Document ID #P107674

Evaluation of Salmon Spawning Below Bonneville Dam

Annual Report

October 2006 – September 2007

Prepared by

Evan V. Arntzen, Robert P. Mueller, Katherine J. Murray, and Yi-Ju Bott

Pacific Northwest National Laboratory
Richland, Washington

Prepared for

U.S. Department of Energy
Bonneville Power Administration
Division of Fish and Wildlife
Portland, Oregon

Project No. 1999-003-01
Contract No. 26934

August 2008

Foreword

Since FY 2000, scientists at Pacific Northwest National Laboratory (PNNL) have conducted research to assess habitat requirements and the extent of spawning by chum salmon (*Oncorhynchus keta*) and fall Chinook salmon (*O. tshawytscha*) in the lower mainstem Columbia River. Their work supports a larger project funded by the Bonneville Power Administration (BPA) aimed at characterizing the physical habitat used by mainstem fall Chinook and chum salmon populations. Multiple collaborators in addition to PNNL are involved in the BPA project—counterparts include the Washington Department of Fish and Wildlife (WDFW), U.S. Fish and Wildlife Service (USFWS), Pacific States Marine Fisheries Commission (PSMFC), U.S. Geological Survey (USGS), and Oregon Department of Fish and Wildlife (ODFW). The overall goal of the project is to provide a sound scientific basis for operation of the Federal Columbia River Power System (FCRPS) in ways that will effectively protect and enhance the chum and tule fall Chinook salmon populations—both listed as threatened under the *Endangered Species Act of 1973* (ESA).

Background

Fall Chinook salmon, thought to originate from Bonneville Hatchery, were first noted to be spawning downstream of Bonneville Dam by WDFW biologists in 1993. Known spawning areas include gravel beds on the Washington side of the river near Hamilton Creek and near Ives Island. Limited surveys of spawning ground were conducted in the area around Ives and Pierce islands from 1994 through 1997. Based on those surveys, it is believed that fall Chinook salmon are spawning successfully in this area. The size of this population from 1994 to 1996 was estimated at 1,800 to 5,200 fish. Chum salmon also have been documented spawning downstream of Bonneville Dam. Chum salmon were listed as threatened under the ESA in March 1999.

From 1999 through 2007, the Fish and Wildlife Program of the Bonneville Power Administration funded a project to determine the number of fall Chinook and chum salmon spawning downstream of Bonneville Dam, the characteristics of their spawning areas, and the flows necessary to ensure their long-term survival. Data were collected to ensure that established flow guidelines are appropriate and provide adequate protection for the species of concern. The projects objectives are consistent with the high priority placed by the Northwest Power and Conservation Council Independent Scientific Advisory Board and the salmon managers on determining the importance of mainstem habitats to the production of salmon in the Columbia River Basin. Because of the influence of mainstem habitat on salmon production, there is a continued need to better understand the physical habitat variables used by mainstem fall Chinook and chum salmon populations and the effects of hydropower project operations on spawning and incubation.

During FY 2007, Pacific Northwest National Laboratory focused on 1) locating and mapping deep-water fall Chinook salmon and chum salmon spawning areas, 2) investigating the interaction between groundwater and surface water near fall Chinook and chum salmon spawning areas, and 3) providing in-season hyporheic temperature and water surface elevation data to assist state agencies with emergence timing and redd dewatering estimates.

Report Scope

This report documents the studies and tasks performed by PNNL during FY 2007. Chapter 1 provides a description of the searches conducted for deepwater redds—adjacent to Pierce and Ives islands for fall Chinook salmon and near the Interstate 205 bridge for chum salmon. The chapter also provides data on redd location, information about habitat associations, and estimates of total spawning populations. Chapter 2 documents the collection of data on riverbed and river temperatures and water surface elevations, from the onset of spawning to the end of emergence, and the provision of those data in-season to fisheries management agencies to assist with emergence timing estimates and evaluations of redd dewatering.

Acknowledgments

The authors thank Scott Titzler, Fenton Khan, Corey Duberstein, Brian Bellgraph, and Nate Phillips of Pacific Northwest National Laboratory for their assistance in conducting the video surveys, preparing geographic information system maps, and analyzing videotapes. Brian Miller, Kyle Larson, Cherylyn Tunnicliffe, and Jennifer Panther assisted with temperature data collection. Chris Murray assisted with data analysis. Gregg Gustafsen helped maintain the real-time data collection system. Rob Mackley assisted with vertical elevation surveys. Andrea Currie provided editorial assistance. PNNL, a multiprogram national laboratory, is operated for the U.S. Department of Energy by Battelle under Contract DE-AC05-76RL01830.

Contents

Foreword iii
Acknowledgments v

Chapter 1
Deepwater Spawning of Fall Chinook Salmon (*Oncorhynchus tshawytscha*) near Ives and Pierce Islands of the Columbia River, 2006

Summary 1.1
Introduction 1.2
Methods 1.2
Results 1.5
Fall Chinook Salmon Spawning Surveys 1.5
Chum Salmon Spawning Surveys 1.9
Discussion 1.10
References 1.12
Appendix – Maps Illustrating Fall Chinook Salmon Redd Spawning Areas, 1999 Through 2005 ..... A.1

Chapter 2
Temperature Data Collected To Improve Emergence Timing Estimates and Refine Habitat Availability Estimates for Chum and Fall Chinook Salmon Downstream of Bonneville Dam

Summary 2.1
Introduction 2.2
Study Site 2.3
Methods 2.4
Temperature and Water Surface Elevation Monitoring 2.4
Two-Dimensional Riverbed Temperature Mapping 2.5
Effect of Changing Discharge on Hyporheic Temperature at Various Riverbed Elevations 2.5
Results and Discussion 2.8
Temperature and Water Surface Elevation Monitoring 2.8
Two-Dimensional Riverbed Temperature Mapping 2.11
Effect of Changing Discharge on Hyporheic Temperature at Various Riverbed Elevations 2.15
References 2.19
Appendix A – Temperature Sensor Location Information A.1
Appendix B – Temperature Data Collected Downstream from Bonneville Dam in the Ives Island Area, FY 2007 ..... B.1
Appendix C – Temperature Data Compendium C.1
Appendix D – Temperature Mapping with Statistical Summary D.1
Appendix E – 32 Onset Point Used To Evaluate Riverbed Temperature Profile at Various Riverbed Elevations During River Stage Fluctuations E.1

Figures

1.1 Search Zone Locations Relative to Ives and Pierce Islands 1.3

1.2 Chum Salmon Search Zones Upstream of the Interstate 205 Bridge 1.3

1.3 Chum Salmon Search Zones near Skamania Island 1.4

1.4 Percentage of Fall Chinook Salmon Redds Relative to Water Depth in the Primary and Secondary Search Zones 1.6

1.5 Location of Fall Chinook Salmon Redds in the Mainstem of the Columbia River Downstream from Bonneville Dam in 2006 ..... 1.7

1.6 Fall Chinook Salmon Spawning Area for Redds Found During 2006 ..... 1.8

1.7 Location of Chum Redds Found at the Woods Landing Site During Boat-Based Surveys 1.9

1.8 Location of Chum Redds Found at the Rivershore Site During Boat-Based Surveys 1.10

1.9 Proportion of Fall Chinook Salmon Redds Found in the Primary and Secondary Spawning Zones Adjacent to Pierce Island 1.11

2.1 Ives Island, Multnomah Falls, and Interstate 205 Rivershore and Woods Landing Spawning Areas 2.3

2.2 Piezometer Locations in Chum Salmon Spawning Areas and Fall Chinook Salmon Spawning Locations at Ives Island, Multnomah Falls, and Woods Landing and Rivershore Sites 2.4

2.3 Chum Salmon Redd Locations from the Ives Island Area and the I-205 Locations, Piezometer Locations, and Temperature Mapping Points at Ives Island, Woods Landing, and Rivershore Sites 2.6

2.4 Onset Sensors As Spaced on Transects 2.7

2.5 Onset Sensor Attached to Rebar Stake 2.7

2.6 Temperature for River and Hyporheic Sensors Within Channel North of Ives Island 2.9

2.7 Temperature for River and Hyporheic Sensors for Ives Island Locations T5MC and Hamilton Creek 2.9

2.8 Temperature for River and Hyporheic Sensors at Multnomah Falls, Rivershore, and Woods Landing Sites 2.10

2.9 Kriging-Estimated Hyporheic Temperature, River Temperature, and Calculated Temperature Difference at the Rivershore Site 2.12

2.10 Kriging-Estimated Hyporheic Temperature, River Temperature, and Calculated Temperature Difference at Woods Landing Site 2.13

2.11 Kriging-Estimated Hyporheic Temperature, River Temperature, and Calculated Temperature Difference at the Ives Island Site 2.14

2.12 Distribution of Onset Temperature Data at Relatively Low River Stage 2.16

2.13 Distribution of Onset Temperature Data at Relatively High River Stage 2.17

2.14 Temperature Profile of Buried Onset Sensors in Chum Salmon Spawning Location N6 During River Stage Fluctuation for a Two-Week Period During the Chum Salmon Spawning Season 2.18

2.15 Temperature Profile of Buried Onset Sensors in Fall Chinook Salmon Spawning Location N2 During River Stage Fluctuation 2.18

2.16 Water Surface Elevation in the Ives Island Area in 2005 and 2006 During the Fall Salmon Spawning Season 2.19

Tables

1.1 Average Discharge and River Elevation Conditions Recorded During the Underwater Video Survey Periods, 2006 ..... 1.5

1.2 Number of Fall Chinook Redds Found in Primary and Secondary Search Zones, 2006..... 1.6

1.3 Estimated Number of Fall Chinook Salmon Redds Occurring in the Primary and Secondary Search Zones near Ives and Pierce Islands, December 4–6, 2006, Following the Peak Spawning Period 1.8

1.4 Adult Fall Chinook Salmon Population Estimates Based on Shallow and Deepwater Redd Surveys 1.9

1.5 Fall Chinook Redd Counts and Approximate Spawning Areas Near Ives and Pierce Islands, 1999–2006 ..... 1.11

Chapter 1

Deepwater Spawning of Fall Chinook Salmon (*Oncorhynchus tshawytscha*) near Ives and Pierce Islands of the Columbia River, 2006

Robert P. Mueller

Summary

Pacific Northwest National Laboratory (PNNL) conducted boat-based underwater video surveys to identify spawning areas of fall Chinook salmon (*Oncorhynchus tshawytscha)* located in deep water (greater than 1 m) downstream of Bonneville Dam in fall 2006. This chapter documents the number and extent of Chinook salmon spawning near Ives and Pierce islands of the Columbia River. The main objectives of this study were to find deepwater spawning locations of fall Chinook salmon in the main Columbia River channel and provide estimates of adult spawners in the surveyed area. The primary search area was adjacent to the upper portion of Pierce Island, and the secondary search zone was downstream of this area near the lower portion of Pierce Island.

The total number of fall Chinook salmon redds found in water depths greater than 2 m in the Ives and Pierce island complex during the 2006 spawning season was estimated at 103. This count was the lowest over the past 4 years and continues a downward trend from a record of 336 redds counted in 2003. The count does not include redds observed in shallow water during visual surveys by the Oregon Department of Fish and Wildlife. The redds found during 2006 encompassed an area of 8.16 ha adjacent to the lower part of Ives Island and Pierce Island. Peak spawning activity, based on redd counts and live fish seen near redds, was on or near November 17, 2006. An expanded redd count based on percentage video coverage in the primary and secondary search zones was 946 fall Chinook salmon redds at water depths exceeding approximately 1.5 m (at approximately 125 kcfs), with an estimated spawning population of 3,215. Water depths at redd locations ranged from 0.5 to 5.6 m (median = 2.6 m) in the primary and 3.0 to 6.5 m (median = 4.9 m) in the secondary zone.

A secondary objective was to document the occurrence of any chum salmon (*O. keta*) redds in the deeper sections downstream of Hamilton Creek, near Skamania Island and near the Interstate 205 bridge. Five chum salmon redds were found upstream of the Interstate 205 bridge (three at the upstream site and two at the lower site) but none at the other surveyed sites in 2006. The redds were found near the shoreline in water depths of 1.6 to 4.1 m. Several live fish were observed.

Introduction

Since 1993, fall Chinook salmon (*Oncorhynchus tshawytscha)* have used Ives and Pierce islands downstream of Bonneville Dam for spawning (Hymer 1997). Extensive shallow and deepwater redd surveys have been conducted in this region since 1999. Two stocks of fall Chinook salmon spawn in the area—lower river or Tule, currently listed as threatened (U.S. Fish and Wildlife Service 1999), and upriver bright stock, most of which spawn in the Hanford Reach of the Columbia River (Huntington et al. 1996). The size of this population was estimated at 1,800 to 5,200 fish from 1994 to 1996 (Hymer 1997). The Oregon Department of Fish and Wildlife (ODFW) has been conducting ongoing fall Chinook salmon surveys in the Ives and Pierce Island complex since 1998. That agency's estimates have ranged from a low of 550 in 1998 to 1,882 in 2002 (van der Naald et al. 2004). In 2006, the Pacific States Marine Fisheries Commission estimated an adult fall Chinook salmon population of approximately 10,000 (Wilson 2006). These estimates are based on carcass tagging and recoveries near shallow water and do not take into account fish that spawn nearer the main river channel in water depths exceeding approximately 2 m.

Pacific Northwest National Laboratory (PNNL) has conducted underwater video surveys from 1999 through 2006 downstream of Bonneville Dam (Mueller 2001, 2002, 2003, 2004, 2005). The primary objectives in 2006 were to locate and map deepwater (greater than 1 m) spawning areas of fall Chinook salmon near the main Columbia River channel and to collect additional data on the physical habitat at spawning sites. The secondary objective was to map any chum salmon (*O. keta*) redds located in deeper sections in Hamilton Slough, near Skamania Island and Multnomah Falls, and along the Washington shoreline at two sites upstream of the Interstate 205 (I-205) bridge.

Methods

The survey area for fall Chinook salmon consisted of three different search zones approximately 3.5 km downstream of Bonneville Dam near rkm 228.5. The primary zone (125,000 m^2) along the main channel side of Pierce Island was segmented into 39 regularly spaced transects, 20 m apart and 160 m long, running perpendicular to the shoreline. The secondary zone (94,900 m^2) was at the lower end of Pierce Island and consisted of 30 additional transects, 20 m apart and 130 m long. The third search zone was a smaller area downstream of Moffett Creek and consisted of 7 transects 40 m in length (Figure 1.1).

The chum salmon survey zones comprised regions within Hamilton Slough between Ives and Pierce islands, near the mouth of Woodward Creek, two regions near Skamania Island (six transects each 150 m long spaced 12 m apart, and two similarly sized sites upstream from the I-205 bridge (Figures 1.2 and 1.3). These areas were established based on previous surveys that documented fall Chinook and chum salmon redd occurrences (Mueller and Dauble 2000; Mueller 2001, 2002, 2003, 2004, 2005).

Two separate underwater video surveys were conducted by boat in late November and early December 2006. The surveys were conducted just after November 17, the peak spawning date for fall Chinook salmon (Fish Passage Center 2008). This date was based on timing of ODFW staff visual observations of fall Chinook redds along the shoreline regions.

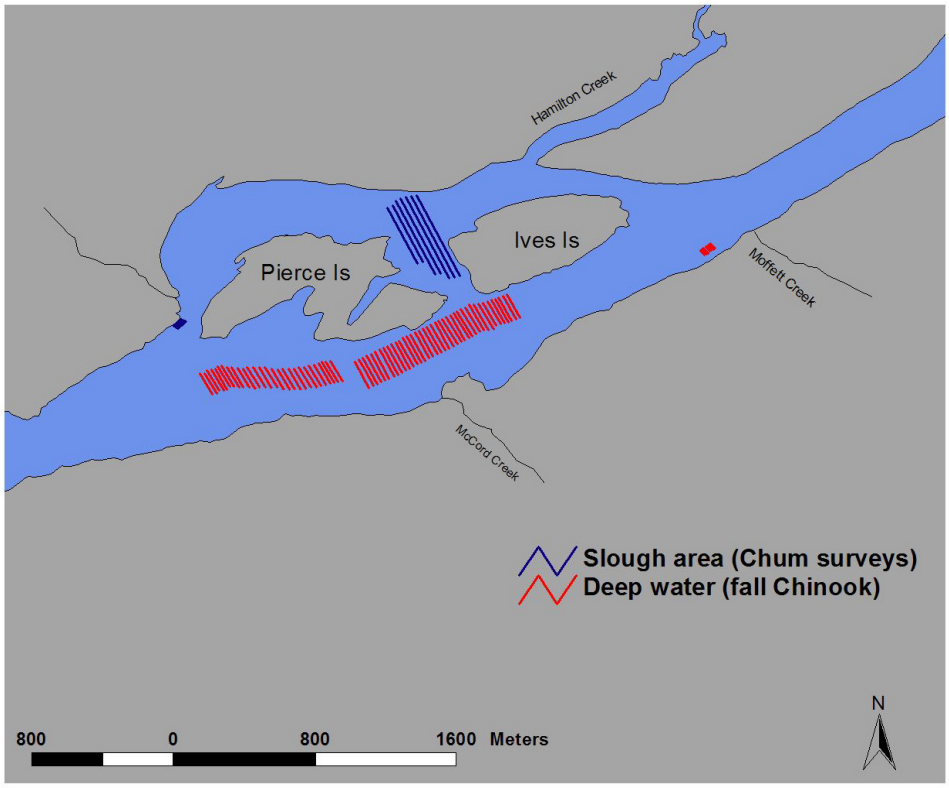


Figure 1.1. Search Zone Locations Relative to Ives and Pierce Islands

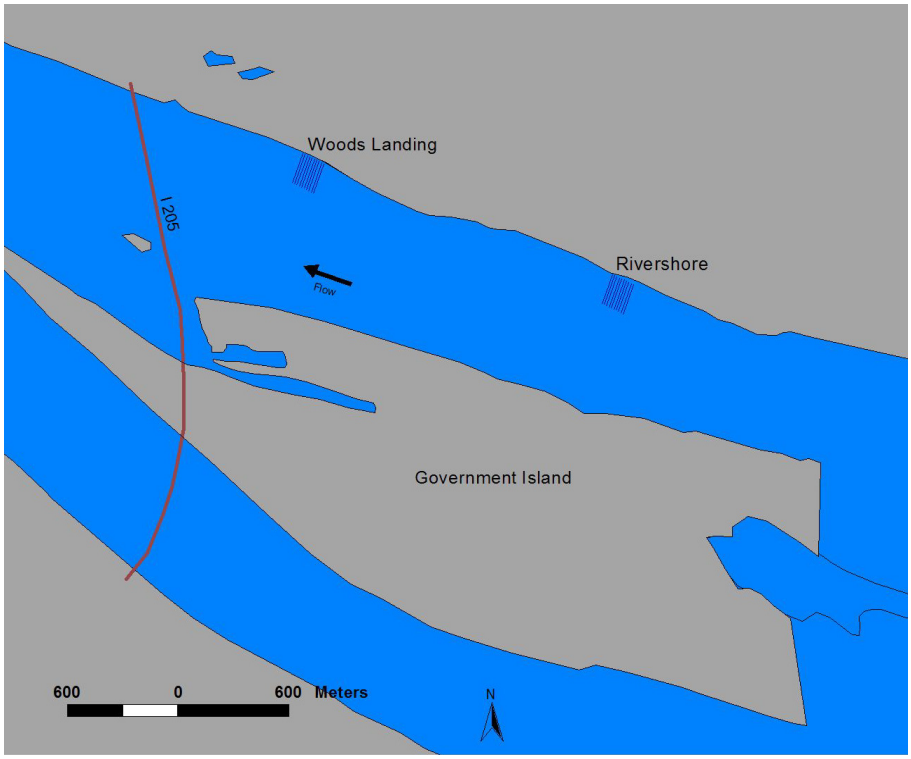


Figure 1.2. Chum Salmon Search Zones Upstream of the Interstate 205 Bridge

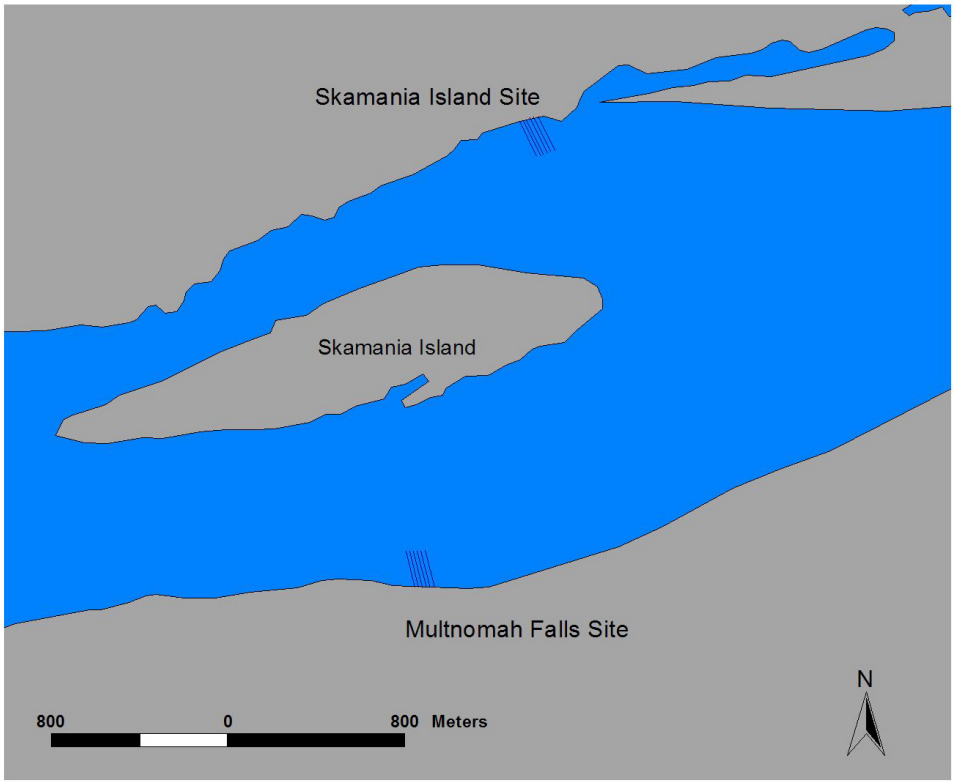


Figure 1.3. Chum Salmon Search Zones near Skamania Island

The boat-deployed video system consisted of a high-sensitivity remote camera (Sartek SDC-MAL) attached to a weighted platform. The camera was positioned at a 40° angle forward from vertical so that redd characteristics (bed elevation) could be detected more easily. Recordings were made using an 8-mm digital recorder (Sony Model GVD 7000) situated on the survey vessel. Two high-resolution monitors provided real-time viewing of the video by operators of the boat and the winch. An integrated video/tow cable attached to a manual winch with slip ring mechanisms was used to raise and lower the sled to the desired depth. The presence of disturbed cobble indicated by changes in background contrast as well as tail-spill piles were the primary criteria used to determine spawning activity.

