, and suckers, were in the Hanford Slough in 1999 (Table 1), a year with high flows and less daily shoreline fluctuations than 1998 and 2000. Additionally, estimated instantaneous mortality rates of age-0 northern pikeminnow and suckers in the Hanford Reach were generally lower in 1999 (Figures 11 and 12). There is also the possibility, however, that instead of mortality, observed lower abundances in some locations in 1998 and 2000 may be an artifact of greater water level fluctuations in these years moving age-0 fish offshore away from sample sites.

Nonetheless, it has been documented that water level fluctuations may be detrimental to age-0 fish growth and survival in shoreline nursery areas (Sheidegger and Bain 1995). As water levels rise and fall, fish are forced to move into different habitats resulting in increased stress. Lowering of water levels results in exposure and mortality of submergent vegetation and other changes in habitat and food web structure. Lowered water levels can also force young fish into deeper, offshore waters, exposing them to higher levels of predation. In a worst-case scenario, water-level fluctuations may strand fish in shoreline pools, resulting in mortality due to heat stress, or eventually, desiccation.

During late August, mean standard lengths of the four most abundant taxa were greater in 1998 (Table 3), coinciding with higher water temperatures in this year, and concurring with many studies relating faster growth to higher temperatures (e.g., Broughton and Jones 1978; Mann 1991; Bestgen 1996, and others). However, during all years instantaneous growth rates (G) of age-0 northern pikeminnow were lower in the Hanford Reach than in the upper John Day Reservoir, although temperatures in these two areas were similar (Barfoot et al. 1998; Figure 11). Additionally, mean lengths of northern pikeminnow in early September in the Hanford Reach were generally smaller than early September mean standard lengths in the upper John Day Reservoir (46.3, 40.0, and 32.0 mm SL in 1994, 1995, and 1996, respectively; Barfoot et al. 1999). Smaller northern pikeminnow mean sizes in September in the Hanford Reach could be the result of continued recruitment of newly-emerged larvae into shorelines through late August. Smaller fish have been shown to experience higher overwinter mortality and be in worse condition the following spring (Miranda and Hubbard 1994; Cargnelli and Gross 1997).

Sites and years with higher mortality also generally displayed higher growth rates for both northern pikeminnow and suckers (Figures 11 and 12). This may be an indication of size-selective mortality; if smaller fish were dying at high rates, this would result in an appearance of accelerated growth. Greater mortality of smaller fish could be due to higher vulnerability to predation, perhaps exacerbated by forced offshore movements into unprotected deeper waters due to water level changes. Smaller fish are also more vulnerable to starvation, having less body reserves and not competing as efficiently as older cohorts for prey. Small fish may be at a particular disadvantage in areas with very high larval and juvenile fish densities such as the Hanford Reach, since this could increase competition if food was limiting.

Indeed, carrying capacity may explain why mean lengths of age-0 fishes at the end of the sampling season did not indicate growth was greater in Hanford Reach sloughs than in main-channel areas. Sloughs and backwaters have been shown in many systems to be highly productive larval fish nursery sites because of warmer temperatures and enhanced food availability (Sheaffer and Nickum 1986; Scott and Nielsen 1989; Brown and Coon 1994). However, although Hanford Reach sloughs had higher temperatures, growth did not appear to be enhanced. Food may be inadequate for the high densities of fish larvae in this area, particularly if water level fluctuations desiccate aquatic vegetation and disrupt shoreline prey sources. Alternatively, larger fish may have migrated out of slough nursery sites to the main-channel, thus decreasing the mean size of age-0 fishes in the slough by late August.

In conclusion, we found slower growth of northern pikeminnow larvae and juveniles in shorelines of the Hanford Reach compared to Columbia River reservoirs, but also lower mortality rates in the Reach. Growth of the most abundant age-0 resident fishes in the Reach was generally greatest in 1998, a year with warmer summer shoreline temperatures, and survival may have been enhanced in 1999, a year with high flows and low water level fluctuations. However, overall abundances of age-0 fish were very high in Hanford Reach shorelines compared to other areas of the Columbia River indicating good spawning conditions and adequate larval and juvenile rearing habitat. High initial densities of resident fish larvae in the Hanford Reach may mitigate for any effects that shoreline water level variations could have on age-0 fish growth and survival.

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Table 1. CPUE of larval and juvenile fishes collected by beach seining in the Hanford Reach, Columbia River, during July-August 1998-2000.

	1998		1999		2000	
	Main channel	Sloughs	Main channel	Sloughs	Main channel	Sloughs
Number of hauls:	42	23	43	12	46	31
Total number of fish collected:	44,820	36,484	45,352	69,468	77,025	20,927
CPUE	1,067	1,586	1,055	5,789	1,674	675
Taxon ([a] = introduced)						
Clupeidae (herring)[a]						
American shad *Alosa sapidissima*	0	24	0	0	0	<1
Cyprinidae (minnows)						
Chiselmouth *Acrocheilus alutaceus*	<1	0	0	0	0	0
Common carp[a] *Cyprinus carpio*	<1	0	0	3	<1	0
Peamouth *Mylocheilus caurinus*	70	212	71	775	59	122
Northern pikeminnow *Ptychocheilus oregonensis*	218	787	285	980	513	95
Dace *Rhinichthys* spp.	27	5	3	20	67	21
Redside shiner *Richardsonius balteatus*	389	149	70	298	374	32
Undetermined spp.	17	56	<1	0	199	103
Catostomidae (suckers)						
Catostomus spp.	338	351	621	3,698	454	294
Gasterosteidae (sticlebacks)						
Threespine stickleback *Gasterosteus aculeatus*	<1	<1	1	7	<1	<1
Centrarchidae (sunfishes)[a]						
Pumpkinseed *Lepomis gibbous*	0	0	<1	0	0	0
Bluegill *Lepomis macrochirus*	<1	1	<1	0	<1	<1
Lepomis spp.	<1	0	0	0	0	0
Smallmouth bass *Micropterus dolomieui*	7	1	1	2	5	1
Largemouth bass *Micropterus salmoides*	<1	<1	0	0	0	0
Micropterus spp.	<1	0	0	0	<1	0
Percidae (perches)[a]						
Yellow perch *Perca flavescens*	0	0	0	2	0	0
Cottidae (sculpins)						
Cottus spp.	0	<1	1	0	<1	<1

Table 2 Mean catch per unit effort (CPUE) of age-0 peamouth (PEM), northern pikeminnow (NPM), redside shiner (RSS), and suckers (SUC) collected in beach seine hauls at three main-channel and one backwater location in the John Day Reservoir (JDA) and below Bonneville Dam (BON), Columbia River, during 1995 and 1996 (Gadomski, unpublished data). The period of July-August is presented for all locations except the lower John Day Reservoir, which was only sampled during August. N = number of hauls.

	Mean CPUE - 1995					Mean CPUE - 1996				
Location	PEM	NPM	RSS	SUC	N	PEM	NPM	RSS	SUC	N
Below BON										
Main channel	6	<1	0	2	18	39	0	<1	1	16
Backwater	37	9	<1	100	7	65	1	0	19	9
Lower JDA	2	2	0	<1	6	2	0	0	0	8
Upper JDA	18	248	<1	24	24	19	231	0	180	27

Table 3. Mean standard lengths (mm) and standard deviations (in parentheses) of young-of-the-year peamouth, northern pikeminnow, redside shiner, and suckers during late August of 1998, 1999, and 2000 in the Hanford Reach, Columbia River. n = number of fish measured.

