B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Evaluation of Salmon Spawning Below Bonneville Dam

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Evaluation of Salmon Spawning Below Bonneville Dam

Annual Report

October 2005 – September 2006

Prepared by

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Foreword

Since FY 2000, scientists at Pacific Northwest National Laboratory (PNNL) have conducted research to assess 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). Data resulting from the individual tasks each agency conducts are providing a sound scientific basis for developing strategies to operate 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* (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 1800 to 5200 fish. Chum salmon also have been documented spawning downstream of Bonneville Dam. Chum salmon were listed as threatened under the ESA in March 1999.

At present there is a need 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. Ongoing discussions regarding the minimum and maximum flows will result in optimal spawning habitat usage and survival of embryos of both species. Collection of additional data as part of this project will ensure that established flow guidelines are appropriate and provide adequate protection for the species of concern. This is 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. Thus, there is a 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.

Pacific Northwest National Laboratory was asked to participate in the cooperative study during FY 2000. Since then, we have focused on 1) investigating the interactions between groundwater and surface water near fall Chinook and chum salmon spawning areas; 2) providing in-season hyporheic temperature data and assisting state agencies with emergence timing estimates; 3) locating and mapping deep-water fall Chinook salmon spawning areas; and 4) providing support to the WDFW for analysis of stranding data. Work conducted during FY 2006 addressed these same efforts.

Report Scope

This report documents the studies and tasks performed by PNNL during FY 2006. 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. Technical assistance provided to the WDFW and PSMFC in evaluation of stranding data is summarized in Chapter 3.

Acknowledgments

The authors thank Scott Titzler, Fenton Khan, Corey Duberstein, and Nate Phillips of Pacific Northwest National Laboratory for their assistance in conducting the video surveys, preparing geographic information system maps, and analyzing videotapes. Tim Hanrahan, Kathleen McGrath, Nathan Phillips, Brian Miller, Kyle Larson, Cherylyn Tunnicliffe, and James Bernhard assisted with temperature data collection. Gregg Gustafsen helped maintain the real-time data collection system. 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.

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Chapter 1

Deepwater Spawning of Fall Chinook Salmon (*Oncorhynchus tshawytscha*) near Ives and Pierce Island of the Columbia River, 2005

Robert P. Mueller

Summary

Pacific Northwest National Laboratory (PNNL) conducted boat-based 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 2005. This report documents the number of redds and extent of fall Chinook salmon spawning near Ives and Pierce islands of the Columbia River and is the sixth in a series of annual project reports prepared since 1999. 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. A secondary objective was to document the occurrence of any chum salmon (*O. keta*) redds in the deeper sections downstream of Hamilton Creek (slough zone search area) and downstream of the Interstate 205 bridge.

The total number of fall Chinook salmon redds counted in the Ives and Pierce Island complex during the 2005 spawning season was 191. This count was lower than that of the previous 2 years and lower than the previous 3-year average of 273 for the period 2001–2004. The count does not include 10 redds found by PNNL downstream from Moffett Creek in the mainstem or the redds observed in shallow water during visual surveys by Oregon Department of Fish and Wildlife. The redds found during 2005 encompassed an area of 10.1 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 15, 2005. An expanded redd count based on percentage video coverage in the primary and secondary search zones was 3,198 fall Chinook salmon redds at water depths exceeding approximately 1.5 m (at approximately 125 kcfs), with an estimated spawning population of 10,800. Water depths at redd locations ranged from 1.4 to 5.8 m (median = 2.7 m) in the primary zone and 3.0 to 7.9 m (median = 5.3 m) in the secondary zone. For redds found downstream of Moffett Creek, water depths ranged from 8.1 to 9.1 m (median = 8.2 m).