The coverage area varied throughout the survey period and was influenced by ambient light levels, water clarity, boat speed, and, to a lesser extent, bottom slope and composition. Dual underwater lasers (C-Map Systems Model HL6312G) provided a reference scale within the camera image. The distance from the camera lens to the substratum varied depending on water clarity and water depth; the average effective vertical view path was approximately 0.75 m for the first surveys and 0.9 m for the second surveys.

An on-board, real-time differential global positioning system (DGPS) (Trimble Pathfinder Pro XR) was used to collect positional data and to navigate on preset transect grids during the surveys. The integrated DGPS beacon receiver and antenna provided DGPS corrections to calculate accuracy to below approximately 0.5 m. The system software (Terra Sync) displayed a background map of the study site on a personal computer so that researchers could navigate to site locations on a predetermined transect line and visually verify data accuracy in the field. Both the DGPS and video system were synchronized via a time stamp. When redds were encountered, the time was noted in the logbook; the notation was later

associated with a GPS position. Further analysis and verification of redds were performed at PNNL in Richland, Washington. The location of any new redds also was mapped to an ArcView 9.2 geographic information system (GIS).

To eliminate the possibility of counting a redd more than once during the two survey periods, we omitted any redds that fell within a 1.8-m radius of a nearby redd. This distance was based on an overall redd size of 10 m^2, which is indicative of fall Chinook salmon redds within the Columbia River (Burner 1951; Chapman et al. 1983; Visser 2000). In addition, the cumulative number of redds found during both survey periods was extrapolated to estimate the total number of redds constructed within the primary search zone. These estimates were calculated by taking the total number of redds found during the initial surveys and expanding this number based on the percentage of coverage (assuming normal distribution) within the preferred spawning zone as determined by drawing a boundary around the zone in which redds were found.

Water turbidity was recorded using a LaMotte turbidimeter (Model 2008). Recorded tapes were reviewed in detail at the PNNL computer laboratory using a high-resolution monitor. Bathymetric data were obtained using a one-dimensional, unsteady river flow and water quality computer model, MASS1 (Modular Aquatic Simulation System 1D (Waichler et al. 2005, pp. 3.1–3.3).

Results

Fall Chinook Salmon Spawning Surveys

A total of 103 fall Chinook salmon redds were found and mapped during surveys conducted in November and December 2006. Initial deepwater redd surveys of the main channel near Ives and Pierce islands were completed November 21–22, 2006, shortly after the peak spawning date of November 17 for fall Chinook salmon (Fish Passage Center 2008). A second survey was conducted December 4–6 in the same area. Average discharge recorded at Bonneville Dam was variable, ranging from 114 to 130 kcfs during the two survey periods (Table 1.1).

Table 1.1. Average Discharge and River Elevation Conditions Recorded During the Underwater Video Survey Periods, 2006

Date	Average Discharge at Bonneville Dam (kcfs)	Ives Island Staff Gage 1 (ft)
November 21, 2006	117	1.01
November 22, 2006	114	1.17
December 4, 2006	130	1.01
December 5, 2006	121	1.03
December 6, 2006	124	1.25

During the initial survey period (November 21–23), 49 fall Chinook redds were located and mapped within all surveys zones near Pierce and Ives islands. This total includes 41 within the primary search zone and 8 in the secondary zone (Table 1.2). Water turbidity was poor for the first survey period, with a turbidity reading of approximately 4.5 NTU. The second deepwater fall Chinook salmon redd survey was

completed December 4–6, 2006. Average river discharge at Bonneville Dam during the second survey period ranged from 121 to 130 kcfs. Water clarity improved; turbidity values ranged from 1.8 to 2.7 NTU during the survey period. A total of 54 additional redds were found, including 40 in the primary search zone and 14 in the secondary zone. Additional surveys were conducted near the mouths of Woodward, McCord, Moffett, and Tanner creeks, and no redds were found.

Water depths at redd locations ranged from 0.5 to 5.6 m (median = 2.6 m) in the primary and 3.0 to 6.5 m (median = 4.9 m) in the secondary zone (Figure 1.4).

Table 1.2. Number of Fall Chinook Redds Found in Primary and Secondary Search Zones, 2006

Survey Date	Primary Zone (includes redds found at lower Ives Island)	Secondary Zone	Moffett Creek
November 21–23, 2006	41	8	0
December 4–6, 2006	40	14	0
Totals	81	22	0

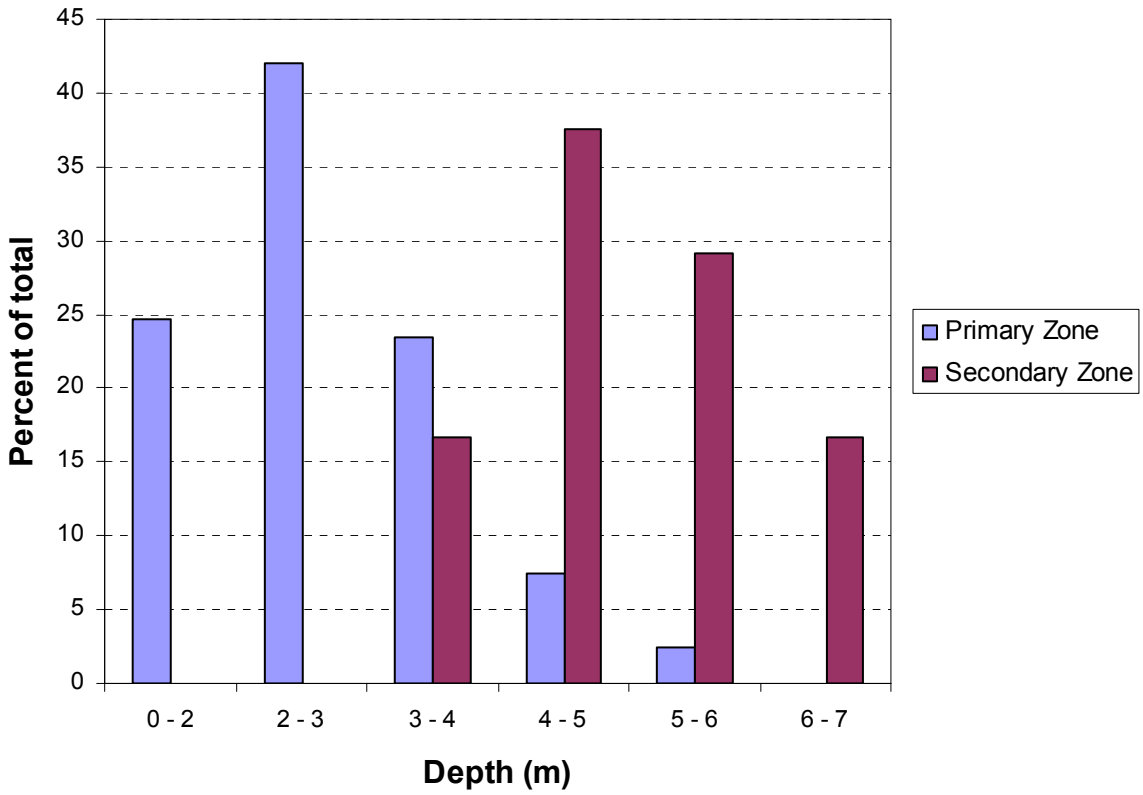


Figure 1.4. Percentage of Fall Chinook Salmon Redds Relative to Water Depth in the Primary and Secondary Search Zones

The location of all salmon redds (fall Chinook; n = 103) found during the 2006 surveys near Pierce and Ives islands is shown in Figure 1.5. The MASS1-modeled river depth was superimposed on the river layer to illustrate the redds in relation to water depth at a river flow of 125 kcfs measured at Bonneville Dam.

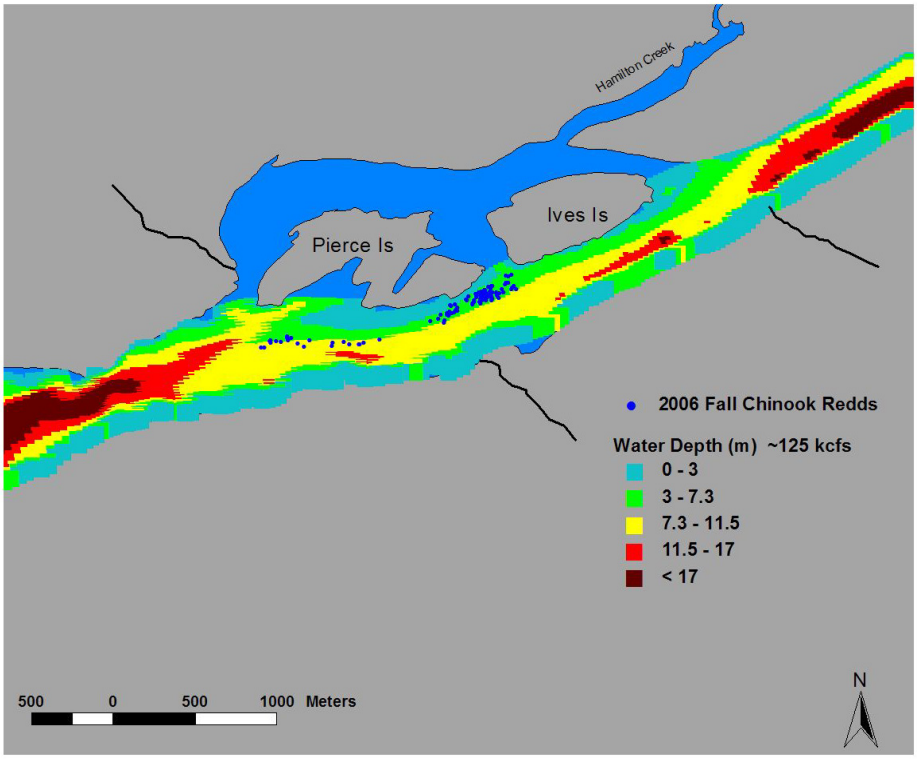


Figure 1.5. Location of Fall Chinook Salmon Redds (*n* = 103) in the Mainstem of the Columbia River Downstream from Bonneville Dam in 2006

The total area utilized for spawning by fall Chinook salmon in 2006 near Pierce and Ives islands was estimated at 8.16 ha consisting of 4.86 ha in the primary zone and 3.3 ha in the secondary zone. These area estimates were made by drawing a convex polygon around all redd locations in both zones and then calculating the overall size of the composite zone (Figure 1.6). Additional maps showing how the spawning area has changed over the 6-year period from 1999 through 2006 are shown in the Appendix to this chapter.

During the past 7 years of deepwater redd surveys by PNNL, a total population of spawning fish was estimated by extrapolating the redd count based on the portion of the area surveyed by video camera. The average vertical coverage along each transect line was estimated to be approximately 0.88 m, based on video coverage using the calibrated lasers as a reference during the December 4–6 survey in which 54 redds were found. The coverage area within the preferred spawning zones (Figure 1.6) was estimated to be 5.7% for the primary and 5.8% for the secondary zone. Using the percentage and the actual number of redds found, we estimated 946 redds were present in both survey zones, assuming equal distribution. To estimate the total spawning population within the spawning zones, we used a multiplier of 3.4 adult fish for each redd (Visser 2000). The resulting estimate was the presence of approximately 3,215 adult fish during the peak spawning period in early December 2006 (Table 1.3).

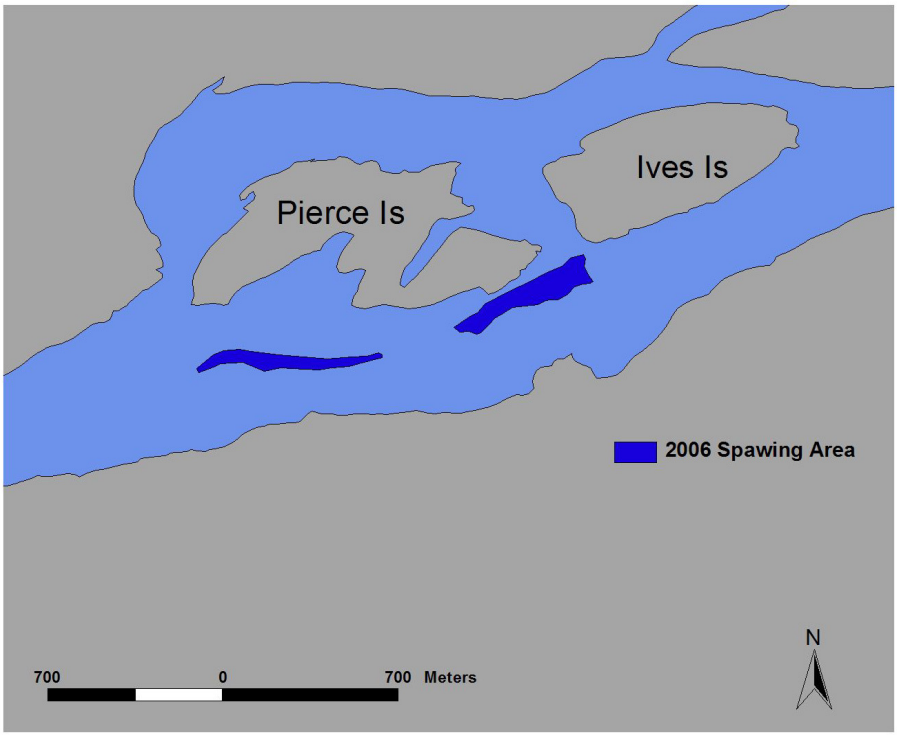


Figure 1.6. Fall Chinook Salmon Spawning Area for Redds Found During 2006

Table 1.3. Estimated Number of Fall Chinook Salmon Redds Occurring in the Primary and Secondary Search Zones near Ives and Pierce Islands, December 4–6, 2006, Following the Peak Spawning Period

Location	Total Area Surveyed (m^2)[(a)]	Video Coverage (%)	Number of Redds Found	Extrapolated Redd Estimate	Adult Population Estimate
Primary	2,764	5.7	40	703	2,391
Secondary	1,906	5.8	14	242	824
Total	4,670		54	945	3,215

(a) Coverage area was based on buffering transect lines in the GIS based on the camera field of view for each survey and then totaling the area covered for each survey.

In addition to the PNNL deepwater surveys conducted during 2006, shallow-water boat surveys were conducted by ODFW personnel. The ODFW recorded a peak number of 340 fall Chinook salmon redds observed on November 17, 2006, in water depths of 2 m or less (Fish Passage Center 2008). These redds were found at the upper part of Pierce Island and in the shallow channel between Ives and Pierce islands and near the mouth of Hamilton Creek. An estimate of the overall population, which incorporates the redds found by the ODFW during shallow-water surveys with those of the PNNL deepwater redd counts, is provided in Table 1.4.

Table 1.4. Adult Fall Chinook Salmon Population Estimates Based on Shallow and Deepwater Redd Surveys

Year	ODFW	PNNL	PNNL Extrapolated	Total	Adult Population Estimate[(a)]
2000	200	76	787	987	3,356
2001	48	43	717	765	2,601
2002	214	192	1,768	1,982	6,739
2003	190	336	3,218	3,408	11,587
2004	337	293	3,137	3,474	11,812
2005	319	190	1,705	2,024	6,882
2006	340	103	945	1,285	2,230

(a) Expansion factor or 3.4 fish/redd.

Chum Salmon Spawning Surveys

Chum salmon surveys were conducted on November 22 at the Skamania Island and Multnomah Falls sites, but no redds of either fall Chinook or chum salmon were found. On December 4, two sites near the Interstate 205 bridge were surveyed. A total of five redds were found, two at the Wood's Landing site and three at the Rivershore site (Figures 1.7 and 1.8). Water depths for redds found at these two I-205 bridge sites ranged from 1.6 to 4.1 m. Several live chum salmon and a few carcasses also were observed near the redd sites. A survey within Hamilton Slough was conducted on December 6, and one additional redd was found in 1.2-m deep water.