Taxon	1998 Main channel	1998 Sloughs	1999 Main channel	1999 Sloughs	2000 Main channel	2000 Sloughs
Peamouth	45 (6) n = 129	42 (5) n = 120	40 (6) n = 137	35 (5) n = 170	38 (4) n = 23	46 (8) n = 235
Northern pikeminnow	25 (8) n = 266	20 (6) n = 360	19 (12) n = 598	17 (10) n = 335	20 (4) n = 486	19 (5) n = 613
Redside shiner	30 (6) n = 190	24 (5) n = 207	15 (4) n = 250	19 (4) n = 136	22 (4) n = 304	19 (4) n = 148
Suckers	38 (7) n = 147	36 (9) n = 155	29 (9) n = 114	27 (6) n = 155	28 (7) n = 39	28 (6) n = 221

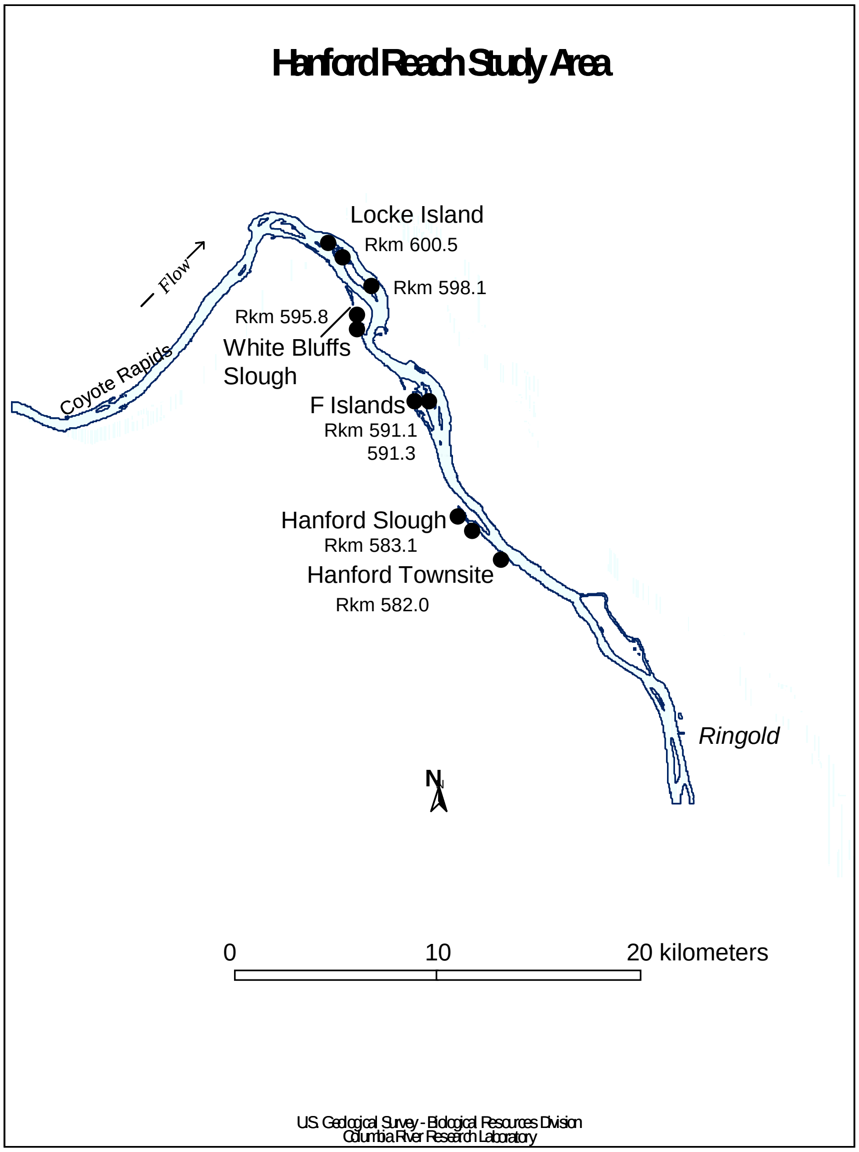
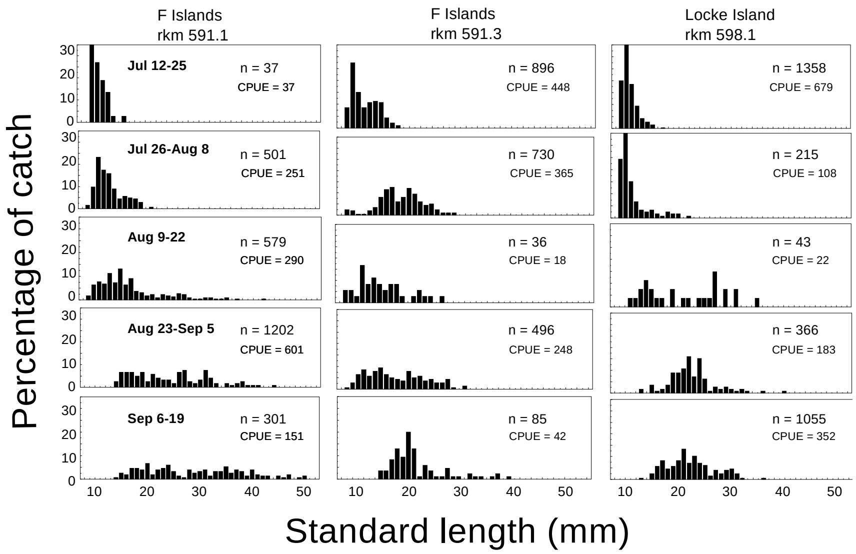
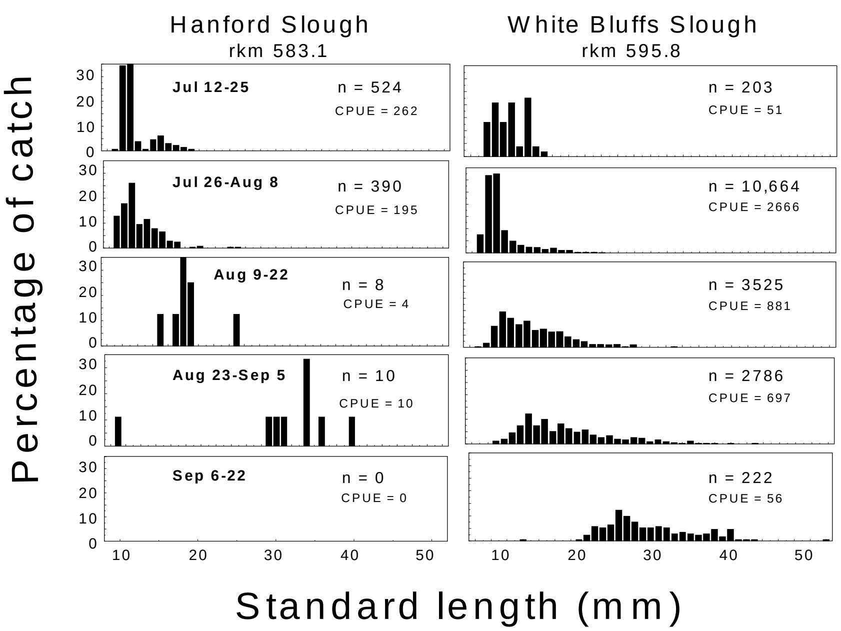


Figure 1. Hanford Reach, Columbia River (Washington), beach seine sample sites during July-September 1998-2000. Each site is indicated by a black circle. Rkm = river kilometer.



Northern pikeminnow 1998 – Main channel



Northern pikeminnow 1998 – Sloughs

Figure 2. Bi-weekly length-frequency distributions of age-0 northern pikeminnow collected by beach seining the Hanford Reach, Columbia River, during July-September 1998. N = total number of fish collected. CPUE = Catch-per unit-effort.