One chum salmon redd was found downstream from the mouth of Hamilton Creek within the relatively deeper sections of Hamilton Slough. Eight additional chum salmon redds were found upstream of the Interstate 205 bridge in water depths ranging from 1.5 to 3.1 m. No 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). 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 latter 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). 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 2005 downstream of Bonneville Dam. The primary objectives in 2005 were to locate and map deepwater (greater than 2 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 and around Ives and Pierce islands and along the Washington shoreline upstream of the Interstate 205 bridge.

Methods

The survey area consisted of three different search zones approximately 4 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 37 regularly spaced transects, 20 m apart and 160 m long, running perpendicular to the shoreline. The secondary zone (60,350 m^2) was at the lower end of Pierce Island and consisted of 18 additional transects, 20 m apart and 120 m long. The third search zone (slough area) consisted of two separate areas. The first was at the lower end of Pierce Island, and the second was within Hamilton Slough between Ives and Pierce islands (Figure 1.1). These areas were established based on previous surveys that documented fall Chinook and chum salmon redd occurrences (Mueller and Dauble 2000; Mueller 2001–2005).

Two separate underwater video surveys were conducted by boat in late November and early December 2005. The surveys were conducted just after November 15, the peak spawning date for fall Chinook salmon (Fish Passage Center 2005). This date was based on visual observations of adult fish and shallow-water redds by the ODFW.

The boat-deployed video system consisted of a high-sensitivity remote camera (Sartek SDC-MAL) attached to a weighted platform or sled. 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 for real-time viewing of the video were used for the boat operator and person operating the