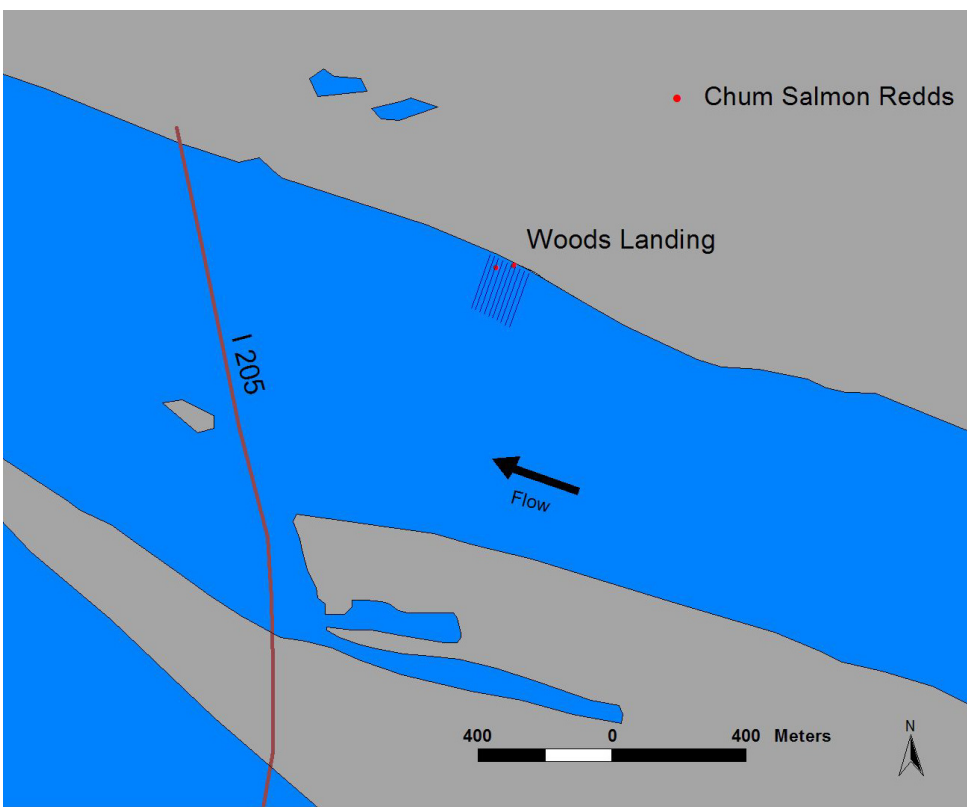


Figure 1.7. Location of Chum Redds Found at the Wood's Landing Site During Boat-Based Surveys

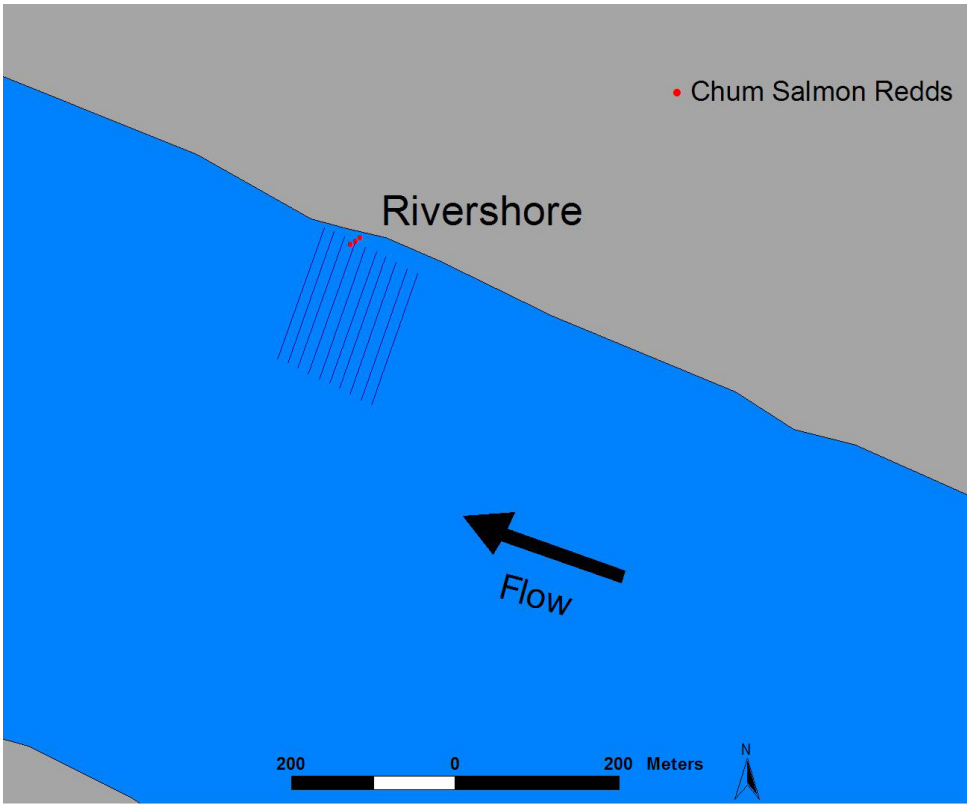


Figure 1.8. Location of Chum Redds Found at the Rivershore Site During Boat-Based Surveys

Discussion

A total of 103 fall Chinook deepwater salmon redds were found near the vicinity of Ives and Pierce islands downstream of Bonneville Dam in 2006. This number is a continuation of a decreasing trend from a record count of 336 redds observed in 2003. In 2005, the estimated deepwater redd count was 190 (Arntzen et al. 2006). The adult fall Chinook salmon count at Bonneville Dam in 2006 was approximately 300,000 fish, which also is a decrease of nearly 118,000 from the 2005 count. Redd counts for fall Chinook spawning in the Hanford Reach also were lower in 2006 than in 2005; an estimated 1,300 fewer redds were counted from aerial surveys by PNNL (Mueller 2007). The proportion of fish using the upper and lower spawning areas adjacent to Pierce Island was decreased at a similar rate from 2005 to 2006 (Figure 1.9).

The approximate size of the overall spawning area in 2006 was 8.16 ha, which was smaller than that of the previous 3 years. The size of the primary search zone of 4.8 ha is very similar to that found in 1999, where the spawning zone was estimated at 4.0 ha and similar numbers of fall Chinook salmon were counted at Bonneville Dam (Table 1.5). The extrapolated number of redds found in 2006 was 945, which was slightly greater than the 787 redds found in 2000.

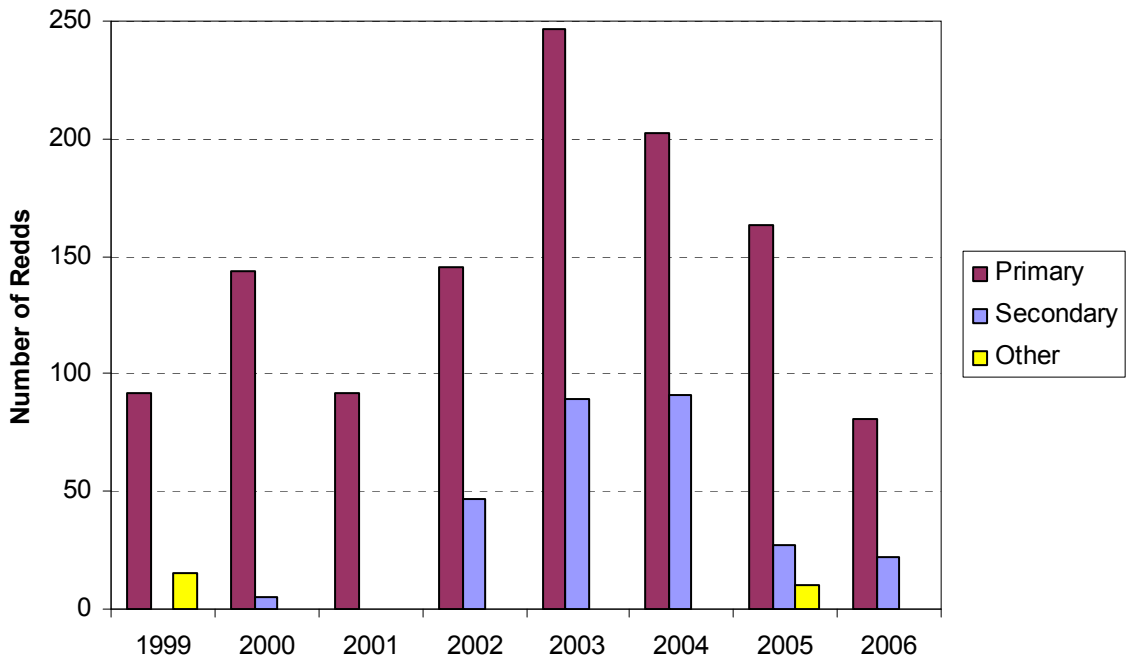


Figure 1.9. Proportion of Fall Chinook Salmon Redds Found in the Primary and Secondary Spawning Zones Adjacent to Pierce Island

Table 1.5. Fall Chinook Redd Counts and Approximate Spawning Areas Near Ives and Pierce Islands, 1999–2006

Year	Redds (*n*)	Approximate Spawning Area (ha), Primary Zone	Approximate Spawning Area (ha), Secondary Zone
1999	64	4.0	0
2000	76	5.3	1.0
2001	43	4.9	0
2002	192	6.4	2.9
2003	336	8.1	5.6
2004	293	9.7	4.9
2005	190	6.8	3.2
2006	103	4.8	3.3

River flow conditions were generally stable during the spawning period (November 15 through 30), with daily flows averaging 135 kcfs at Bonneville Dam and a tailrace elevation of 13.7 ft. Redds were found at water depths up to 5.6 m in the primary and 6.5 m in the secondary zones in 2006. This is less than the maximum of 7.9 m at which redds were found in 2005. Less-than-optimal water clarity reduced the ability to detect redds at depths greater than about 5.6 m.

References

Endangered Species Act of 1973. 16 U.S.C. 1531-1544, Public Law 93–205, Approved December 28, 1973, 87 Stat. 884, as amended through Public Law 107-136, January 24, 2002.

Arntzen E, R Mueller, C Murray, Y-J Bott, J Panther, D Geist, and T Hanrahan. *Evaluation of Salmon Spawning Below Bonneville Dam – 2000–2006 Annual Report*. DOE/BP-00000652-35, Bonneville Power Administration, Portland, Oregon.

Burner CJ. 1951. "Characteristics of Spawning Nests of Columbia River Salmon." *Fishery Bulletin* 61, Volume 52, U.S. Fish and Wildlife Service, Washington, D.C.

Chapman DW, DE Weitkamp, TL Welsh, and TH Schaldt. 1983. *Effects of Minimum Flow Regimes on Fall Chinook Salmon Spawning at Vernita Bar 1978–1982.* Don Chapman Consultants, McCall, Idaho, and Parametrix, Inc., Bellevue, Washington.

Fish Passage Center. 2008. "Spawning Data Homepage." Available at http://www.fpc.org/spawning_home.html (July 2008).

Huntington C, W Nehlsen, and J Bowers. 1996. "A Survey of Healthy Native Stocks of Anadromous Salmonids in the Pacific Northwest and California." *Fisheries* 21:6–14.

Hymer J. 1997. *Results of Studies on Chinook Spawning in the Mainstem Columbia River Below Bonneville Dam*. Columbia River Progress Report 97-9, Washington Department of Fish and Wildlife, Battle Ground, Washington.

Mueller RP. 2001. *Deepwater Spawning of Fall Chinook Salmon (Oncorhynchus tshawytscha) Near Ives and Pierce Island of the Columbia River – Annual Report 2000*. DOE/BP-00000652-6, Bonneville Power Administration, Portland, Oregon. Available at http://www.efw.bpa.gov/publications/I00000652-6.pdf (July 2008).

Mueller RP. 2002. *Deepwater Spawning of Fall Chinook Salmon (Oncorhynchus tshawytscha) Near Ives and Pierce Island of the Columbia River – Annual Report 2001*. DOE/BP-00000652-10, Bonneville Power Administration, Portland, Oregon. Available at http://www.efw.bpa.gov/publications//I00000652-10.pdf (July 2008).

Mueller RP. 2003. *Deepwater Spawning of Fall Chinook Salmon (Oncorhynchus tshawytscha) Near Ives and Pierce Island of the Columbia River – Annual Report 2002-2003*. DOE/BP-00000652-13, Bonneville Power Administration, Portland, Oregon. Available at http://www.efw.bpa.gov/publications/I00000652-13.pdf (July 2008).

Mueller RP. 2004. *Deepwater Spawning of Fall Chinook Salmon (Oncorhynchus tshawytscha) Near Ives and Pierce Island of the Columbia River – Annual Report 2003-2004*. DOE/BP-00000652-19, Bonneville Power Administration, Portland, Oregon. Available at http://www.efw.bpa.gov/Publications/I00000652-19.pdf (July 2008).

Mueller RP. 2005. *Deepwater Spawning of Fall Chinook Salmon (Oncorhynchus tshawytscha) Near Ives and Pierce Island of the Columbia River – Annual Report 2004-2005*. DOE/BP-00000652-28, Bonneville Power Administration, Portland, Oregon. Available at http://www.efw.bpa.gov/publications/I00000652-28.pdf (July 2008).

Mueller RP. 2007. "Chinook Salmon." In *Hanford Site Environmental Report for Calendar Year 2006*, TM Poston, RW Hanf, JP Duncan, and RL Dirkes (eds), Chapter 10 ("Environmental and Resource Protection Programs"), Section 10.11.1.1, pp. 10.112–10.113. PNNL-16623, Pacific Northwest National Laboratory, Richland, Washington.

Mueller RP and DD Dauble. 2000. *Evidence of Deepwater Spawning of Fall Chinook Salmon (Oncorhynchus tshawytscha) Spawning Near Ives and Pierce Islands of the Columbia River – Annual Report 1999*. DOE/BP-00000652-2, Bonneville Power Administration, Portland, Oregon. Available at http://www.efw.bpa.gov/Publications/I00000652-2.pdf (July 2008).

U.S. Fish and Wildlife Service. 1999. "Endangered and Threatened Wildlife and Plants; Listing of Nine Evolutionarily Significant Units of Chinook Salmon, Chum Salmon, Sockeye Salmon, and Steelhead." *Federal Register* 64:41835–41839.

van der Naald W, C Duff, T Friesen, R Brooks, and L Tomaro. 2005. *Evaluation of Fall Chinook and Chum Salmon Spawning Below Bonneville Dam – Annual Report 2004-2005*. DOE/BP-00004028-5, Bonneville Power Administration, Portland, Oregon. Available at http://www.efw.bpa.gov/Publications/I00004028-5.pdf (July 2008).

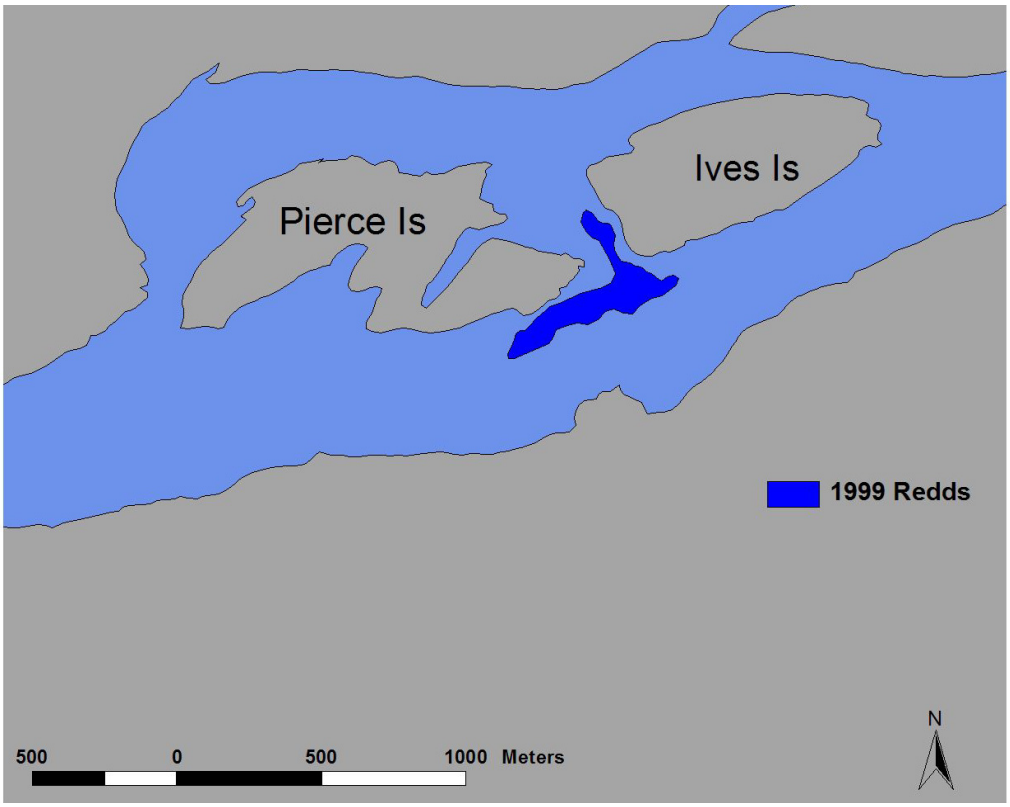
Visser RH. 2000. *Utilizing Remotely Sensed Imagery and GIS to Monitor and Research Salmon Spawning: A Case Study of the Hanford Reach Fall Chinook (Oncorhynchus tshawytscha)*. PNNL-13177, Pacific Northwest National Laboratory, Richland, Washington.

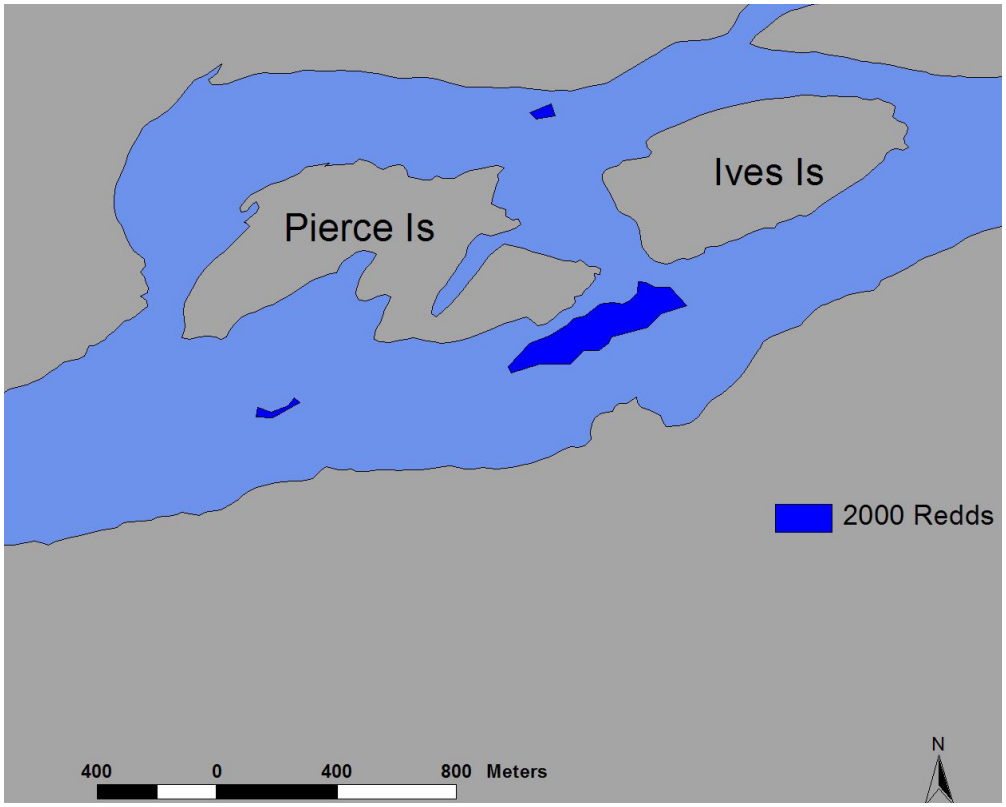
Waichler SR, WA Perkins, and MC Richmond. 2005. *Hydrodynamic Simulation of the Columbia River, Hanford Reach, 1940–2004*. PNNL-15226, Pacific Northwest National Laboratory, Richland, Washington. Available at http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15226.pdf (July 2008).

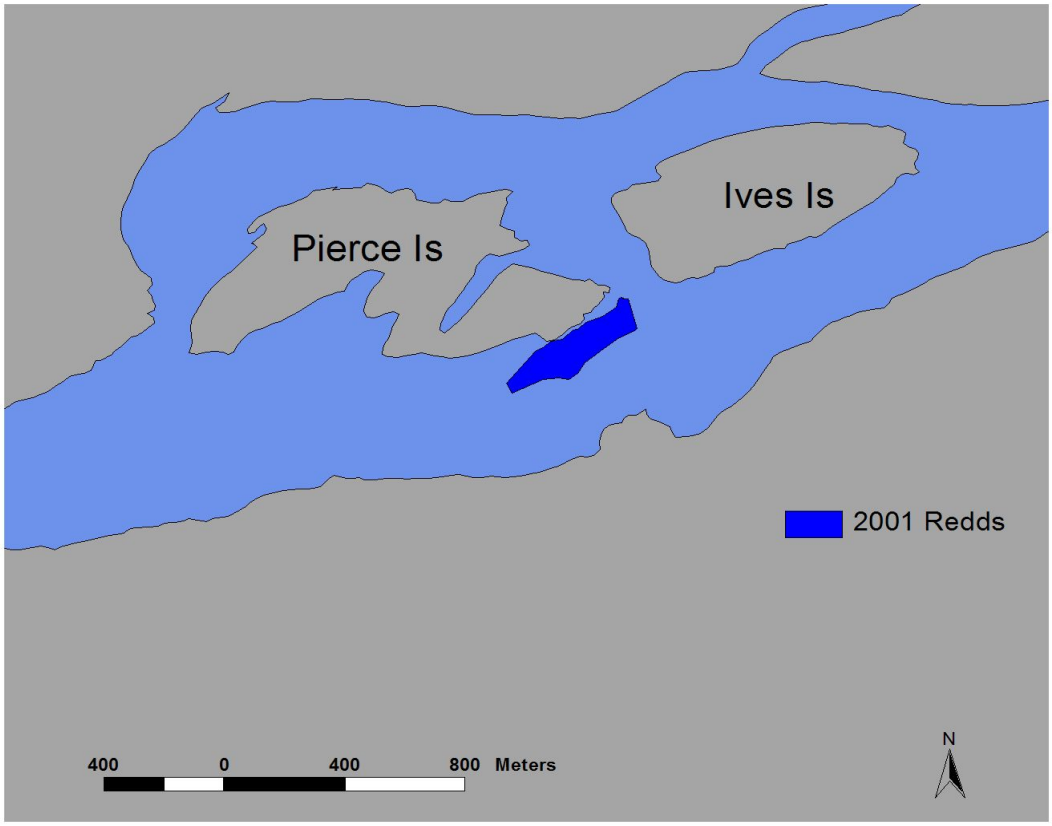
Wilson J. 2006. *Evaluation of Chum, Chinook, and Coho Salmon Entrapment near Ives Island in the Columbia River – 2005 – 2006 Annual Report*. DOE/BP-00004287-5, Bonneville Power Administration, Portland, Oregon.