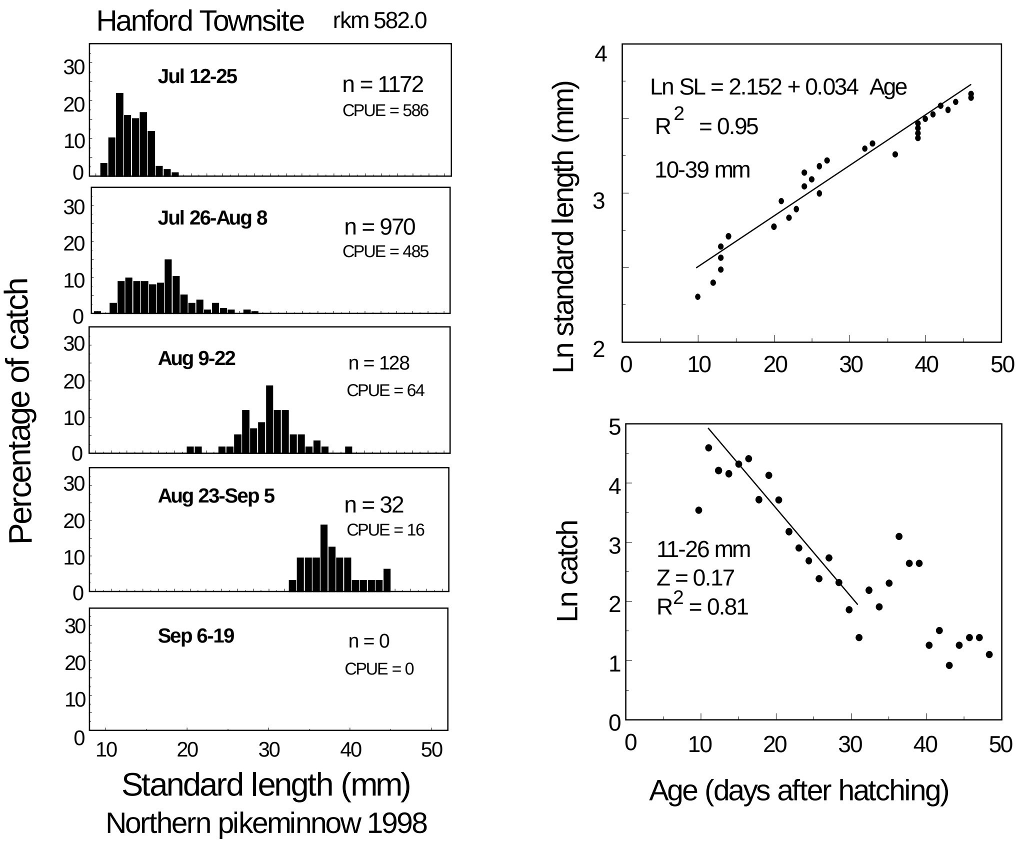


Figure 3. Bi-weekly length-frequency distributions of age-0 northern pikeminnow collected by beach seining at the Hanford Townsite of the Hanford Reach, Columbia River, during July-September 1998. Estimates of growth and instantaneous mortality rates (Z) are also presented.

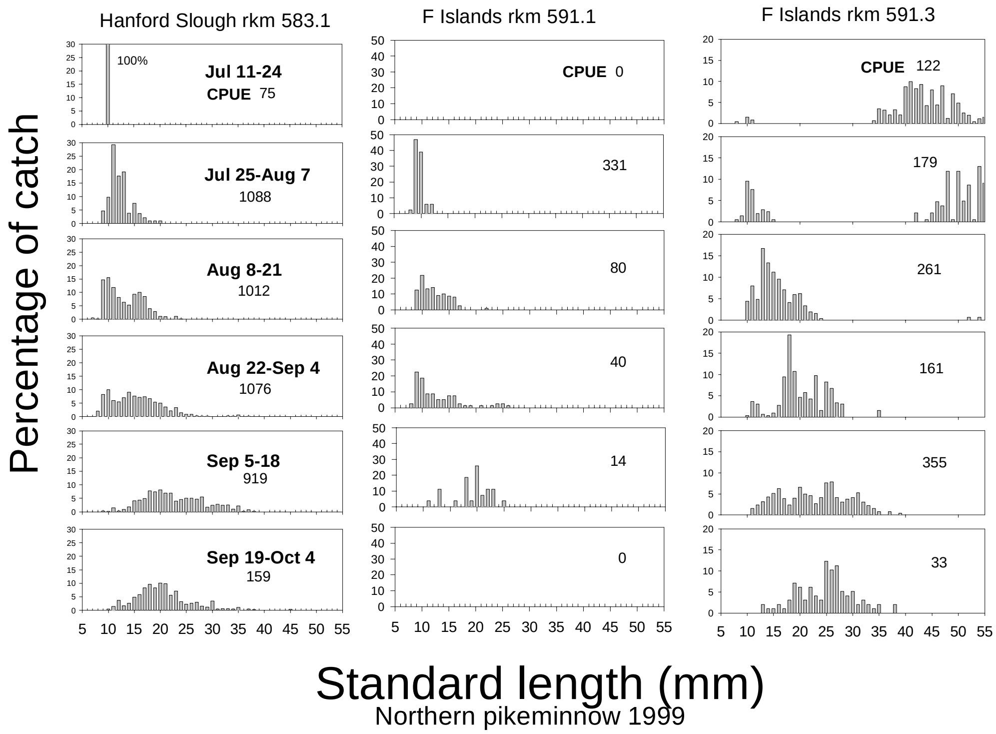


Figure 4. Bi-weekly length-frequency distributions of northern pikeminnow collected by beach seining in the Hanford Reach, Columbia River, during July-September 1999. CPUE = Catch-per-unit-effort.