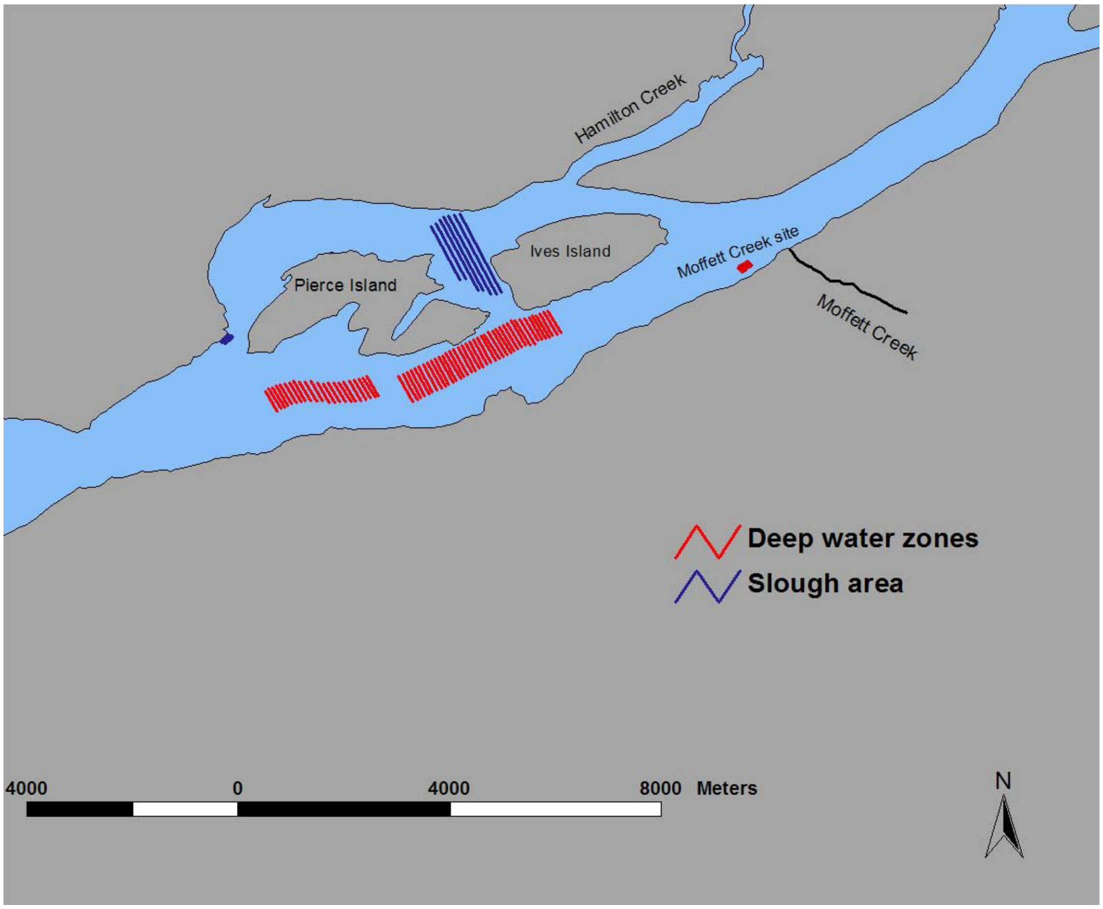

Figure 1.1. Search Zone Locations Relative to Ives and Pierce Islands

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. The distance from the camera lens to the substratum averaged approximately 1.5 m, providing an effective coverage area of approximately 3.6 m^2 at any one location along each transect. The approximate vertical coverage along each transect was 1.5 m.

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 (ASPEN) 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 geographic information system (GIS).

The type and size of the substratum were determined with underwater red lasers (C-Map Systems Model HL6312G). The lasers provided a reference scale within the camera image. The distance from the camera lens to the substratum ranged from 0.9 to 1.4 m, providing an effective view path of approximately 2.5 m^2 along each transect. Substrate classification methods are detailed in Mueller (2005).

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 at 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 191 fall Chinook salmon redds were found and mapped during surveys conducted in November and December 2005. This total included one redd found between Ives and Pierce islands. Initial deepwater redd surveys of the main channel near Ives and Pierce islands were completed November 28 through 30, shortly after the peak spawning date of November 15 for fall Chinook salmon (Fish Passage Center 2005). A second survey was conducted December 7 through 9 in the same area. River flows recorded at Bonneville Dam were considerably variable, ranging from 121 to 170 thousand cubic feet per second (kcfs) (Table 1.1).

Table 1.1. Average River Flow and Elevation Conditions Recorded During Underwater Video Survey Periods, 2005

Date	Discharge at Bonneville Dam (average kcfs)	Ives Island Staff Gage 1 (ft)
November 28, 2005	127.2	0.64
November 29, 2005	116.2	0.88
November 30, 2005	115.8	0.77
December 7, 2005	122.8	0.81
December 8, 2005	126.8	0.81
December 9, 2005	120.8	0.70

During the initial survey period (November 28–30), a total of 136 fall Chinook redds were located and mapped within all survey zones. This total includes 105 within the primary search zone, 10 in the secondary zone, and 10 approximately 265 m downstream of Moffett Creek (Table 1.2). This is the first known occurrence of fall Chinook salmon using this area for spawning. Live fish were also observed near these redds on November 29, while no live fish were observed on redds at the Pierce Island location. Water turbidity was very good, with NTU values averaging 0.96 during the initial survey period. A separate survey was conducted between Ives and Pierce islands on November 29, and one fall Chinook salmon redd was found near the lower end of Ives Island.

Table 1.2. Number of Fall Chinook Redds Found in Primary and Secondary Search Zones, 2005

Survey Date	Primary Zone (includes redds found at lower Ives Island)	Secondary Zone	Moffett Creek
November 28 through 30	105	10	10
December 7 through 9	48	17	0
Total	163	27	10

The second deepwater fall Chinook salmon redd survey was completed December 7 through 9, 2005. Average river discharge at Bonneville Dam during the survey period ranged from 126.8 kcfs on December 8 and fell to 120.8 kcfs on December 9. Water turbidity ranged from 1.3 to 2.8 NTU during the second survey period. A total of 65 additional redds were found, including 48 in the primary search zone and 17 in the secondary zone. Additional surveys were conducted near the mouths of Woodward, McCord, and Tanner Creeks, and no redds were found.