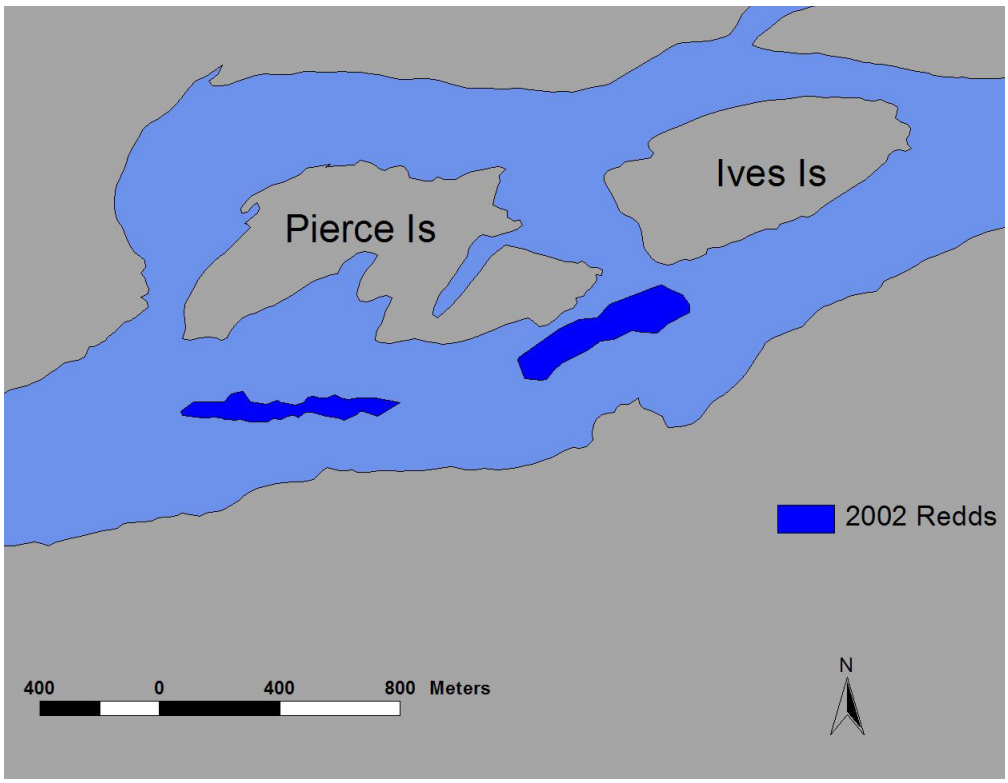
Appendix

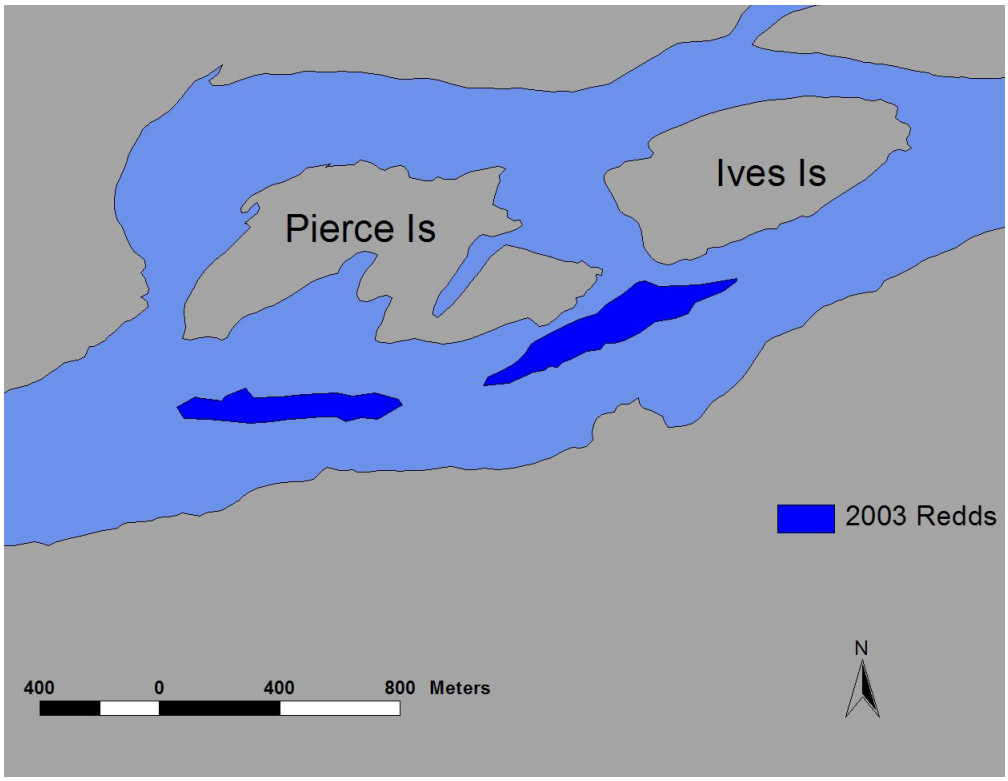
Maps Illustrating Fall Chinook Salmon Redd Spawning Areas, 1999 Through 2005

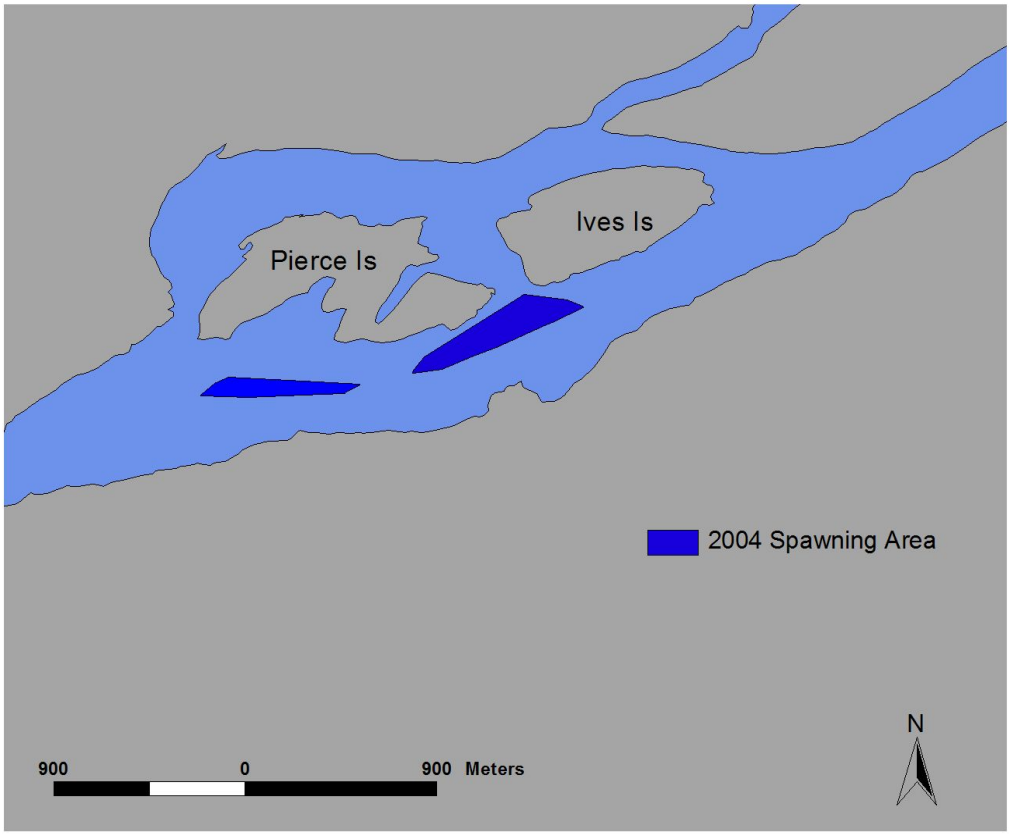

Ives Is
Pierce Is
1999 Redds
500
0
500
1000 Meters
N

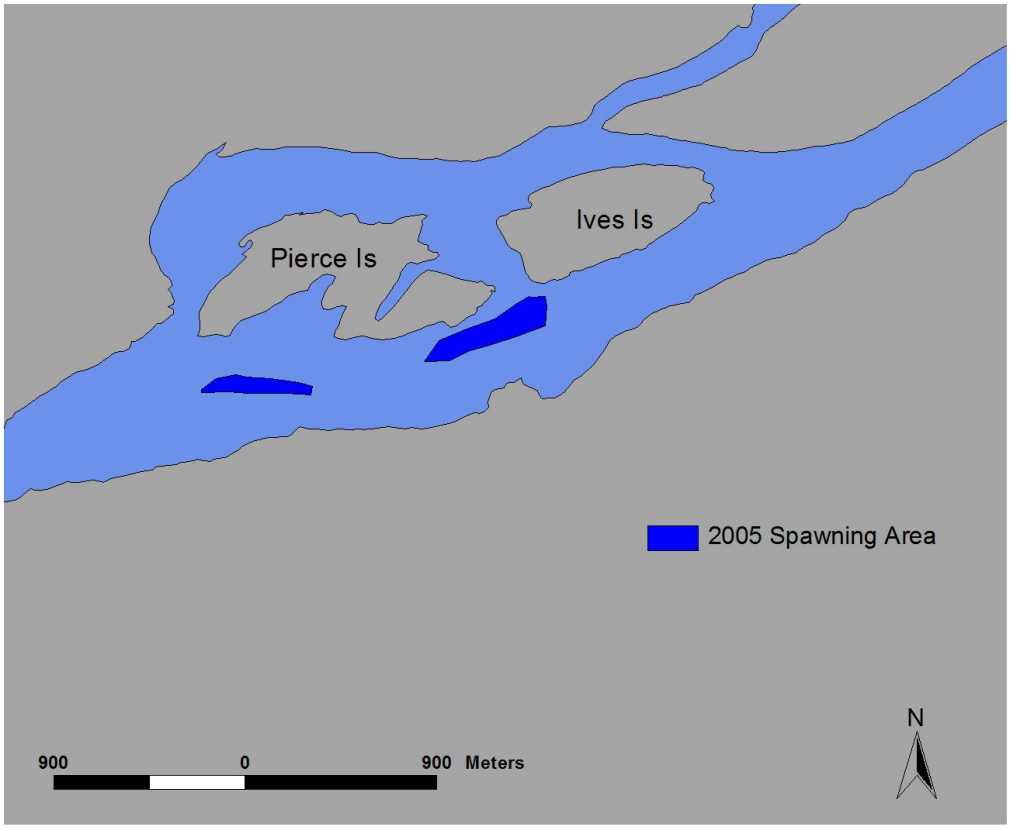

Ives Is
Pierce Is
2000 Redds
400
0
400
800 Meters
N


Ives Is
Pierce Is
2001 Redds
400
0
400
800 Meters
N


Ives Is
Pierce Is
2002 Redds
400
0
400
800 Meters
N


Ives Is
Pierce Is
2003 Redds
400
0
400
800 Meters
N


Ives Is
Pierce Is
2004 Spawning Area
900
0
900 Meters
N


Ives Is
Pierce Is
2005 Spawning Area
N
900
0
900 Meters

Chapter 2

Temperature Data Collected To Improve Emergence Timing Estimates and Refine Habitat Availability Estimates for Chum and Fall Chinook Salmon Downstream of Bonneville Dam

Evan V. Arntzen, Katherine J. Murray, and Yi-Ju Bott

Summary

From 1999 through 2006, Pacific Northwest National Laboratory (PNNL) collected temperature data from within chum salmon (*Oncorhynchus keta*) and fall Chinook salmon (*O. tshawytscha*) spawning gravels and the overlying river at locations in the Ives Island area approximately 4 km downstream from Bonneville Dam. During fiscal year 2007, PNNL collected temperature and water surface elevation data from the Ives Island area as well as additional temperature data from chum salmon spawning locations near Multnomah Falls and the Interstate 205 (I-205) bridge east of Portland, Oregon. Locations included areas where riverbed temperatures were elevated, potentially influencing alevin development and emergence timing. In these locations, operation of the hydrosystem caused large, frequent changes in river discharge that affected salmon habitat by dewatering redds and altering egg pocket temperatures. The study objectives in fiscal year 2007 were 1) to provide real-time data on Ives Island area water temperature and water surface elevation data from the onset of spawning (October) to the end of emergence (June); 2) to map the riverbed temperature distribution within chum salmon spawning locations at Ives Island, Multnomah Falls, and the I-205 bridge; and 3) to determine how fluctuations in water surface elevations within the Ives Island area affect riverbed temperatures at various riverbed elevations there.

Objective 1 was accomplished using temperature and water-level sensors deployed inside piezometers. At the Multnomah Falls and I-205 chum salmon spawning locations and at Ives Island area fall Chinook salmon spawning locations, sensors were retrieved several times during the study, downloaded, and redeployed. Within the Ives Island chum salmon spawning areas, sensors were integrated with a radio telemetry system such that real-time data could be downloaded remotely and posted hourly on the Internet. Objective 2 was accomplished by measuring the temperature at egg pocket depth using thermistor probes deployed in a dense pattern along regularly spaced intervals within chum salmon spawning areas. Samples were collected for each position occupied, enabling development of riverbed temperature distribution maps. For Objective 3, temperature recorders were buried at egg pocket depths distributed over a range of riverbed elevations. The recorders logged temperature changes during surface water fluctuations throughout the spawning season.

Bed temperatures in chum salmon spawning locations were relatively warm, averaging 11.4°C in Ives Island areas, 10.3°C in I-205 locations and 9.6°C in the Multnomah Falls area, compared to 9.2°C in Ives Island fall Chinook salmon spawning locations. Temperature mapping results showed that bed temperatures were warmer than river temperatures at all chum salmon sites mapped, including Ives Island, Rivershore, and Woods Landing. At each location, bed temperatures were warmer in chum salmon spawning areas than adjacent areas of the riverbed. Temperature recorders deployed over a range

of river elevations in the Ives Island area confirmed earlier time-series temperature monitoring results and showed higher bed temperatures within chum salmon spawning areas than in fall Chinook salmon spawning areas. Riverbed temperatures in chum salmon spawning locations were influenced by fluctuations in river stage, decreasing during periods of elevated river stage. In fall Chinook salmon spawning locations, bed temperatures resembled river temperatures.

Introduction

Although historically abundant, Columbia River run sizes of chum salmon (*Oncorhynchus keta*) and fall Chinook salmon (*O. tshawytscha*) had decreased dramatically by the 1950s as a result of habitat degradation, water diversion, overharvest, and artificial propagation (National Marine Fisheries Service 1998). Populations of both species spawning downstream from Bonneville Dam are currently listed as threatened under the *Endangered Species Act of 1973* (U.S. Fish and Wildlife Service 1999). Spawning surveys conducted at Ives Island since 1998 indicated that chum salmon and fall Chinook salmon spawn in spatially distinct clusters (U.S. Fish and Wildlife Service and Oregon Department of Fish and Wildlife, unpublished data). This clustering suggests that these species may select specific, and different, spawning habitat features within the study area (Geist and Dauble 1998). Understanding the spatial distribution of subsurface temperature variation is critical to accurate emergence timing estimation and establishment of meaningful minimum flows for the protection of spawning habitat in this area.

From 1999 through 2007, the Bonneville Power Administration (BPA) funded BPA Project No. 1999-00301 to quantify fall Chinook salmon and chum salmon spawning downstream from Bonneville Dam and the three dams upstream, the timing of spawning, emergence and rearing, characteristics of their spawning habitat, and flows necessary to ensure their long-term survival. The primary site of this study is near Ives Island, an off-channel spawning area approximately 4 km downstream from Bonneville Dam.

During 1999, Pacific Northwest National Laboratory (PNNL) researchers identified areas where relatively warm subsurface water upwelled through chum salmon spawning gravels in the Ives Island spawning complex (Geist et al. 2002). Since 1999, PNNL has monitored river and bed temperatures in the Ives Island channel to assist the Oregon Department of Fish and Wildlife (ODFW) with emergence timing predictions for fall Chinook salmon and chum salmon and to assess the impacts of hydrosystem operation on groundwater–surface water interaction in fall Chinook salmon and chum salmon spawning locations (Geist et al. 2008). During 2004, the U.S. Fish and Wildlife Service (USFWS) and ODFW confirmed the presence of three additional chum salmon spawning locations. One is near Multnomah Falls, on the south bank of the Columbia River. The second, Woods Landing, is on the north bank of the Columbia approximately 1 km east of the Interstate 205 (I-205) bridge near Vancouver, Washington. The third, known as Rivershore, is on the north bank approximately 3 km east of the I-205 bridge. We included those additional sites during our 2005–2007 evaluations.

During FY 2007, the PNNL project objectives were 1) to provide real-time data on Ives Island area water temperature and water surface elevation from the onset of spawning (October) to the end of emergence (June); 2) to map the riverbed temperature distribution within chum salmon spawning locations at Ives Island, Multnomah Falls, and the I-205 locations; and 3) to determine how fluctuating water surface elevations in the Ives Island area affect riverbed temperatures at various riverbed elevations there. The PNNL objectives support the activities of several other collaborating agencies. Riverbed

temperature data are provided to the Fish Passage Center and used by the ODFW to assist with emergence timing estimates. Water surface elevation data are used by the USFWS to evaluate redd dewatering. One incentive for riverbed temperature mapping is to improve habitat availability estimates by incorporating hyporheic variables. Information about hyporheic temperature fluctuation during changes in dam operation is useful to the USGS in evaluating salmon spawning behavior during river discharge fluctuations (Tiffan et al. 2002) and to hydrosystem operators evaluating the effects of operation on spawning habitat.

This chapter summarizes the methods used and temperature and water surface elevation data obtained by PNNL during the 2006–2007 study year in order to accomplish all three objectives. A digital appendix containing all temperature and water surface elevation data collected is included. We describe differences in temperature between the river and the hyporheic zone and between chum salmon and fall Chinook salmon spawning areas. However, we do not attempt to analyze the relationships between hydrosystem operation and hyporheic zone characteristics (e.g., temperature and water flux). An analysis of the effect of hydrosystem operation on hyporheic zone characteristics was prepared separately and published in the *North American Journal of Fisheries Management* (Geist et al. 2008).

Study Site

Data were collected from spawning areas adjacent to the Pierce National Wildlife Refuge in the north Ives Island channel (rkm 230), near the Oregon shore of the Columbia River adjacent to Multnomah Falls (rkm 220), and east of the I-205 bridge on the Washington shore (rkm 185) (Figure 2.1). The location coordinates of all sensors used to collect data presented in this chapter are included in Appendix A.