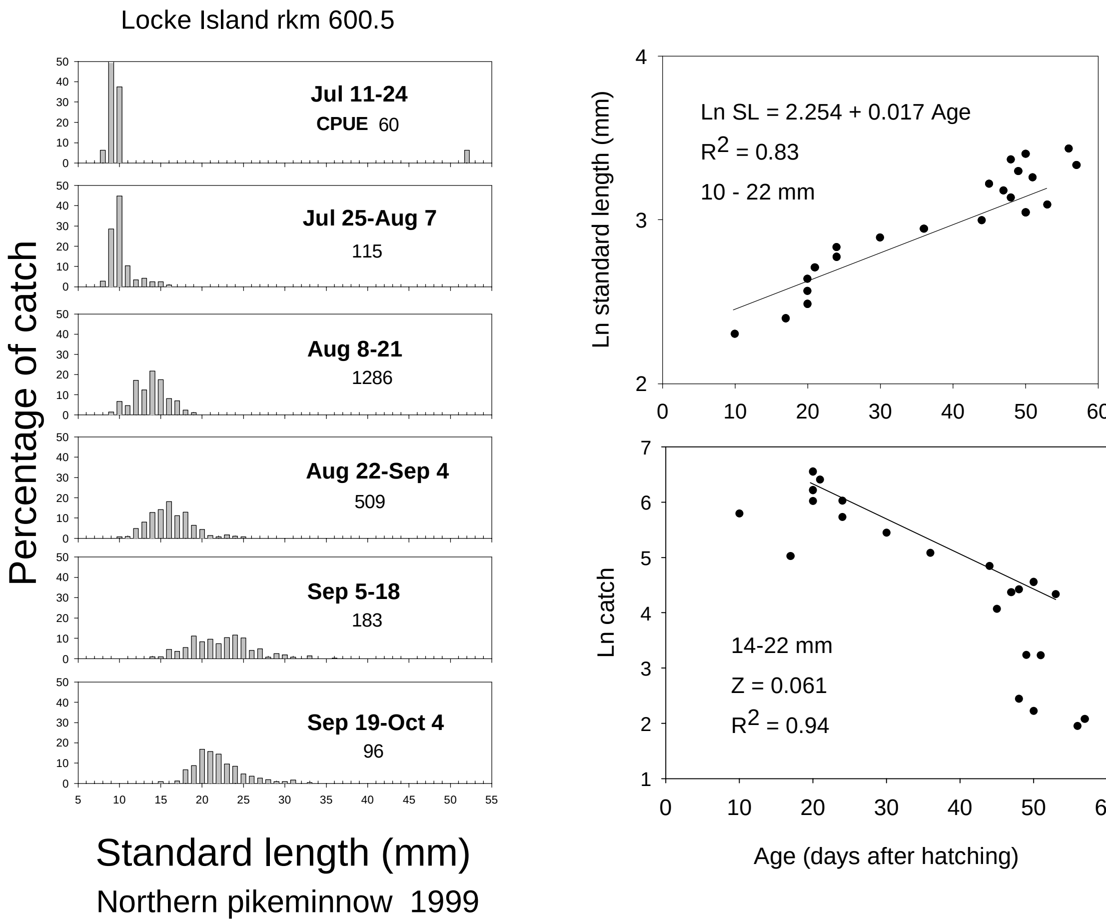


Figure 5. Bi-weekly length-frequency distributions of age-0 northern pikeminnow collected by beach seining at the Locke Island of the Hanford Reach, Columbia River, during July-September 1999. Estimates of growth and instantaneous mortality rates (Z) are also presented.

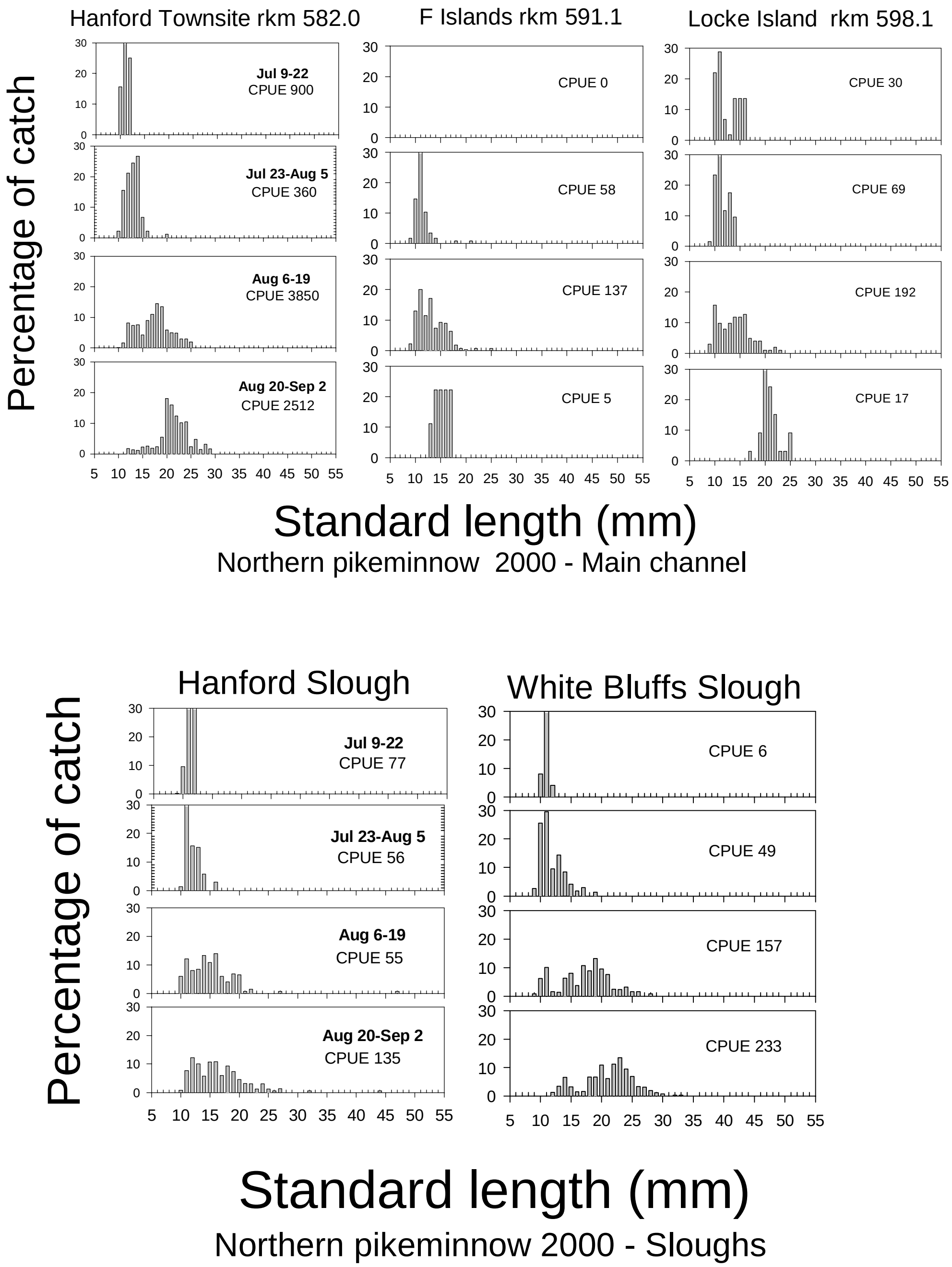


Figure 6. Bi-weekly length-frequency distributions of age-0 northern pikeminnow collected by beach seining in the Hanford Reach, Columbia River, during July-August 2000. CPUE = Catch-per-unit-effort.