Water depths at redd locations ranged from 1.4 to 5.8 m (median = 2.7 m) in the primary zone and 3.0 to 7.9 m (median = 5.3 m) in the secondary zone (Figure 1.2). Water depths for redds found downstream of Moffett Creek ranged from 8.1 to 9.1 m (median = 8.2 m).

The location of all salmon redds (both fall Chinook and chum; n = 191) found during the 2005 surveys near Pierce and Ives islands is shown in Figure 1.3. The MASS1 model 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. Substrate composition was similar to measurements taken in previous years, with most of the redds constructed in cobble-sized substrates (7.6–15.2 cm). Distribution of the fall Chinook salmon redds counted in 2005 is shown in Figure 1.4.

The Hamilton Slough survey was conducted on November 29, 2005. Several carcasses were found, and one chum salmon redd characterized by smaller substrates and overall size was found downstream of Hamilton Creek. Additional chum or coho (*O. kisutch*) salmon carcasses were found at the mouth of Woodward Creek.

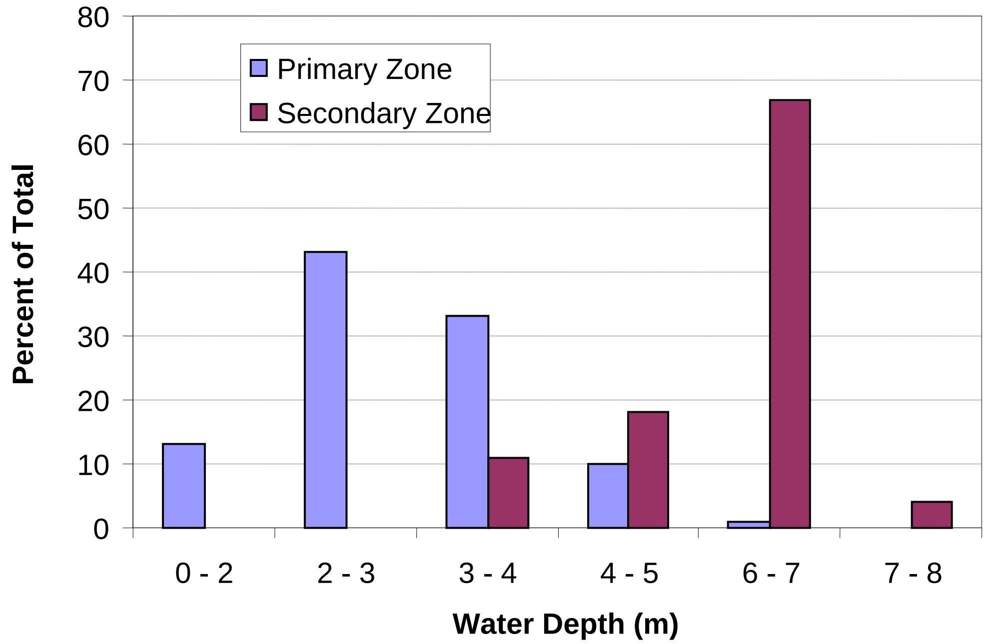

Figure 1.2. Percentage of Fall Chinook Salmon Redds Relative to Water Depth in Primary and Secondary Search Zones

The total area used by fall Chinook salmon for spawning was calculated by drawing a boundary line around the redd locations within the primary and secondary zones. A maximum convex polygon was created from points recorded at all salmon redds at both the upper and lower spawning areas. The radius of the polygon was then buffered 3 m to account for the redd areas that defined the polygon vertices. This buffer was then combined with the convex polygon, and the area was calculated. The preferred spawning area encompassed 6.85 ha in the primary and 3.18 ha in the secondary zone (Figure 1.5). The Moffett Creek site had a total spawning area of 500 m^2. Additional maps showing how the spawning area has changed over the 5-year period from 1999 through 2004 are shown in the Appendix.