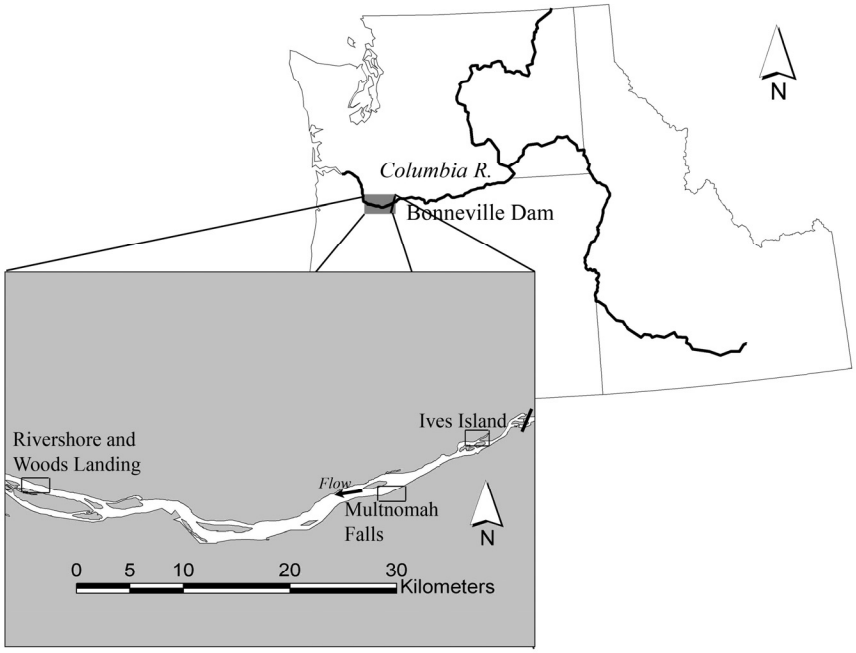


Figure 2.1. Ives Island, Multnomah Falls, and Interstate 205 Rivershore and Woods Landing Spawning Areas

Methods

Temperature and Water Surface Elevation Monitoring

We used eight monitoring locations in the Ives Island area, which were classified as either chum salmon or fall Chinook salmon spawning areas (Figure 2.2). Monitoring locations T1LB, T2LB, T2MC, T2RB, T4LB, T4MC, T4RB, and T5MC were previously occupied as described in Arntzen et al. (2006). At locations T1LB, T2LB, and T2MC, we continued to maintain the real-time temperature and water level data collection system installed during 2003 (Arntzen et al. 2006). The real-time data collection system employed Model PT2X pressure and temperature sensors (Instrumentation Northwest, Inc., Kirkland, Washington). PT2X sensors record temperature with a resolution of 0.1°C; water level is recorded with an accuracy of ±0.6 cm. During the 2006–2007 study season, locations T2RB, T4LB, T4MC, T4RB, and T5MC were instrumented with data loggers to monitor river and riverbed temperatures. We recorded temperatures at these locations using either Solinst Model 3001 LT leveloggers (Solinst Canada Ltd., Georgetown, Ontario, Canada; temperature accuracy ±0.1ºC), Onset Optic Stowaway loggers (Onset Computer Corp., Pocasset, Massachusetts; temperature accuracy ±0.2ºC), or PT2X sensors (Instrumentation Northwest, Inc., Kirkland, Washington; temperature accuracy ±0.1ºC).

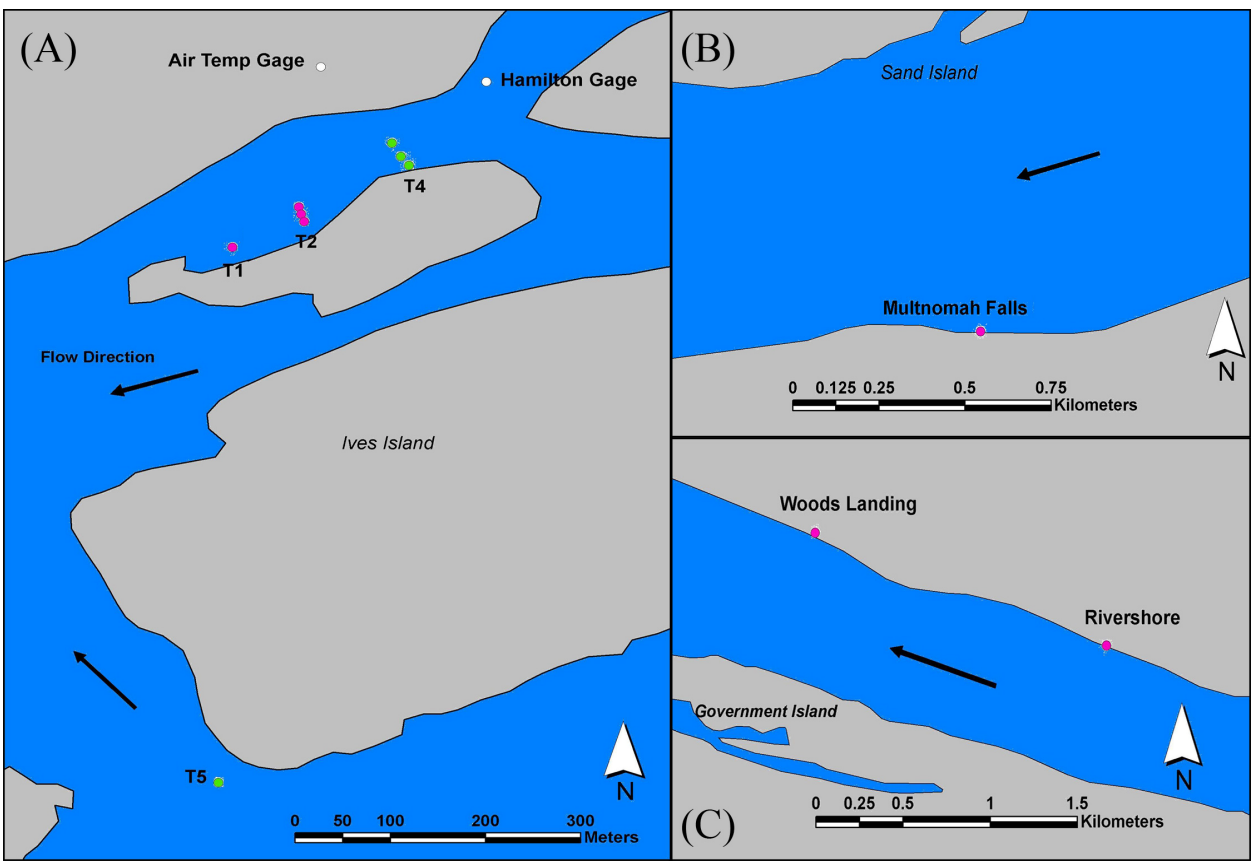


Figure 2.2. Piezometer Locations in Chum Salmon Spawning Areas (red circles) and Fall Chinook Salmon Spawning Locations (green circles) at A) Ives Island, B) Multnomah Falls, and C) Woods Landing and Rivershore Sites

Water temperature was recorded similarly at the mouth of Hamilton Creek and at the Multnomah Falls, Rivershore, and Woods Landing locations (Figure 2.2). At the latter sites, water level was recorded and reported as water depth above the riverbed at each location. The hyporheic piezometers were screened at egg pocket depth within the riverbed, and the river piezometers were screened above the riverbed. The locations and depths below the riverbed of all monitoring locations are included in Appendix A. Temperature data availability are summarized in Appendix B. All time-series data collected are included in Appendix C.

Two-Dimensional Riverbed Temperature Mapping

During the 2006-2007 study year, our objective was to map water temperatures of the river and riverbed within the Ives Island complex as well as at Multnomah Falls and the I-205 areas. Our goal was to evaluate differences between spawning and adjacent unused habitat at each location. High water levels prevented temperature mapping in the Multnomah Falls area and allowed for only partial mapping within the Ives Island area during FY 2007. We collected data at Ives Island on December 1, 2006. Sites near the I-205 bridge were mapped on January 3, 2007. Our methodology was similar to previous work done to map river and riverbed temperatures in the Ives Island area (Geist et al. 2002). Forty-seven transects were sampled at Ives Island, 17 transects at Rivershore, and 15 transects at Woods Landing for a total of 259 individual sampling locations (Figure 2.3). Transects were spaced 10 to 20 m apart throughout the study site. At each sampling location, a post-pounder was used to drive a customized temperature probe 10 cm into the riverbed. Each probe consisted of a length (125 or 155 cm) of GeoProbe drive rod (2.5 cm outside diameter, 1.8 cm inside diameter) that had a threaded drive point attached to the bottom and a slotted drive cap attached to the top. The bottom 20 cm of the rod were perforated with approximately 30 holes (3 mm diameter), which allowed water to enter the rod and contact a thermistor (Omega). The thermistor was soldered to copper extension wire encased within polyethylene tubing (0.5 cm inside diameter). The slotted drive cap allowed the extension wire to exit the rod and attach to the temperature indicator (Omega Model 866). Both the thermistor and temperature indicator have a stated accuracy of 0.1°C. Once the thermistor equilibrated (2–4 min), the water temperature of the riverbed was recorded. The rod was then extracted from the riverbed and a measurement of river temperature taken. Finally, a real-time corrected Trimble ProXR GPS was used to acquire the Universal Transverse Mercator (UTM) coordinates of each measurement point.

Ordinary kriging (Isaaks and Srivastava 1989) was used to interpolate the temperature data (river and 10 cm below the surface of the bed) onto regular grids as described in Arntzen et al. (2007). Within the Ives Island area, data located on opposite sides of Ives Bar were kriged as two separate areas, one termed Ives northwest, the other Ives southeast. Temperature mapping data and their statistical summaries from the Ives Island and I-205 sites are included in Appendix D.

Effect of Changing Discharge on Hyporheic Temperature at Various Riverbed Elevations

Additional temperature data were collected with a network of 38 Onset data loggers (HOBO Water Temp Pro) deployed from October 31, 2006, through September 28, 2007, in chum salmon and fall Chinook salmon spawning areas within the Ives Island complex. Our goal was to collect data that could be used later to evaluate whether spawning behavior is influenced by hyporheic temperature cues during

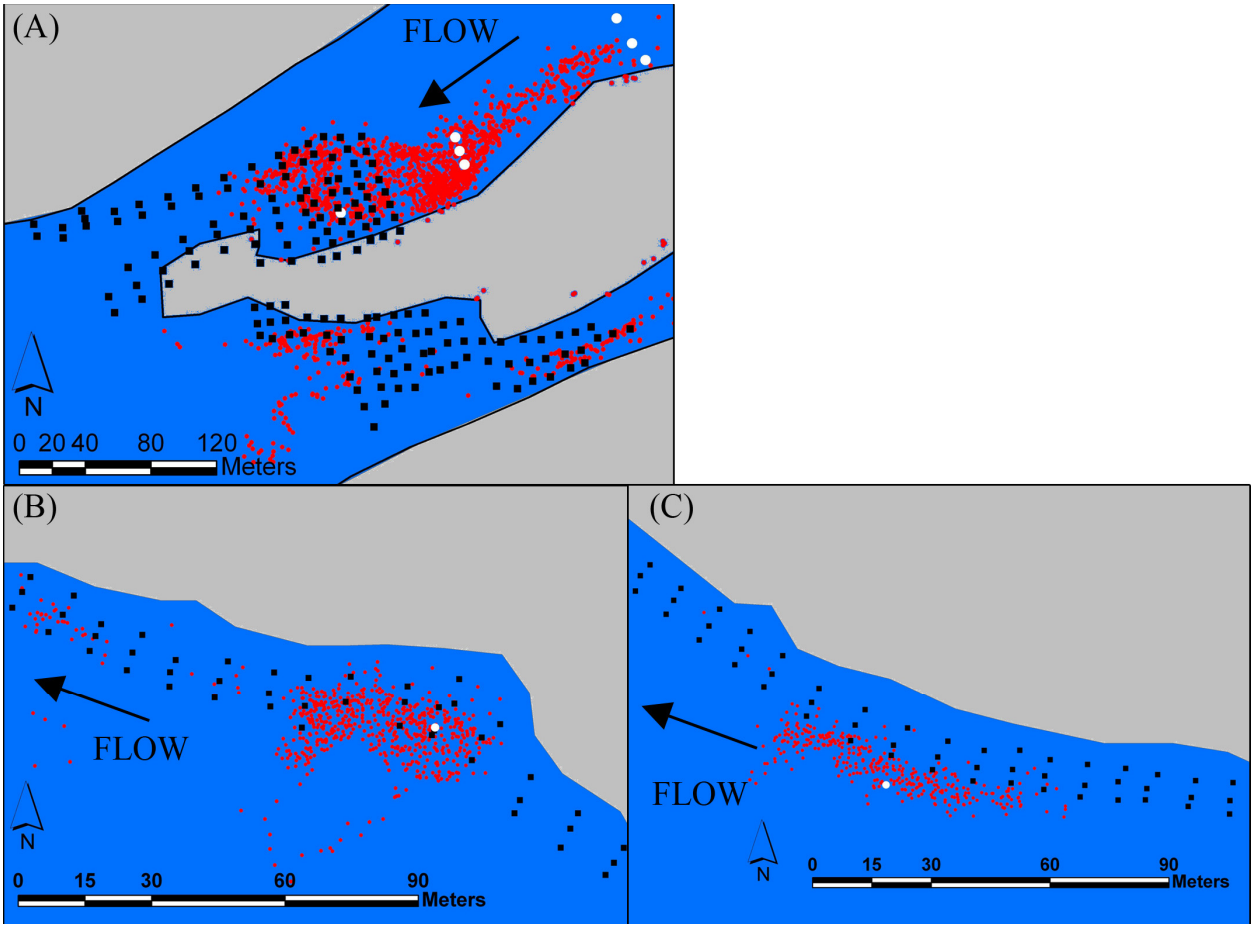


Figure 2.3. Chum Salmon Redd Locations (red circles) from the Ives Island Area (2000-2006) and the I-205 Locations (2003-2006), Piezometer Locations (white circles), and Temperature Mapping Points (black squares) at A) Ives Island, B) Woods Landing, and C) Rivershore Sites

surface water elevation fluctuations. Although we present the data and discuss general trends, we have not statistically summarized the data or attempted to evaluate their influence on spawning behavior.

Of the 38 sensors deployed, five sensors were removed by the river or by other causes; we recovered a total of 33 Onset loggers (Figure 2.4). Onset sensors were spaced 10 m apart along transects labeled N1 through N7 and N10 (Figure 2.4). Sensors within each transect were labeled alphabetically (N1A, N1B, N1C, and so on) from left bank to right bank. Lost sensors were from locations N1E, N4C, N5E, N7G, and N7H. The sensor at N2F was recovered, but we believe it was excavated during the deployment and therefore was not used for the analysis.

Onset sensors were secured with their sensor ends near the bottom of 20-cm-long rebar stakes. Sensors were secured to the stakes with cable ties and electrical tape (Figure 2.5). The stake was buried with the senor tip located approximately 20 cm below the riverbed. Each sensor had a specified accuracy of ±0.02ºC.

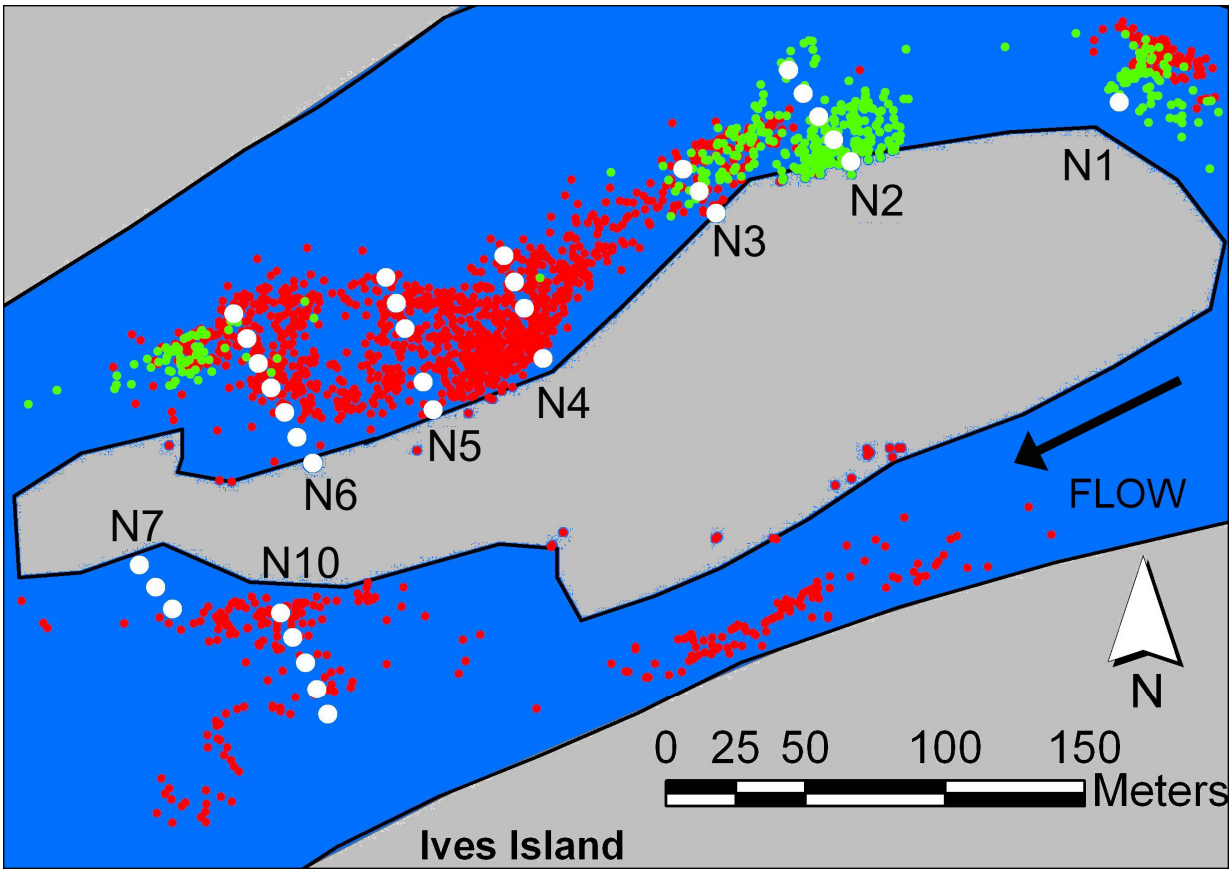


Figure 2.4. Onset Sensors (white circles) As Spaced on Transects. Along each transect, sensor locations were labeled A, B, C, and so on, progressing from left bank toward the right bank. Redd locations for chum salmon (red circles) are based on redd surveys conducted during 2000–2006. Locations for fall Chinook salmon redds (green circles) are based on surveys conducted during 2000–2004.

Figure 2.5. Onset Sensor Attached to Rebar Stake

Following installation, we surveyed the tops of the rebar stakes relative to a control point provided by the USFWS. The control point was located at 5053112.1 North, 578230.7 East, UTM Zone 10 North, datum NAD83, with a vertical elevation of 19.67 feet, datum NGVD 29. The USFWS used an RTK base station setup on a monument in Beacon Rock State Park to establish the control point. At each of our sampling locations, we determined the elevation of the top of the rebar stake as compared to the elevation of the USFWS control point. To determine the elevations of the tops of the rebar stakes, we conducted a survey using the differential level technique with a Sokkia Set 330R EDM total station. The difference in elevation between each Onset point was ±1 cm. The elevation of each temperature sensor was determined by subtracting the distance of the sensor tip (20 cm) from the top of the rebar stake. Survey results are included in Appendix E.1.

During periods of low river stage, sensors positioned within higher riverbed elevations were dewatered, and the associated data were not representative. When dewatering occurred, the data were removed as described by Arntzen et al. (2007). We present all the data collected for Objective 3 in Appendix E.2. We used Tecplot to generate an animation of the temperature data recorded using the onset sensor network (Appendix E.3).

Results and Discussion

Temperature and Water Surface Elevation Monitoring

Location coordinates and sensor depths below the riverbed are included for each location where temperature data or water surface elevation data were collected (Appendix A). Temperature data availability is summarized in Appendix B. All temperature data collected from October 2006 through September 2007 are presented in Appendix C. During 2006 through 2007, riverbed and river water temperatures were provided to the Fish Passage Center to assist federal and state agencies in estimating chum and fall Chinook salmon emergence timing and to help determine periods during which redds were dewatered in the Ives Island area. For this reason, our results focus on data that were collected during the spawning through emergence period (October 1–June 30). We provide general comparisons of data between riverbed and river sensors and between sites used by chum and fall Chinook salmon. Although incomplete records are included in Appendix C and in Figures 2.6 and 2.8, data from partial records were not used in statistical comparisons. Piezometers were located in either chum or fall Chinook salmon spawning sites (Figure 2.2). Spawning associations were based on visual comparison of spawning count data for 2000–2006 (ODFW, unpublished data). Transects T1, T2, Multnomah Falls, Rivershore, and Woods Landing are associated with chum salmon spawning, while transects T4 and T5 are associated with fall Chinook salmon spawning. Complete data records were generally available at our monitoring locations from October 2006 through June 2007. Exceptions occurred at Woods Landing 1 Bed, where a sensor malfunctioned, and at Woods Landing 2 River and Multnomah Falls River due to piezometer damage.