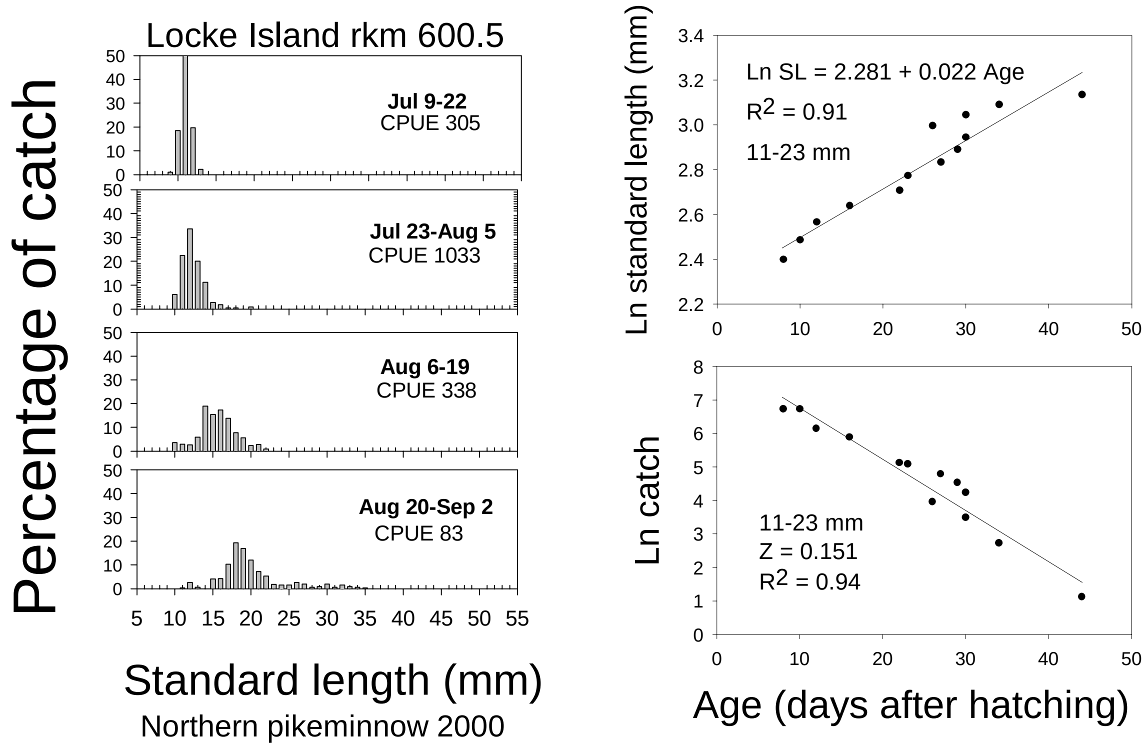


Figure 7. Bi-weekly length-frequency distributions of age-0 northern pikeminnow collected by beach seining at Locke Island in the Hanford Reach, Columbia River, during July-August 2000. Estimates of growth and instantaneous mortality rates (Z) are also presented.

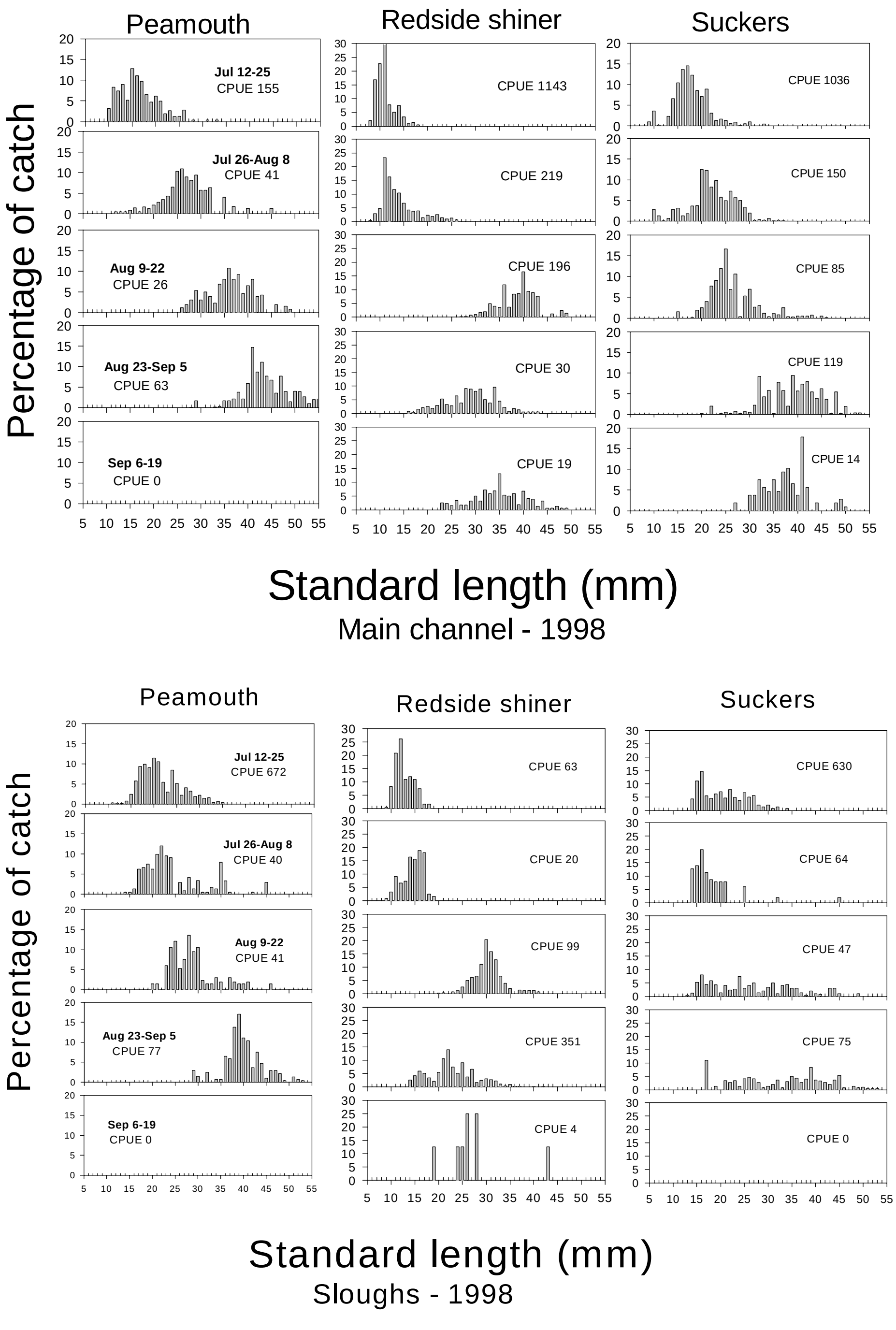
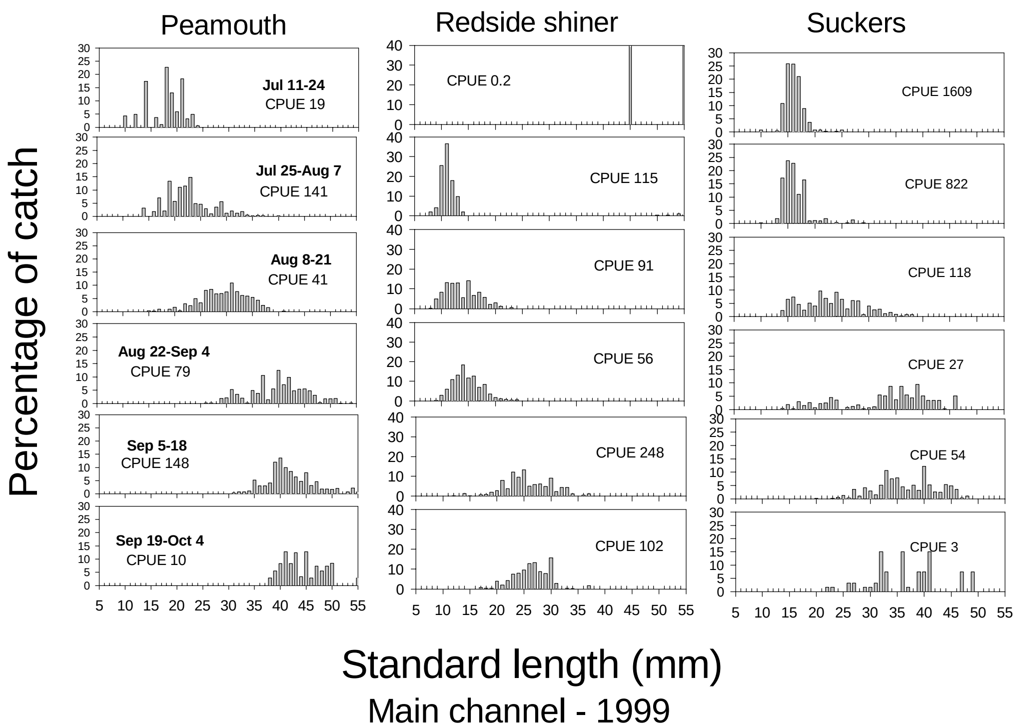


Figure 8. Bi-weekly length-frequency distributions of peamouth, redside shiner, and suckers collected by beach seining in the Hanford Reach, Columbia River, during July-September 1998.