During the past 5 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 1.5 m based on video coverage using the calibrated lasers as a reference during the November 28–29 survey. On the initial survey, the population estimate was based on the larger number of redds found and low water turbidity. The coverage area within the preferred spawning zones (Figure 1.5) was estimated to be 6.9% for the primary and 5.4% for the secondary zone. Using the percentage and the actual number of redds found, we estimated 1700 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 5800 adult fish during the peak spawning period in late November 2005 (Table 1.3). An estimate of the overall population, which incorporates redds found by the ODFW during shallow-water surveys in the nearshore region

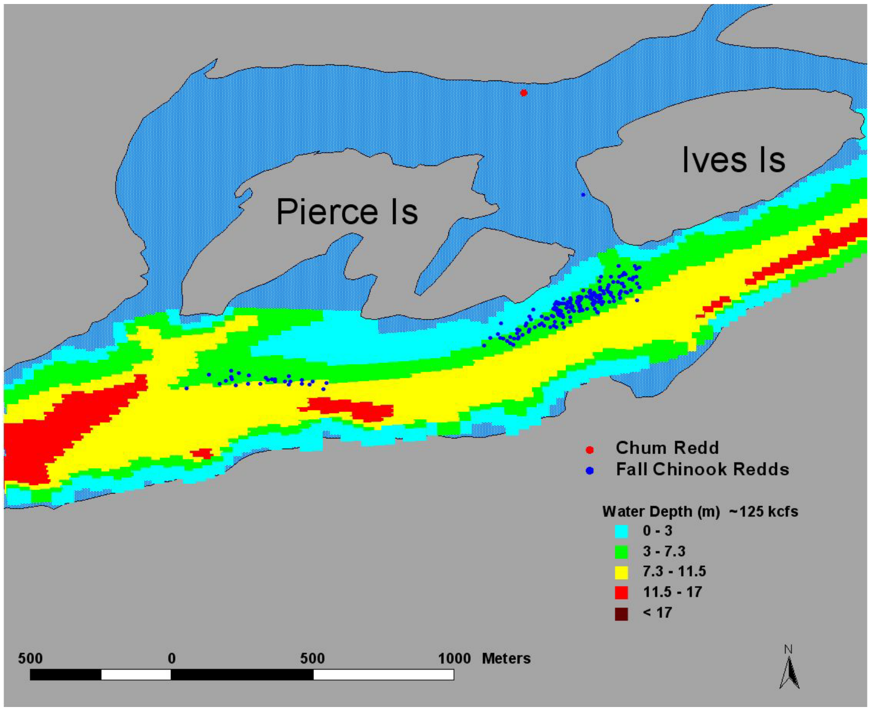

Figure 1.3. Location of Fall Chinook and Chum Salmon Redds (n = 191) in the Mainstem of the Columbia River Below Bonneville Dam in 2005