In the Ives Island area, temperature patterns observed during October 2006 through June 2007 were generally similar to those observed during previous years (Arntzen et al. 2006, 2007; Geist et al. 2008). Mean (SD) bed temperatures in Ives chum salmon spawning areas ranged from 10.1°C (2.5°C) at T2RB to 12.3°C (2.9°C) at T2LB (Figure 2.6). Composite mean bed temperature in Ives chum salmon areas was 11.4°C. Composite mean river temperature in chum salmon spawning areas was 9.1°C (Figure 2.6).

Mean (SD) bed temperatures in Ives fall Chinook salmon spawning areas ranged from 8.7°C (4.3°C) at T4RB to 9.9°C (4.2°C) at T5MC (Figures 2.6 and 2.7). The composite mean bed temperature in Ives fall Chinook salmon spawning areas was 9.2°C. Composite mean river temperatures in Ives fall Chinook areas was 8.9 °C. Mean (SD) surface water temperature in the mouth of Hamilton Creek was 8.9°C (4.3°C).

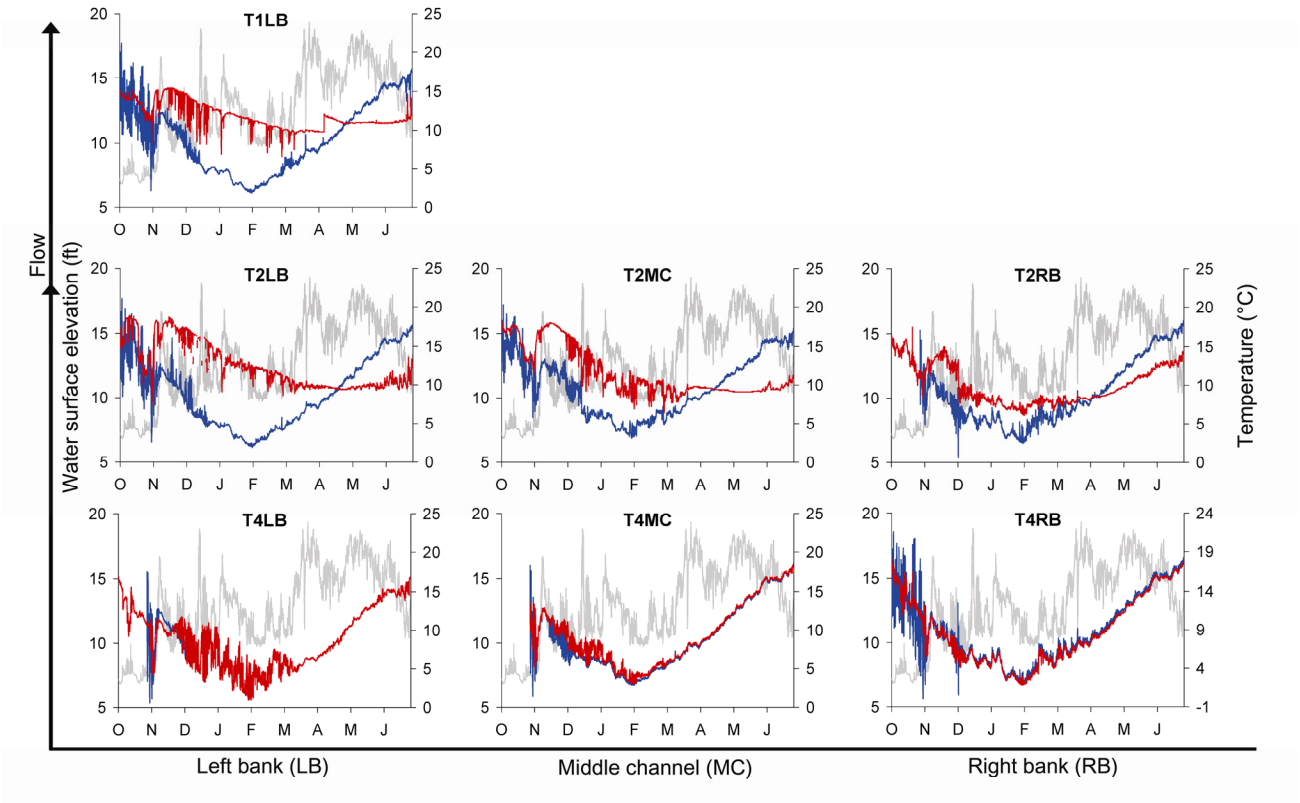


Figure 2.6. Temperature for River (blue) and Hyporheic (red) Sensors Within Channel North of Ives Island. The grey line is water surface elevation (recorded at T2MC). Plots are arranged according to sensor location, with plots at the top farthest downstream and plots on the left along the left bank.

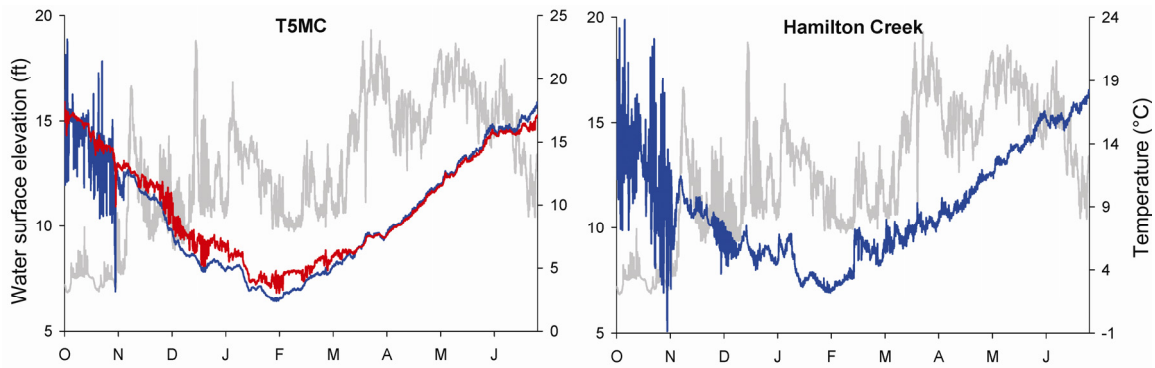


Figure 2.7. Temperature for River (blue) and Hyporheic (red) Sensors for Ives Island Locations T5MC and Hamilton Creek

In other lower Columbia River chum salmon spawning locations (i.e., Multnomah Falls, Rivershore, and Woods Landing), mean (SD) bed temperatures ranged from 9.4°C (2.0°C) at Rivershore to 10.9°C (0.04°C) at Woods Landing 2 (Figure 2.8). Composite mean bed temperature for Rivershore, Woods Landing 1, and Multnomah Falls was 9.9°C. The mean river temperature was not representative of the entire study period at the Multnomah Falls and Woods Landing 2 sites, where only partial river data sets were available (Figure 2.8). At Rivershore, mean (SD) river temperature was 9.9°C (4.2°C) while at Woods Landing 1, mean (SD) river temperature was 10.3°C (1.4°C).

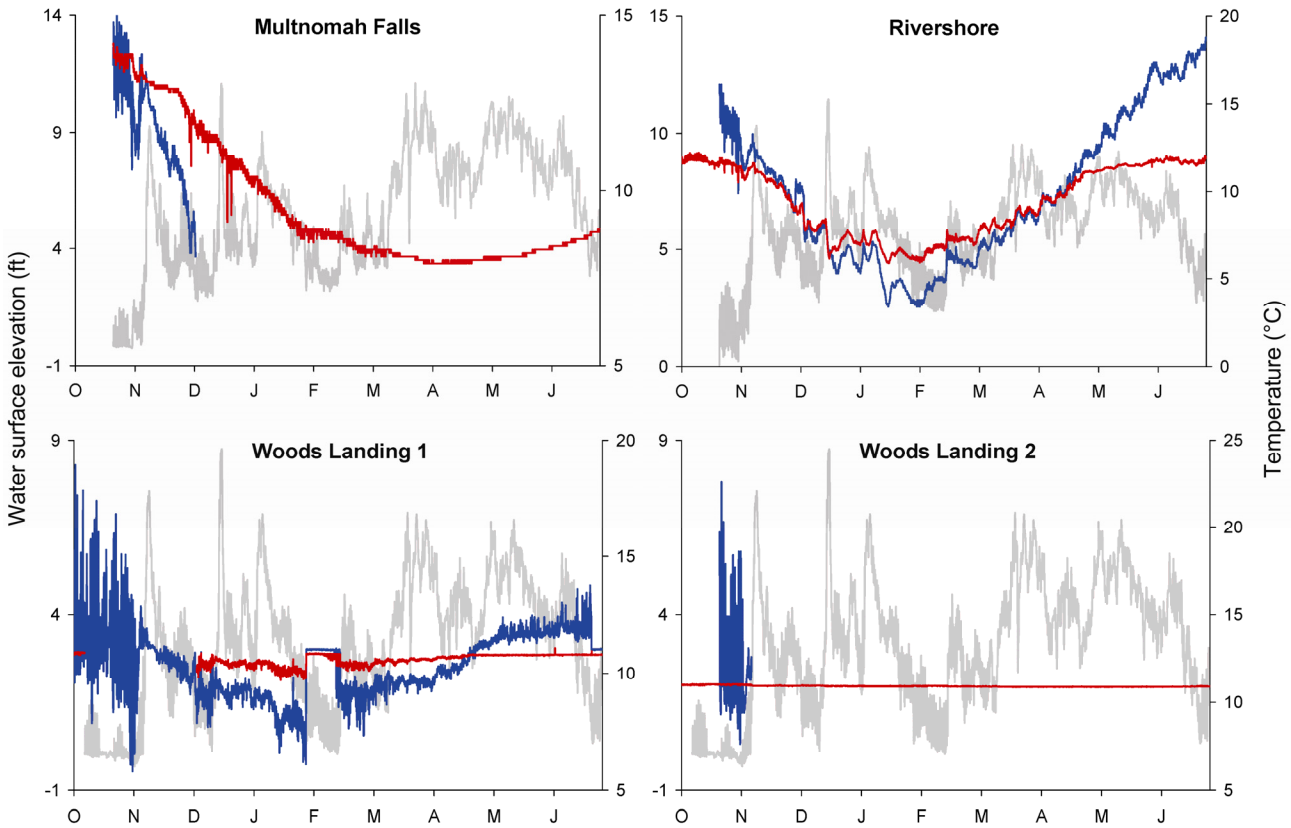


Figure 2.8. Temperature for River (blue) and Hyporheic (red) Sensors at Multnomah Falls, Rivershore, and Woods Landing Sites

There was a pronounced difference, as has been the case in previous monitoring years, between the riverbed temperature and the river temperature within Ives Island chum salmon spawning locations (Figure 2.6). During a significant portion of the spawning and incubation period for chum salmon (i.e., during November through most of April at T1LB, T2LB, and T2MC and through March at T2RB), bed temperatures were several degrees centigrade warmer than adjacent surface water temperatures (Figure 2.6). This was in contrast to fall Chinook salmon spawning locations (T4RB, T4LB, T4MC, and T5MC), where riverbed temperatures remained relatively similar to surface water temperatures (Figures 2.6 and 2.7). The trends monitored during FY 2007 were very similar to those noted during

FY 2006. During FY 2007, complete data records were available at T2RB and T4MC, locations where FY 2006 data loss prevented evaluation between bed temperatures and river temperatures. The trends in temperature difference between bed and river at the various monitoring locations appear to be very consistent over the several years' time scale of our investigation.

At the other lower Columbia monitoring locations, bed temperature responses differed from those in the Ives Island area, suggesting varying degrees of groundwater–surface water interaction. At Rivershore, trends in bed temperature were similar to those in the Ives area, although values were lower on average (Figure 2.8). At the Multnomah Falls site, bed temperature was elevated during fall chum salmon spawning similar to the Ives Island area. During incubation, Multnomah Falls bed temperatures were cooler and more stable, suggesting relatively constant discharge of groundwater into the river and potentially delaying alevin development and the onset of emergence (Figure 2.8). Bed temperatures were extremely stable at Woods Landing, with very little response to changing river stage. This suggests nearly constant discharge of groundwater into the river there, providing incubation temperatures similar to those measured in the Ives Island area (Figure 2.8).

Two-Dimensional Riverbed Temperature Mapping

We summarized the hyporheic and river temperature data for each site (Appendix D, Tables D.2 and D.3). The largest mean temperature difference between the hyporheic zone and the river was 2.3°C at Ives Island, with differences of 0.5°C at Rivershore and 0.4°C at Woods Landing.

Variogram modeling (Appendix D, Figure D.1) of the hyporheic temperature data from the three sites found the spatial correlation range parallel to the shore equal to 13 m at Rivershore and Woods Landing, 40 m at Ives Island NW, and 50 m at Ives Island SE. Cross-river ranges were 40 m at Ives Island NW and 30 m at Ives Island SE (Appendix D, Table D.4). For the Rivershore and Woods Landing sites, insufficient data were available for calculation of variograms perpendicular to the shoreline, so variogram ranges for the cross-channel direction similar to those found in earlier studies in the lower Columbia (Geist et al. 2002) were used for kriging the temperature data (Appendix D, Table D.4). Variograms were calculated and modeled in both along-river and cross-river channel directions at Ives Island, and those models (Appendix D, Table D.4) were used for kriging the temperature data at Ives Island.

A visual analysis of the ordinary kriging maps of temperature for the three sites (Figures 2.9 through 2.11) indicates that chum salmon redds tend to be found in areas with high hyporheic temperatures. This supports results found by Geist et al. (2002) concerning chum salmon spawning in areas of higher hyporheic temperatures. Chum salmon in the Ives Island area still keyed in on warmer hyporheic areas for spawning, but during 2006 they spawned on the southeast side of the bar where the temperature differential is not as great. This change in spawning location was due to relatively high water levels that were present during the spawning season, allowing them to spawn at the higher elevations on the southeast side. A large inflow of warm spring water at the Woods Landing site has a sizable impact on overlying river temperature (Figure 2.10). This effect is not as noticeable at the Rivershore site or the northwest section of the Ives Island area (Figures 2.9 and 2.11) where river water depths are greater, decreasing the effect of the warm upwelling spring water on the overlying river temperature.

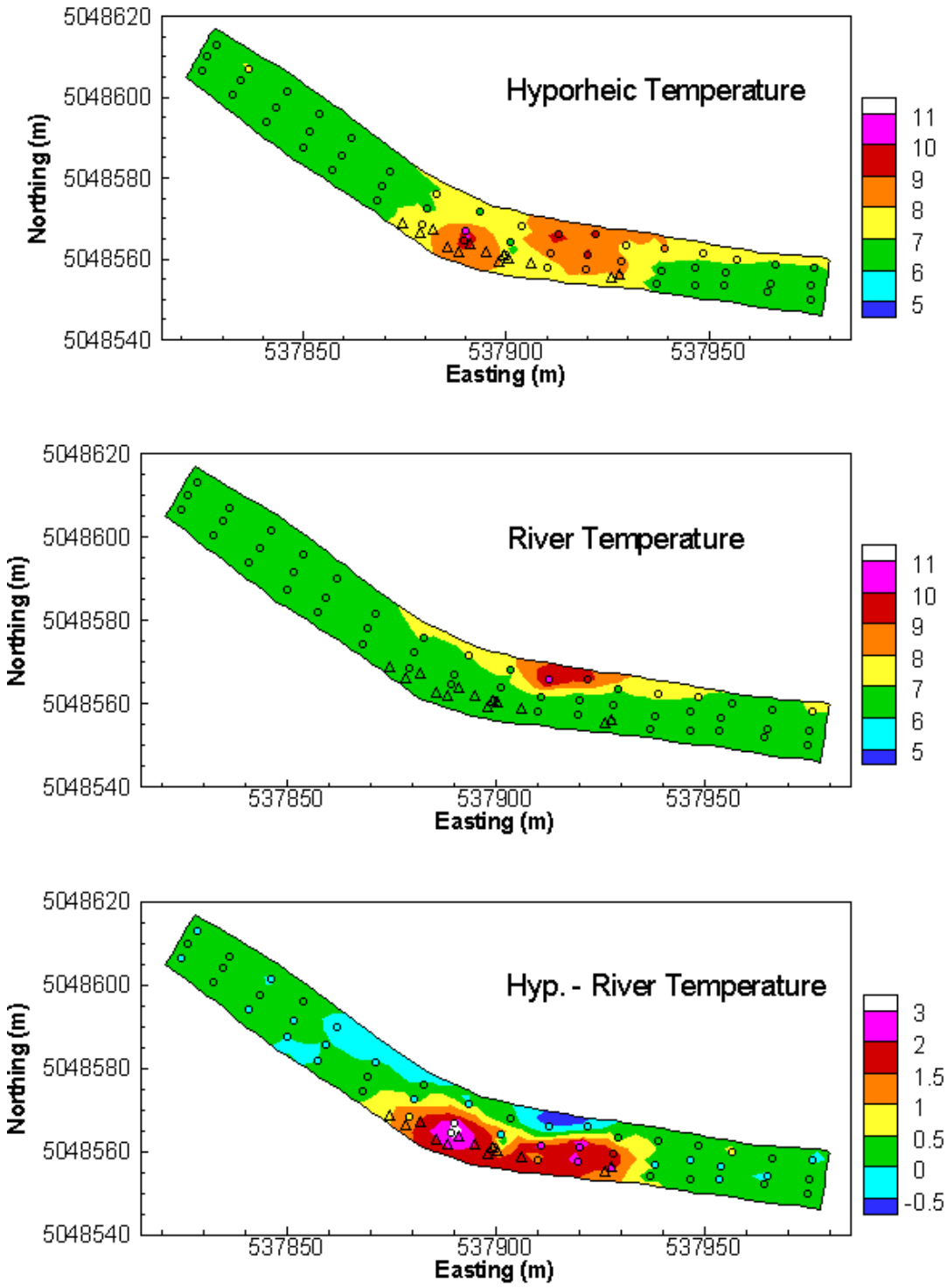


Figure 2.9. Kriging-Estimated Hyporheic Temperature (top), River Temperature (middle), and Calculated Temperature Difference (bottom) at the Rivershore Site. Circles indicate sample locations; triangles denote chum salmon spawning locations during 2006.