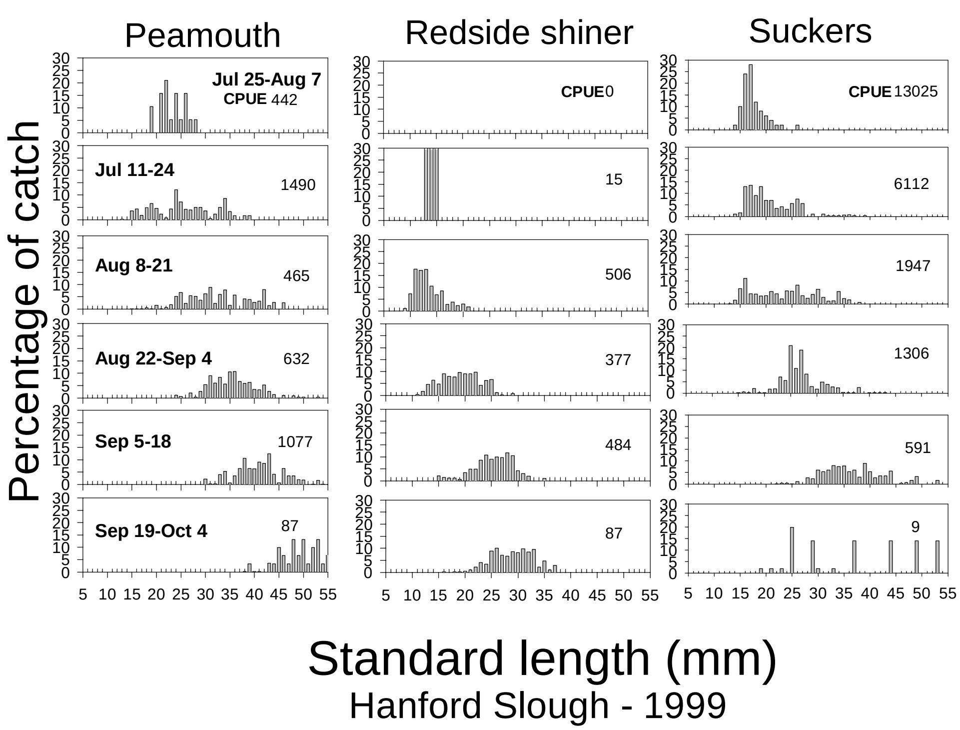


Figure 9. Bi-weekly length-frequency distributions of peamouth, redsid shiner, and suckers collected by beach seining in the Hanford Reach, Columbia River, during July-September 1999.

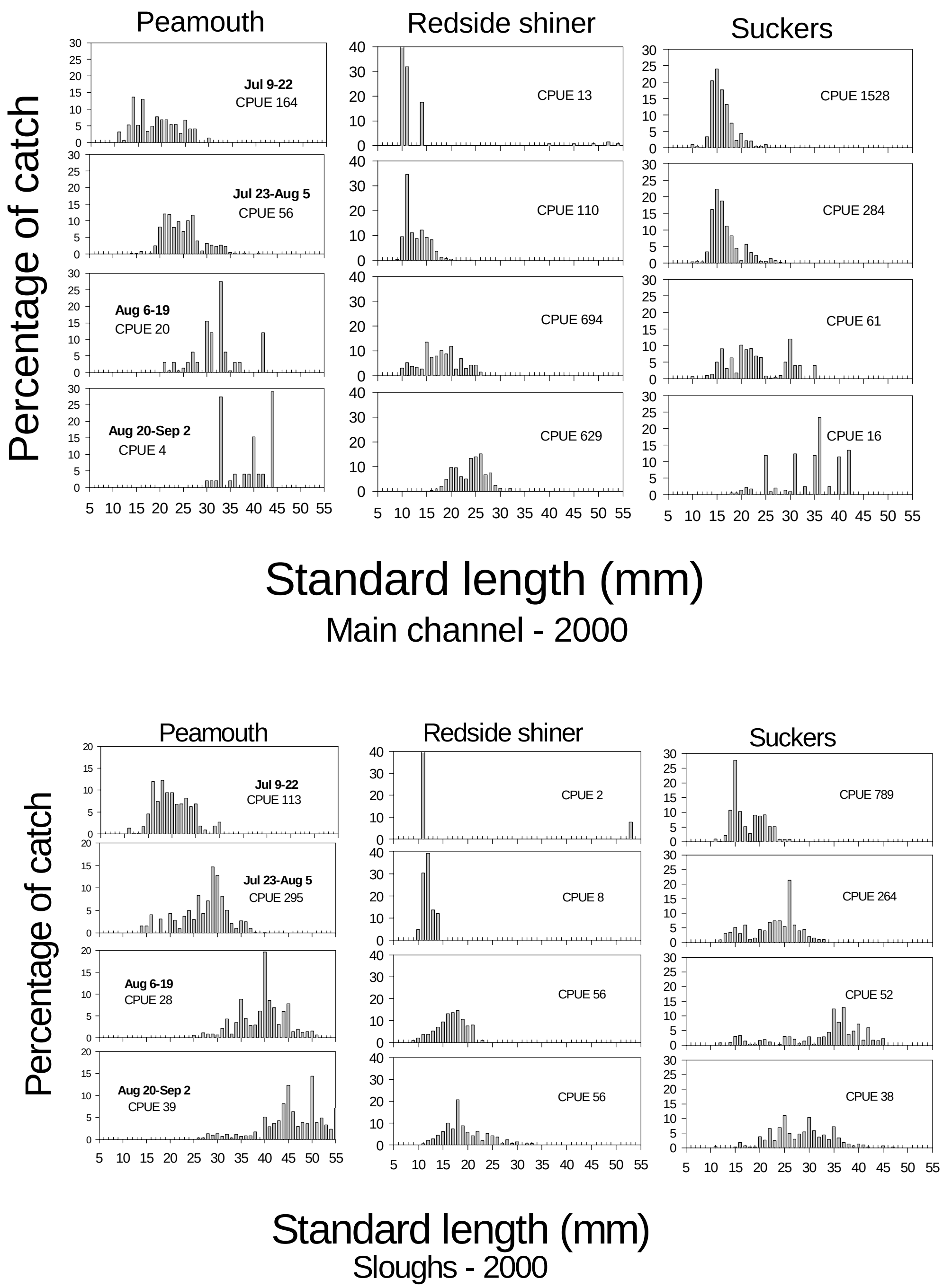


Figure 10. Bi-weekly length-frequency distributions of peamouth, redside shiner, and suckers collected by beach seining in the Hanford Reach, Columbia River, during July-August 2000.