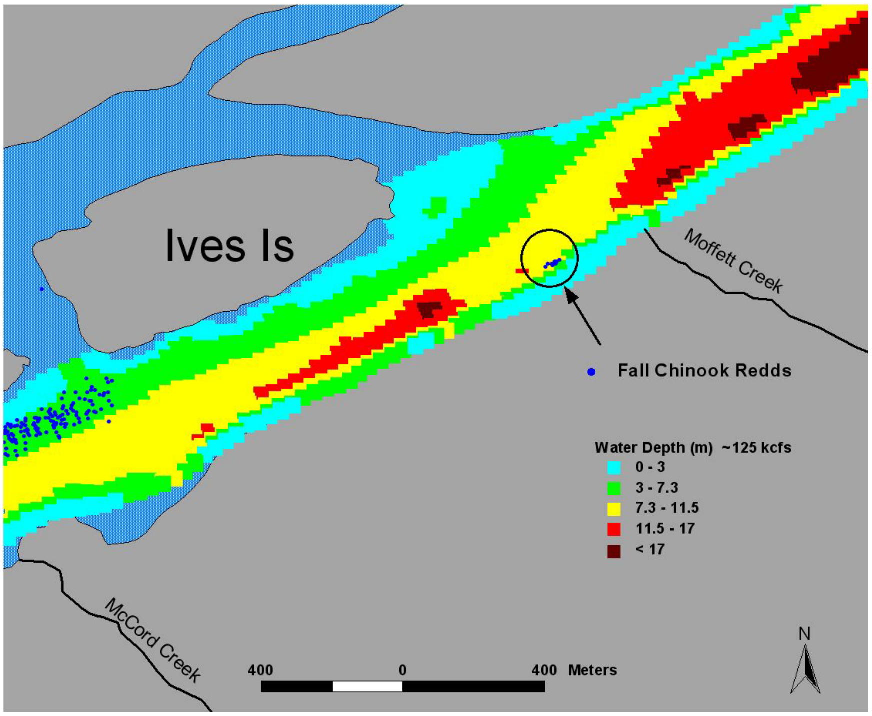

Figure 1.4. Distribution of Fall Chinook Salmon Redds (n = 190) Relative to Water Depth During the November and December 2005 Surveys in the Primary and Secondary Search Zones (river flow ~121 kcfs)

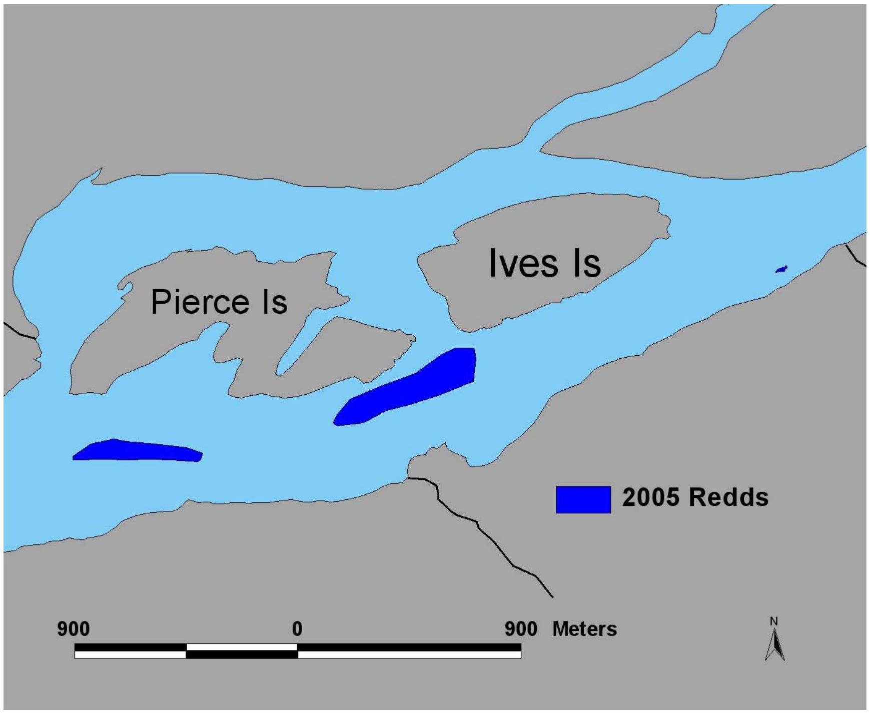

Figure 1.5. Fall Chinook Salmon Spawning Area for Redds Found During 2005

Table 1.3. Estimated Number of Fall Chinook Salmon Redds Occurring in the Primary and Secondary Search Zones near Ives and Pierce Islands, November 28 and 29, 2005, 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	4,738	6.9	105	1,522	5,176
Secondary	1,734	5.4	10	183	624
Total	6,472		115	1,705	5,800

(a) Area coverage within the preferred spawning zones; boat track and average transect length in each based on a 1.5-m vertical video field view along each transect.

of Pierce Island and near the mouth of Hamilton Creek as well as the PNNL deepwater redd counts, is listed in Table 1.4. The population estimate for 2005 was lower than those for the previous two years and similar to that for 2002.