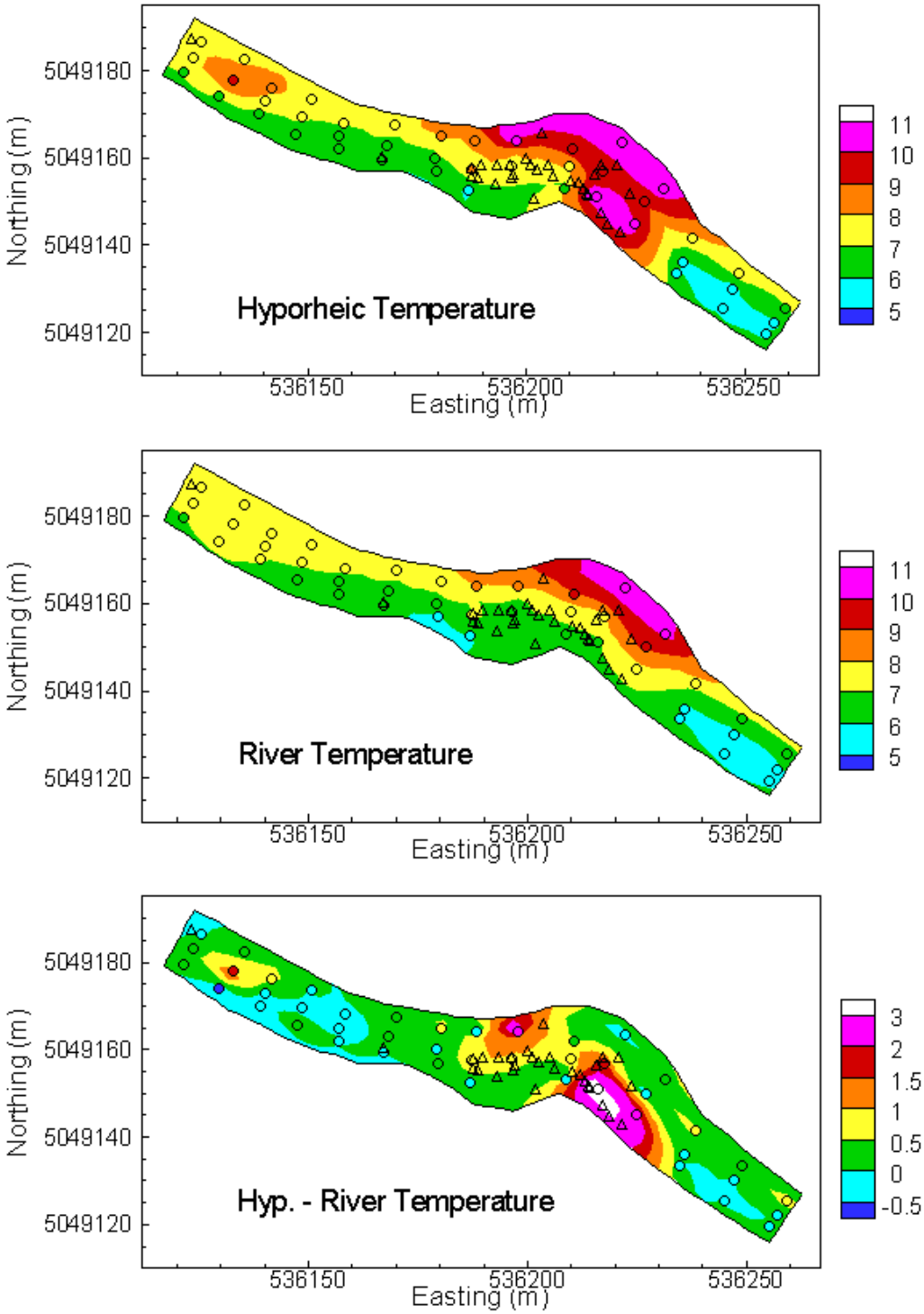


Figure 2.10. Kriging-Estimated Hyporheic Temperature (top), River Temperature (middle), and Calculated Temperature Difference (bottom) at Woods Landing Site. Circles indicate sample locations; triangles denote chum salmon spawning locations during 2006.

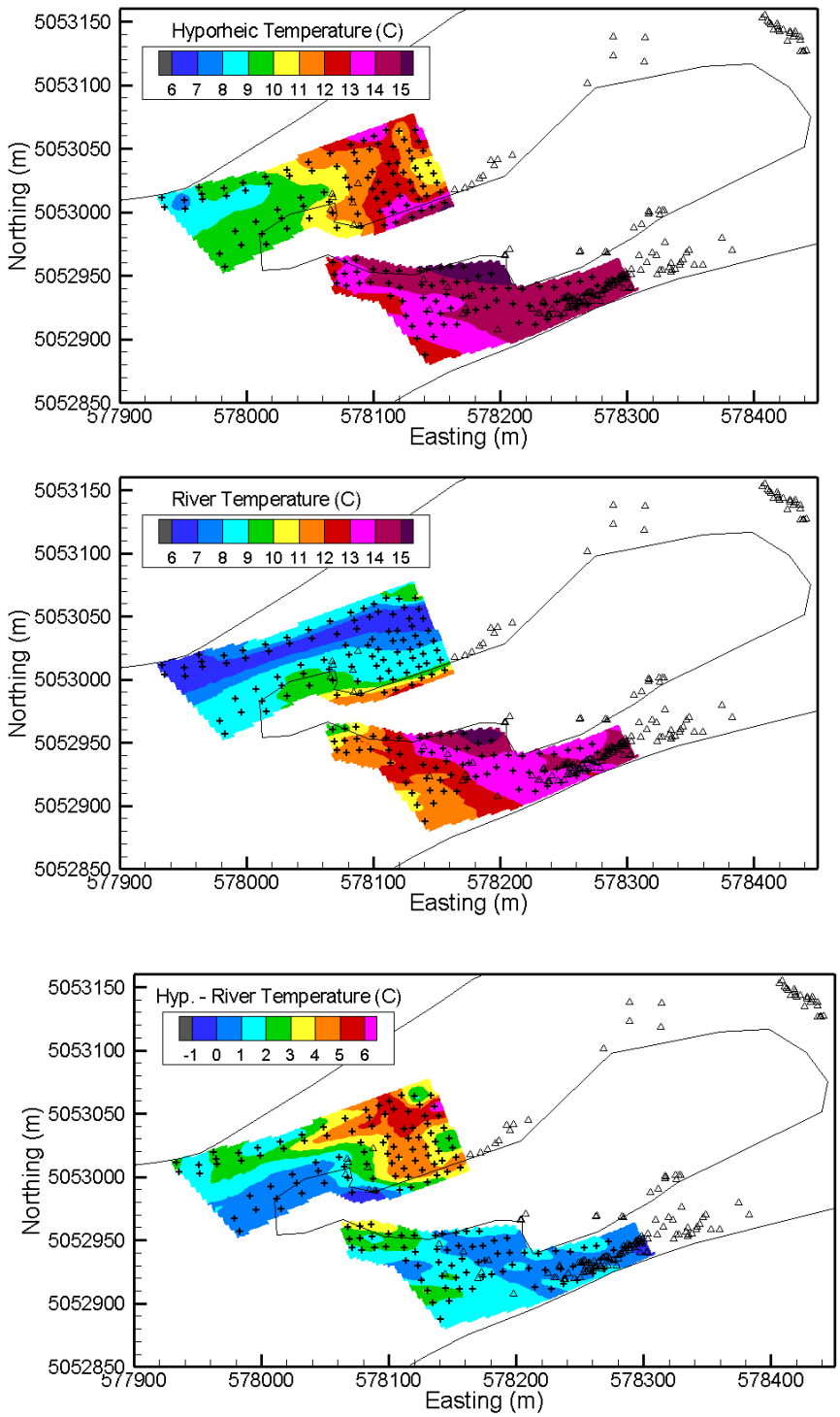


Figure 2.11. Kriging-Estimated Hyporheic Temperature (top), River Temperature (middle), and Calculated Temperature Difference (bottom) at the Ives Island Site. Circles indicate sample locations; triangles denote chum salmon spawning locations during 2006.

At the Rivershore and Woods Landing sites, temperature mapping was conducted during both FY 2006 and FY 2007. During FY 2006, Rivershore hyporheic temperatures averaged 9.0°C, while river temperatures averaged 8.2°C. Temperatures were colder there during FY 2007, averaging 7.2°C within the hyporheic zone and 6.7°C in the overlying river. At Woods Landing during FY 2006, temperatures averaged 9.8°C and 9.2°C in the hyporheic zone and the river, respectively. Temperatures there were likewise cooler during FY 2007, averaging 7.6°C and 7.2°C in the hyporheic zone and the river, respectively. At both locations, hyporheic water was warmer than the river where chum salmon spawned. However, there were substantial differences between the absolute temperatures recorded during FY 2006 and FY 2007. These can likely be explained by the timing during which temperature mapping occurred each year. During FY 2006, mapping occurred during December 5–6, 2005. During FY 2007, mapping occurred on January 3, 2007. This seasonal difference of approximately 1 month allowed for cooling that caused both hyporheic and river temperatures to be lower during FY 2007.

Effect of Changing Discharge on Hyporheic Temperature at Various Riverbed Elevations

The temperature profile in chum salmon spawning areas was strongly influenced by changes in river stage. During periods of low river stage, relatively warm hyporheic water was present at sensor depth below the riverbed near chum salmon spawning locations (Figure 2.12). During periods of high river stage, hyporheic water temperatures more closely resembled the surface water temperature (Figure 2.13). This effect can be examined further in a time-series plot of temperature data from sensors on transect N6 during mid December, within a chum salmon spawning location (Figure 2.14). The hyporheic temperature remained above 10°C when river stage was low. However, when stage increased, the temperature dropped to approximately 5°C to 6°C (Figure 2.14). This pattern was not observed in fall Chinook salmon spawning areas, where the temperature response remained much more stable during the same period, remaining below 7°C at most monitoring locations (at one location, temperatures in excess of 10°C were recorded; Figure 2.15). The more stable response suggests the predominance of downwelling surface water, as previously noted (Geist et al. 2008).

In general, the pattern of increased temperature variability within chum spawning areas during river stage fluctuation was similar to what was observed during 2005 (Arntzen et al. 2007). Interestingly, this occurred despite significant differences in river discharge during November through December 2006 as compared to 2005. During 2006, heavy rainfall during November caused increased river stage in the Ives area (Figure 2.16). Despite the large difference in the water depth between the two years, hyporheic temperatures fluctuated in a similar way both years due to short-term river stage fluctuation. It is thus apparent that short-term river stage fluctuations (e.g., those that occur diurnally or over shorter time scales) have a more pronounced influence than do seasonal changes in water level on temperatures within the hyporheic zone where chum salmon spawn. Differences in the mean hyporheic temperatures were recorded each year, presumably due to seasonal variation in air temperature and river depth, but they were relatively small. Mean temperatures during November (recorded at locations common to both sampling years) were 11.8°C during 2005 and 12.2°C during 2006. At the scale of individual transects (e.g., those identified on Figure 2.4), temperatures were generally either very similar between the two years (i.e., within 0.2°C), or were warmer during 2006. One exception occurred at T4, where mean temperature was 1.0°C warmer during 2005. Temperatures were within 0.2°C during 2005 and 2006 at N1, N3, and N5.

In 2006, mean temperatures at N2 were 0.9°C warmer; at N6, they were 1.0°C warmer and, at N7, 1.4°C warmer.

Onset temperature data from each of the 32 locations sampled are included in Appendix E.2. Additionally, a visualization was created that showed the temperature response and dewatering of sensors within transects N1–N10 in response to changes in water surface elevation. The visualization was created for the period extending from December 11 through December 24, 2006. That visualization is included as a digital file in Appendix E (E.3).

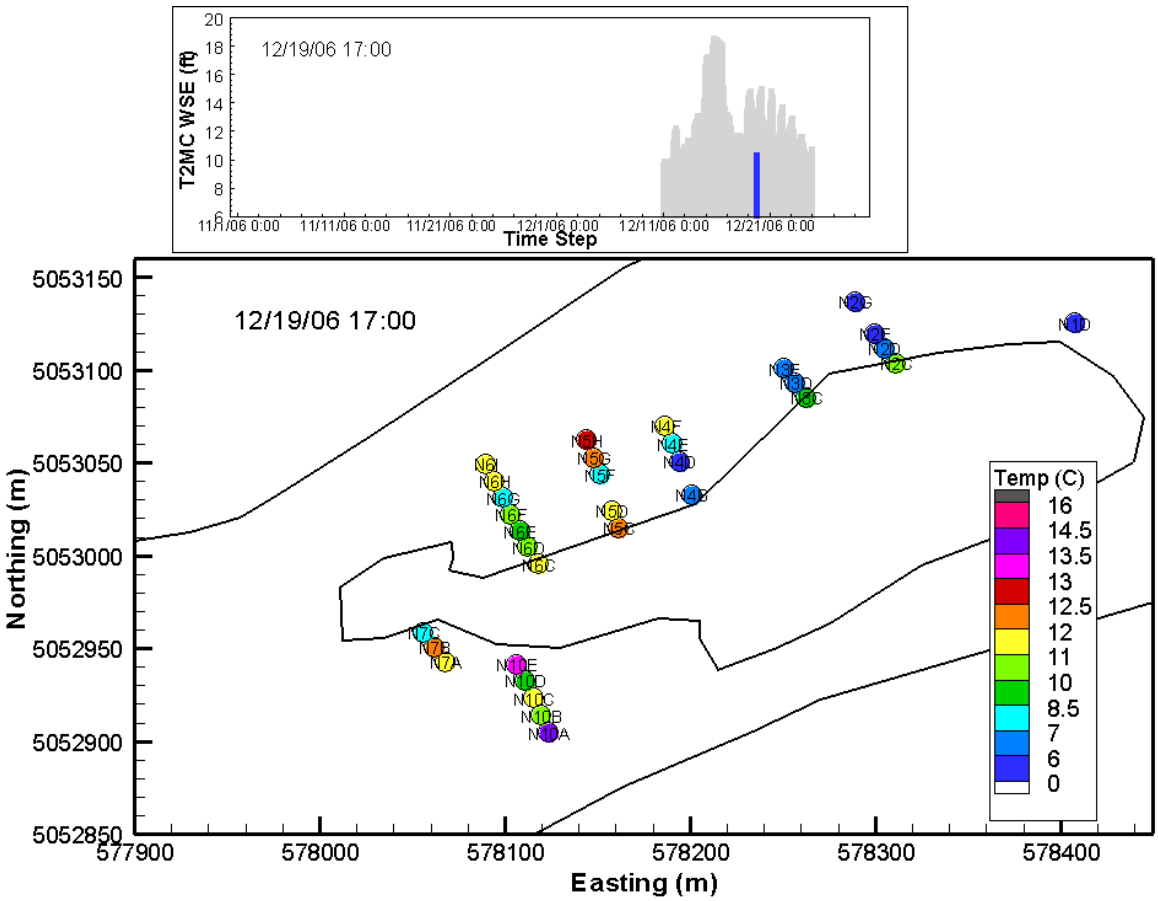


Figure 2.12. Distribution of Onset Temperature Data at Relatively Low River Stage (WSE = 10.6 ft)

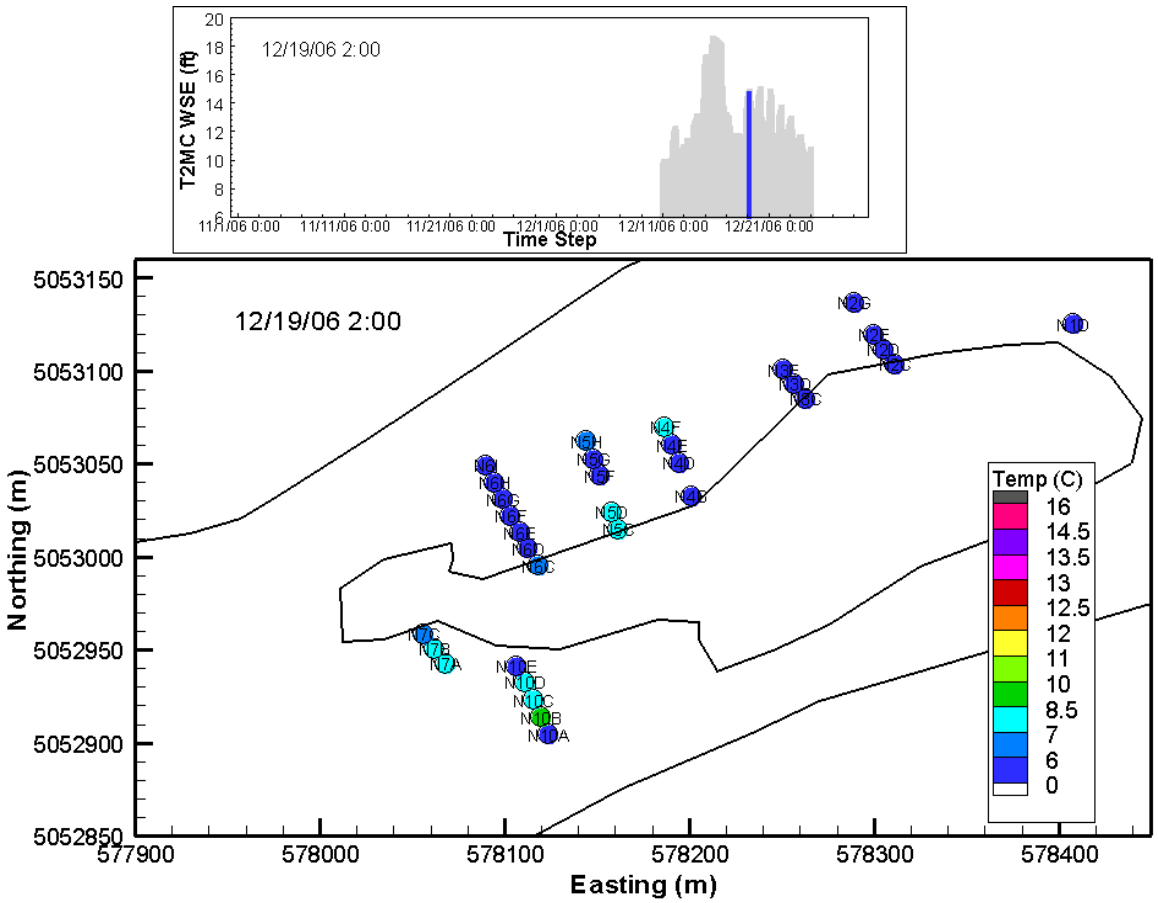


Figure 2.13. Distribution of Onset Temperature Data at Relatively High River Stage (WSE = 14.9 ft)

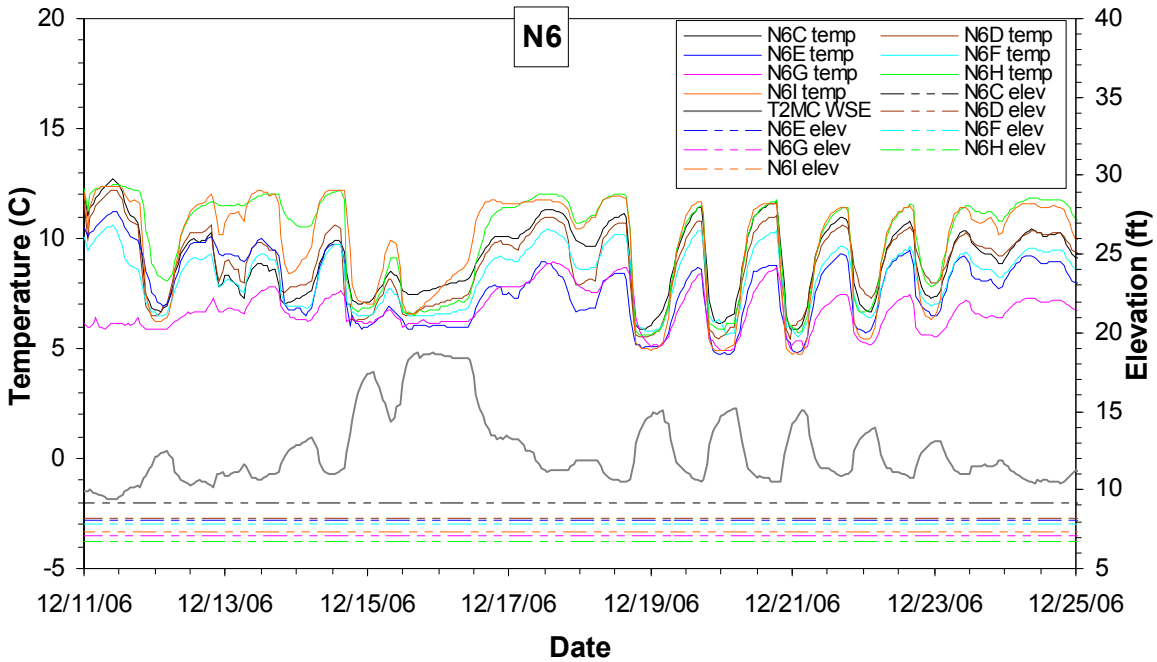


Figure 2.14. Temperature Profile of Buried Onset Sensors in Chum Salmon Spawning Location N6 During River Stage Fluctuation for a Two-Week Period During the Chum Salmon Spawning Season