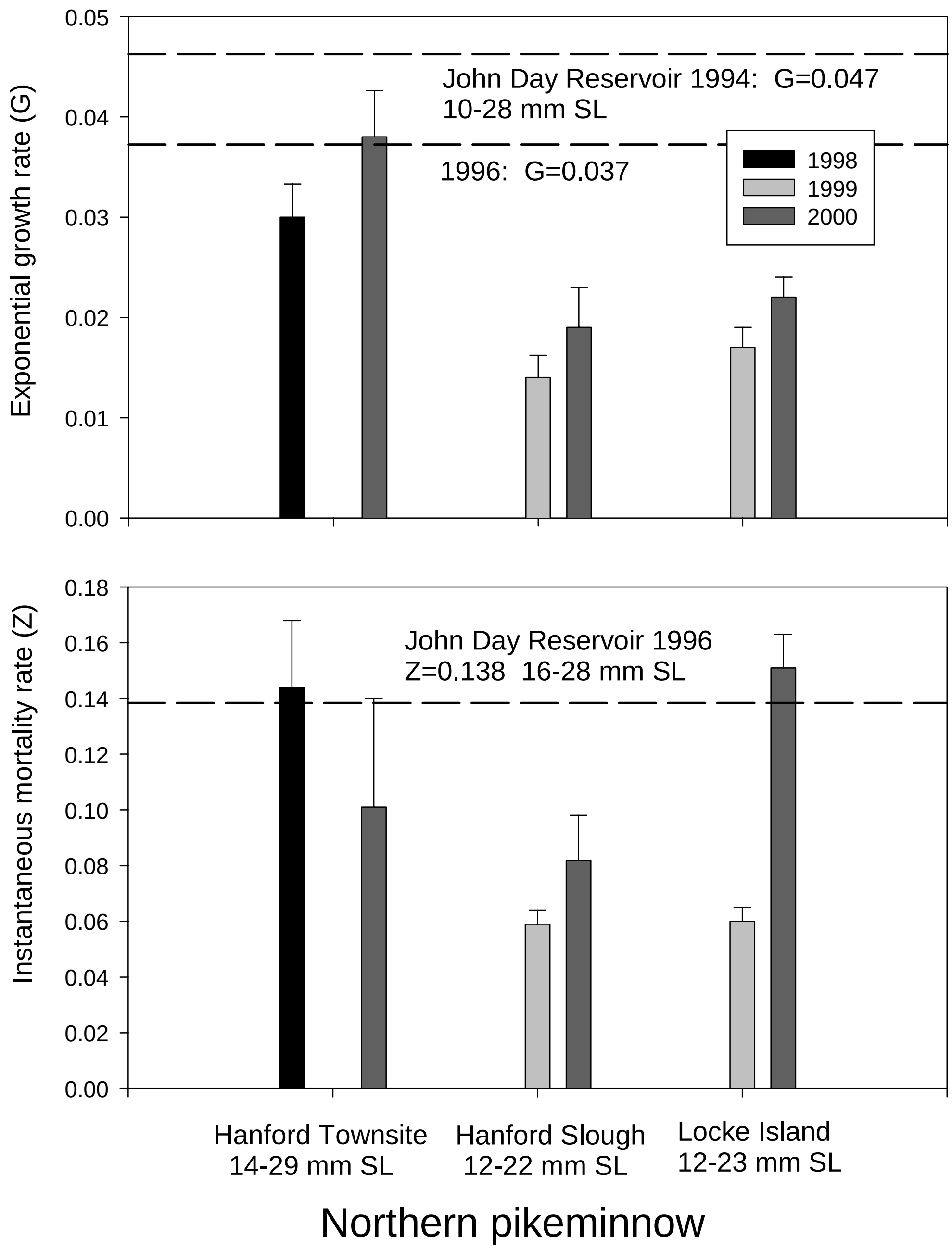


Figure 11. Exponential growth rates and instantaneous mortality rates of northern pikeminnow at three sites in the Hanford Reach during 1998-2000; rates could not be estimated for all sites in all years. Vertical lines represent one standard error. Rates from the John Day Reservoir during 1994 and 1996 are presented for comparison (Barfoot et al. 1999).

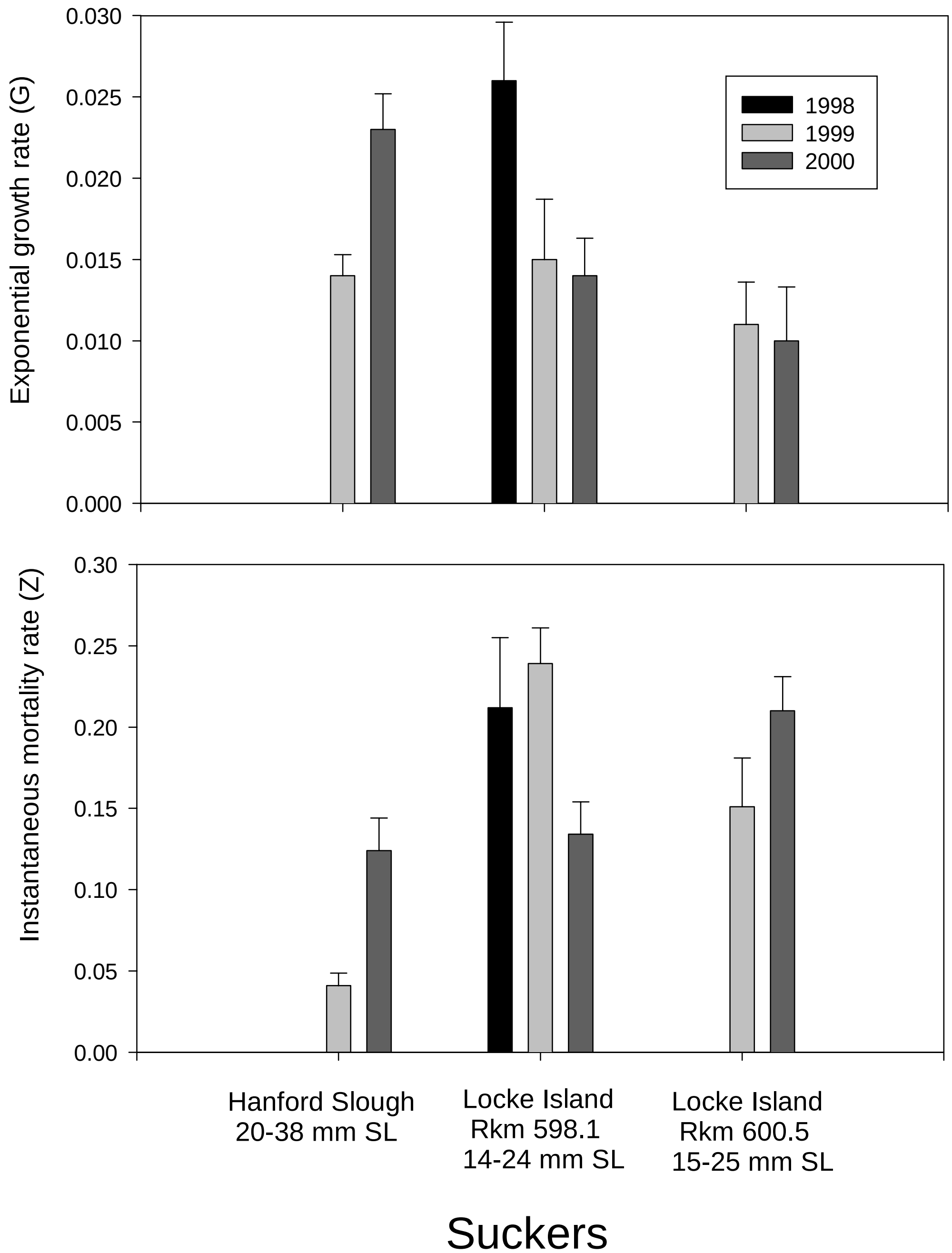


Figure 12. Exponential growth rates and instantaneous mortality rates of suckers at three sites in the Hanford Reach during 1998-2000; rates could not be estimated for all sites in all years. Vertical lines represent one standard error.