In addition to the PNNL deepwater surveys conducted during 2005, a shallow-water survey was conducted by personnel from the ODFW. The ODFW recorded a peak number of 319 fall Chinook salmon redds on November 15, 2005, by wading or from a boat in water less than 2 m deep (van der Naald et al. 2005). 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 (Fish Passage Center 2005). The redd locations were plotted along with redds found by PNNL in the nearshore region, and no overlapping redd coordinates were found.

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[b]	1,705	2,024	6,882

(a) Expansion factor or 3.4 fish/redd.
(b) Excluded fall Chinook redds found downstream of Moffett Creek.

Chum Salmon Spawning Surveys

A survey within Hamilton Slough was conducted on November 29. Only one chum salmon redd was identified, approximately 610 m downstream of Hamilton Creek at a water depth of 0.61 m. Several chum salmon carcasses were found in water depths ranging from 0.6 to 2.5 m. An additional survey for chum salmon was conducted at the Interstate 205 bridge site on December 7, 2005. Seven chum salmon redds were found at the upper site and one at the lower (downstream site) (Figure 1.6). Water depth at which chum salmon redds were found ranged from 1.5 to 3.1 m. No live fish were observed.

Discussion

A total of 191 fall Chinook salmon redds were found near the vicinity of Ives and Pierce islands downstream of Bonneville Dam in 2005. That number is lower than those counted during the three previous years (Mueller 2005). It may be a result of a lower overall run size at Bonneville Dam in 2005—417,100 adult fish compared to the average of approximately 597,100 for the 2003 and 2004 runs. The number of redds found in 2005 was very similar to that of 2002 when 192 redds were found, with a similar run size of approximately 474,500 adult fish. The proportion of fish using the primary and secondary spawning areas adjacent to Pierce Island was lower than what was found for 2003 and 2004 (Figure 1.7). This may be explained by the general smaller spawning population and fish selecting optimal conditions that exist in the upper (primary) spawning location. The general size of the preferred spawning area was roughly 10.1 ha in 2005, which was smaller than that of the previous two years and similar to that of 2002 when a similar number of fall Chinook salmon were counted at Bonneville Dam (Table 1.5).

River flow conditions were generally stable during the spawning period (mid to late November), with flows averaging 125 kcfs at Bonneville Dam and a tailrace elevation of 11.7 ft.