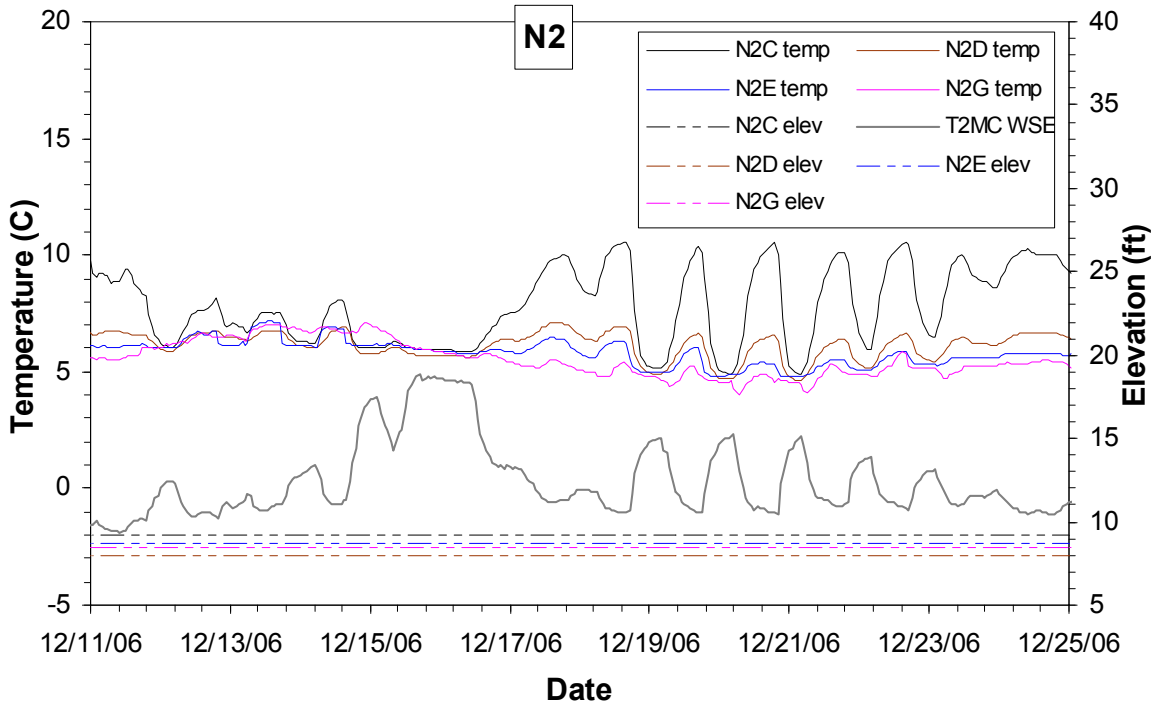


Figure 2.15. Temperature Profile of Buried Onset Sensors in Fall Chinook Salmon Spawning Location N2 During River Stage Fluctuation

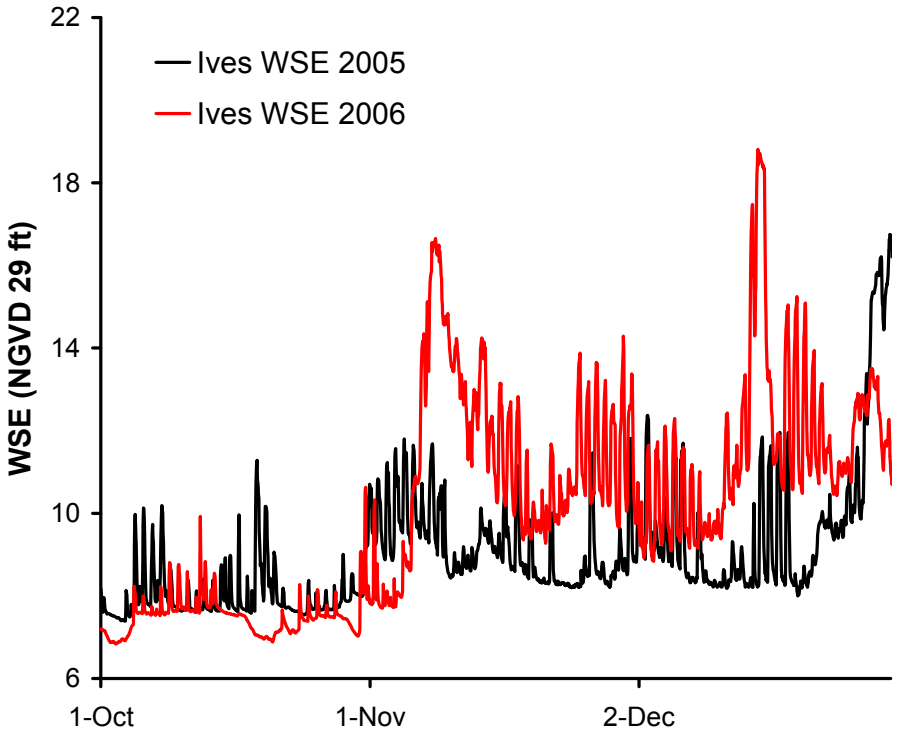


Figure 2.16. Water Surface Elevation in the Ives Island Area in 2005 (black line) and 2006 (red line) During the Fall Salmon Spawning Season

References

Endangered Species Act of 1973. 16 U.S.C. 1531-1544, Public Law 93–205, Approved December 28, 1973, 87 Stat. 884, as amended through Public Law 107-136, January 24, 2002.

Arntzen EV, TP Hanrahan, KE McGrath, CJ Murray, Y-J Chien, and SL Thorsten. 2006. "Summary of Temperature Data Collected to Improve Emergence Timing Estimates for Chum and Fall Chinook Salmon in the Lower Columbia River." Chapter 2 in *Evaluation of Salmon Spawning Below the Four Lowermost Columbia River Dams – 2004-2005 Annual Report*, DR Geist and AJ Currie (eds). DOE/BP-00000652-32, Bonneville Power Administration, Portland, Oregon.

Arntzen EV, RP Mueller, CJ Murray, Y-J Bott, JL Panther, DR Geist, and TP Hanrahan. 2007. *Evaluation of Salmon Spawning Below Bonneville Dam – Annual Report – October 2005–September 2006.* DOE/BP-00000652-35, Bonneville Power Administration, Portland, Oregon.

Geist DR and DD Dauble. 1998. "Redd Site Selection and Spawning Habitat Use by Fall Chinook Salmon: The Importance of Geomorphic Features in Large Rivers." *Environmental Management* 22:655–669.

Geist DR, TP Hanrahan, EV Arntzen, GA McMichael, CJ Murray, and Y-J Chien. 2002. "Physicochemical Characteristics of the Hyporheic Zone Affect Redd Site Selection by Chum Salmon and Fall Chinook Salmon in the Columbia River." *North American Journal of Fisheries Management* 22:1077–1085.

Geist DR, EV Arntzen, CJ Murray, KE McGrath, Y-J Chein, and TP Hanrahan. 2008. "Influence of River Level on Temperature and Hydraulic Gradients in Chum and Fall Chinook Salmon Spawning Areas Downstream of Bonneville Dam, Columbia River." *North American Journal of Fisheries Management* 27:30–41.

Isaaks EH and RM Srivastava. 1989. *An Introduction to Applied Geostatistics*. Oxford University Press, New York.

National Marine Fisheries Service. 1998. "Endangered and Threatened Species: proposed Threatened Status and Designated Critical Habitat for Hood Canal Summer-Run Chum Salmon and Columbia River Chum Salmon." *Federal Register* 63:11773–11795.

Tiffan KF, RD Garland, and DW Rondorf. 2002. "Quantifying Flow-Dependent Changes in Subyearling Fall Chinook Rearing Habitat and Stranding Area Using Two-Dimensional Spatially-Explicit Modeling." *North American Journal of Fisheries Management* 22:713–726.

U.S. Fish and Wildlife Service. 1999. "Endangered and Threatened Wildlife and Plants; Listing of Nine Evolutionarily Significant Units of Chinook Salmon, Chum Salmon, Sockeye Salmon, and Steelhead." *Federal Register* 64:41835–41839.

Appendix A

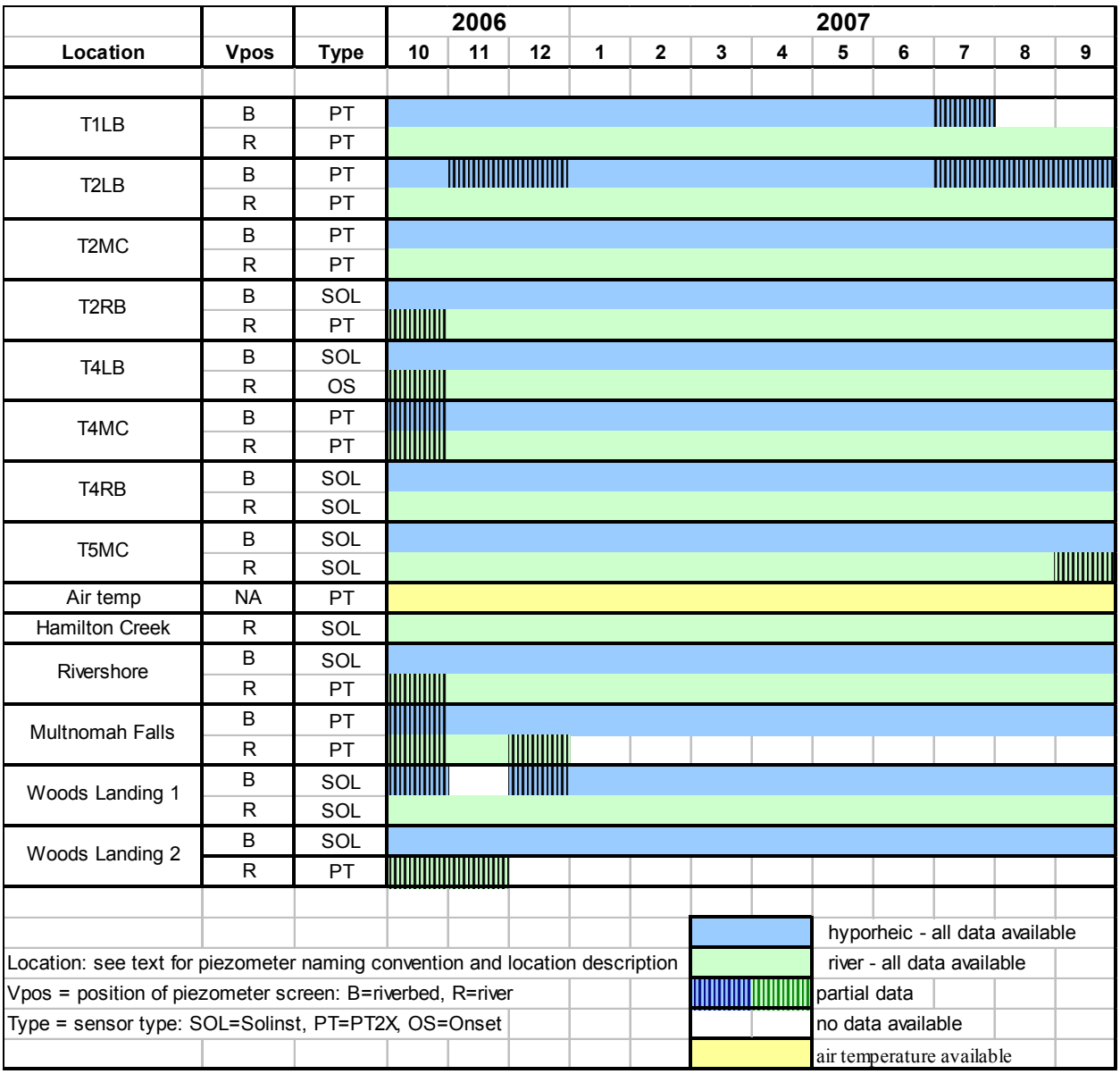
Temperature Sensor Location Information

Name	ΔL[a] (cm)	X[b]	Y[b]
Rivershore	50.0[c]	537888	5048557
Multnomah Falls	55.5[d]	568891	5047743
Woods Landing 1	50.0[e]	536217	5049153
Woods Landing 2	36.0[f]	536217	5049153
T1LB	58.0	578121	5053018
T1MC	30.0	578119	5053032
T2LB	58.4	578197	5053041
T2MC	58.0	578193	5053055
T2RB	30.0[g]	578190	5053064
T4LB	35.5[h]	578306	5053111
T4MC	36.0[i]	578298	5053121
T4RB	30.0[j]	578288	5053136
T5MC	30.0[k]	578106	5052412

(a) ΔL= depth of riverbed sensor below the riverbed.
(b) Horizontal coordinate system UTM Zone 10 North, Datum NAD 83.
(c) ΔL changed to 45.5 cm on 10/27/06.
(d) ΔL changed to 43.5 cm on 10/27/06.
(e) ΔL changed to 46.5 cm on 10/27/06.
(f) ΔL changed to 33.5 cm on 10/27/06.
(g) ΔL changed to 37.0 cm on 10/13/05.
(h) ΔL changed to 36.0 cm on 10/13/05.
(i) ΔL changed to 35.0 cm on 10/13/05. ΔL changed to 28.5 cm on 10/27/06.
(j) ΔL changed to 38.0 cm on 9/7/03. ΔL changed to 36.0 cm on 10/13/05.
(k) ΔL changed to 24.2 cm on 10/10/02. ΔL changed to 36.5 cm on 10/13/05. ΔL changed to 35.0 cm on 10/27/06.

Appendix B

Temperature Data Collected Downstream from Bonneville Dam in the Ives Island Area, FY 2007



Appendix C

Temperature Data Compendium

(Electronic file provided to BPA; please insert hyperlink here.)

Appendix D

Temperature Mapping Data with Statistical Summary

Table D.1. Temperature Data Collected During Mapping Activities at Ives Island, Rivershore and Woods Landing

(Electronic file – **Table_D-1.xls**)

Table D.2. Summary Statistics for the Hyporheic and River Temperature Data for the Ives Island Area

Ives Island	Hyporheic Temperature (ºC)			River Temperature (ºC)		
	All	NW	SE	All	NW	SE
Mean	12.55	11.19	14.26	10.27	8.13	12.91
Standard Error	0.17	0.19	0.10	0.22	0.15	0.16
Median	12.95	10.90	14.50	9.70	8.20	13.20
Standard Deviation	2.13	1.83	0.88	2.77	1.44	1.37
Sample Variance	4.54	3.35	0.77	7.65	2.07	1.88
Kurtosis	−0.84	−0.51	1.29	−1.38	0.83	0.07
Skewness	−0.46	0.22	−0.26	0.13	0.81	−0.61
Range	10.10	9.00	4.90	9.10	6.60	6.20
Minimum	6.60	6.60	11.80	6.20	6.20	9.10
Maximum	16.70	15.60	16.70	15.30	12.80	15.30
Count	164	91	73	163	90	73
Confidence Level of Mean (95.0%)	0.33	0.38	0.21	0.43	0.30	0.32

Table D.3. Summary Statistics for the Hyporheic and River Temperature Data for Rivershore (RS) and Woods Landing (WL)

Temperature (ºC)	Woods Landing (WL)		Rivershore (RS)	
	Hyp.	River	Hyp.	River
Mean	7.63	7.20	7.15	6.65
Standard Error	0.23	0.18	0.15	0.11
Median	7.30	7.15	6.80	6.40
Mode	5.90	5.90	6.40	6.40
Standard Deviation	1.52	1.18	1.06	0.76
Sample Variance	2.31	1.39	1.12	0.58
Kurtosis	−0.11	2.02	1.37	15.40
Skewness	0.91	1.33	1.48	3.72
Range	5.10	4.90	4.00	4.30
Minimum	5.90	5.90	6.20	6.10
Maximum	11.00	10.80	10.20	10.40
Count	44	44	51	51
Confidence Level of Mean (95.0%)	0.46	0.36	0.30	0.21

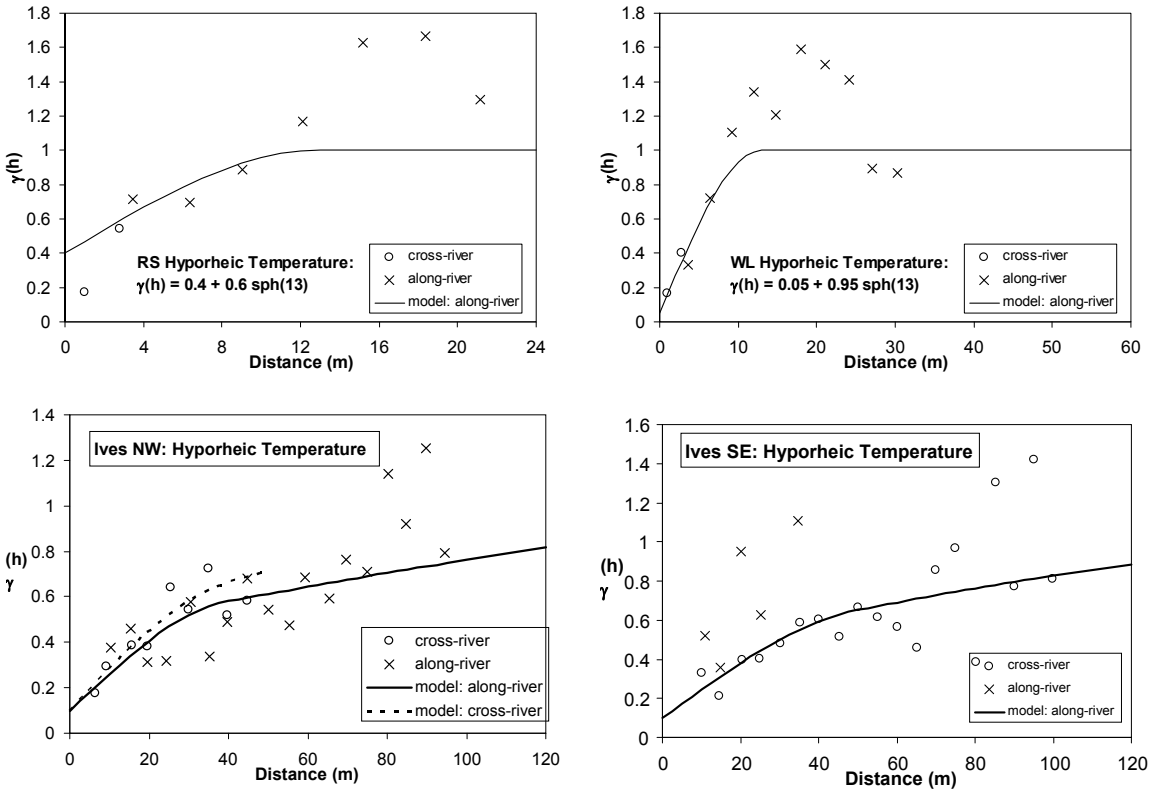


Figure D.1. Experimental Variogram Results (X) and Models (solid black lines) Fit to the Data for the Three Sites

Table D.4. Variogram Model Parameters for the Three Sites

Site	Temperature	Nugget	Sill	Range (in Projected Space)	
				Along-River	Cross-River
Woods Landing (WL)	Hyporheic	0.05	0.95	13	7.5
	River	0.05	0.95	13	5.0
Rivershore (RS)	Hyporheic	0.4	0.6	13	7.5
	River	0.1	0.9	11	7.0
Ives Island: NW	Hyporheic	0.01	0.35	40	40
			0.55	250	150
	River	0.05	0.30	60	15
			0.65	250	40
Ives Island: SE	Hyporheic	0.1	0.35	50	30
			0.55	200	30
	River	0.02	0.28	80	30
			0.70	140	30

Appendix E

32 Onset Point Data Used To Evaluate Riverbed Temperature Profile at Various Riverbed Elevations During River Stage Fluctuations

E.1 Vertical Elevation Survey Results

Location	Elevation[(a)]	Location	Elevation[(a)]
T1D	8.264	T5H	7.896
T2C	8.530	T6C	8.467
T2D	7.368	TCD	7.591
T2E	8.005	T6E	7.355
T2G	7.831	T6F	7.132
T3C	7.942	T6G	6.417
T3D	6.328	T6H	6.066
T3E	6.233	T6I	6.623
T4B	8.431	T7A	6.033
T4D	6.331	T7B	7.575
T4E	5.984	T7C	9.255
T4F	7.060	T10A	7.218
T5C	7.765	T10B	6.576
T5D	6.974	T10C	6.449
T5F	6.958	T10D	6.123
T5G	6.709	T10E	6.390

(a) Elevation is of the sensor tip, NGVD 29, in feet.

E.2 Temperature Data Collected from 32 Onset Sensors

Temperature data from each of the nine transects are included in Appendix E.2, using one file per transect. The files are labeled according to their transect label, i.e., appendixE_2_N1_FY07, appendixE_2_N2_FY07, appendixE_2_N3_FY07, and so on. Summary data for all the sensors used (e.g., location coordinates and sensor serial numbers) are included in appendixE_2_locations.

(Electronic file provided to BPA; please insert hyperlink here.)

E.3 Tecplot Animation of Sensor Temperature Response to River Stage Fluctuation

We used Tecplot to generate an animation of the temperature data recorded with the onset sensor network. A color scale indicates the riverbed temperature at each sensor location on an hourly basis. Dewatered sensors are indicated as white. The river level indicated by piezometer T2MC is provided for reference.

(Electronic file provided to BPA; please insert hyperlink here.)