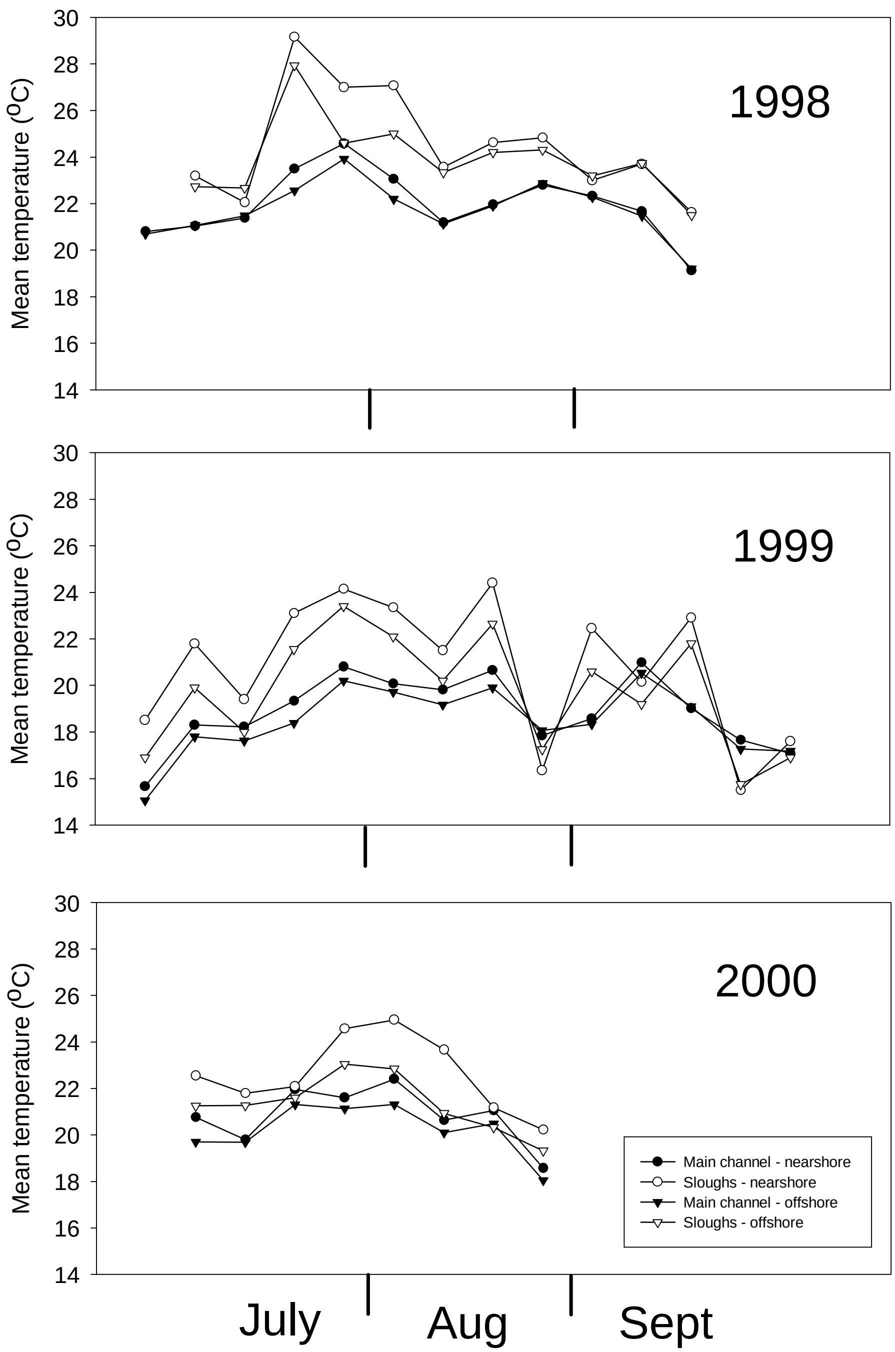


Figure 13. Mean temperatures at Hanford Reach, Columbia River, main-channel and slough beach seine sample sites both nearshore (20 cm depth) and offshore (15 m from shore) during July-September 1998-2000.

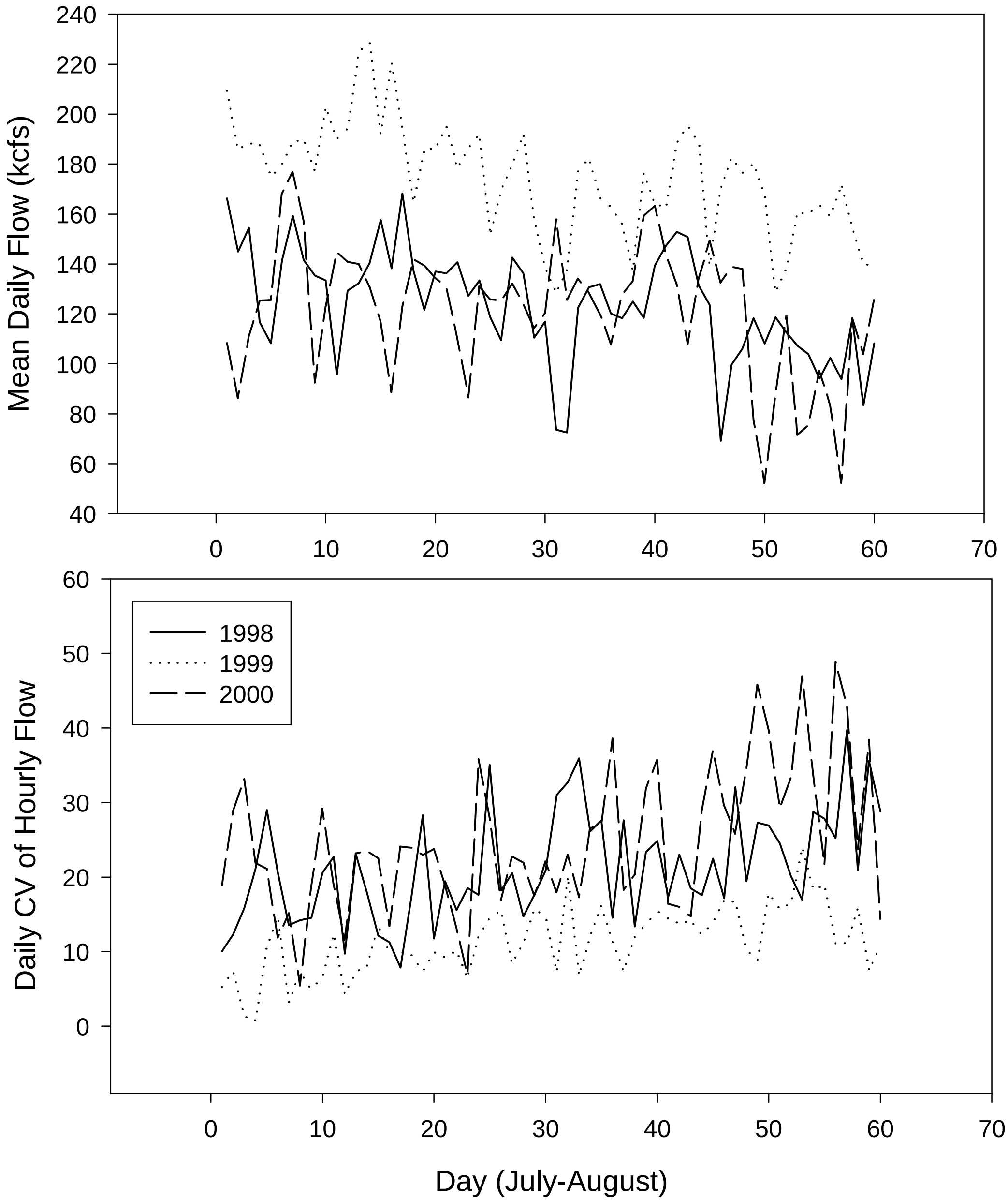


Figure 14. Mean daily flow in kcfs (1000 ft^3/sec) and the daily coefficient of variation (CV) of hourly flow downstream of Priest Rapids Dam, Columbia River. Hourly flow data is courtesy of U.S. Army Corps of Engineers from the following website: http://www.cqs.washington.edu/dart/river_rpt.html.