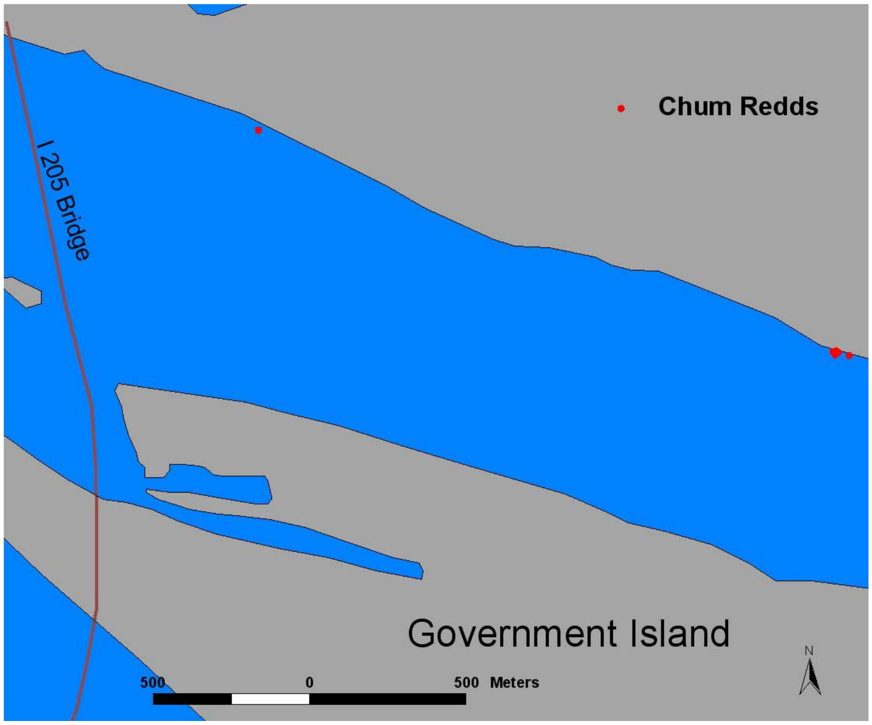

Figure 1.6. Location of Chum Salmon Redds Found During Boat-Based Surveys Near the Interstate 205 Bridge

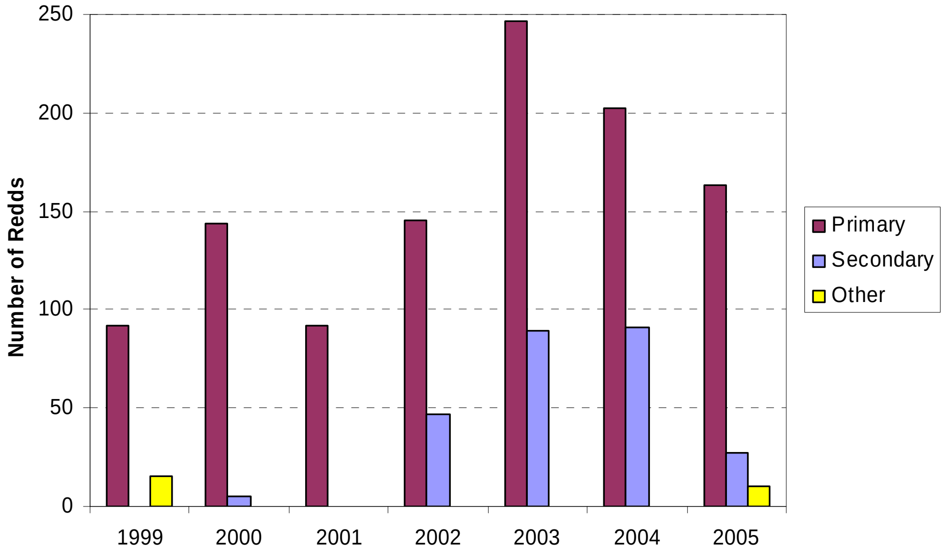

Figure 1.7. Proportion of Fall Chinook Salmon Redds Found in the Primary and Secondary Spawning Zones Adjacent to Pierce Island

Table 1.5. Fall Chinook Redd Counts and Approximate Spawning Areas Near Ives and Pierce Islands, 1999–2005

Year	Redds (n)	Approximate Spawning Area (ha)
1999	64	4.0
2000	76	6.3
2001	43	4.9
2002	192	9.3
2003	336	13.7
2004	293	14.6
2005	190	10.1

The maximum water depths at which redds were detected during 2005 near the Ives/Pierce Island complex was 7.9 m, with an average depth of 2.4 m in the primary and 5.0 m in the secondary zone. Mean water depth for fish spawning in the mainstem downstream of Moffett Creek was 8.1 m. Fall Chinook salmon are known to use deeper water for spawning and have been reported to spawn at depths of 8 to 9 m (Dauble et al. 1999; McMichael et al. 2003; PNNL, unpublished data). Water turbidities were near ideal for conducting video surveys during the first survey and increased to 3.4 NTU during a portion of the second survey, which limited our video footprint somewhat. River flows were consistent during the first survey period at approximately 126 kcfs and ranged from 151 to 102 kcfs during the second. The relatively stable flows during the spawning period were not likely to have influenced habitat use and spawn timing.

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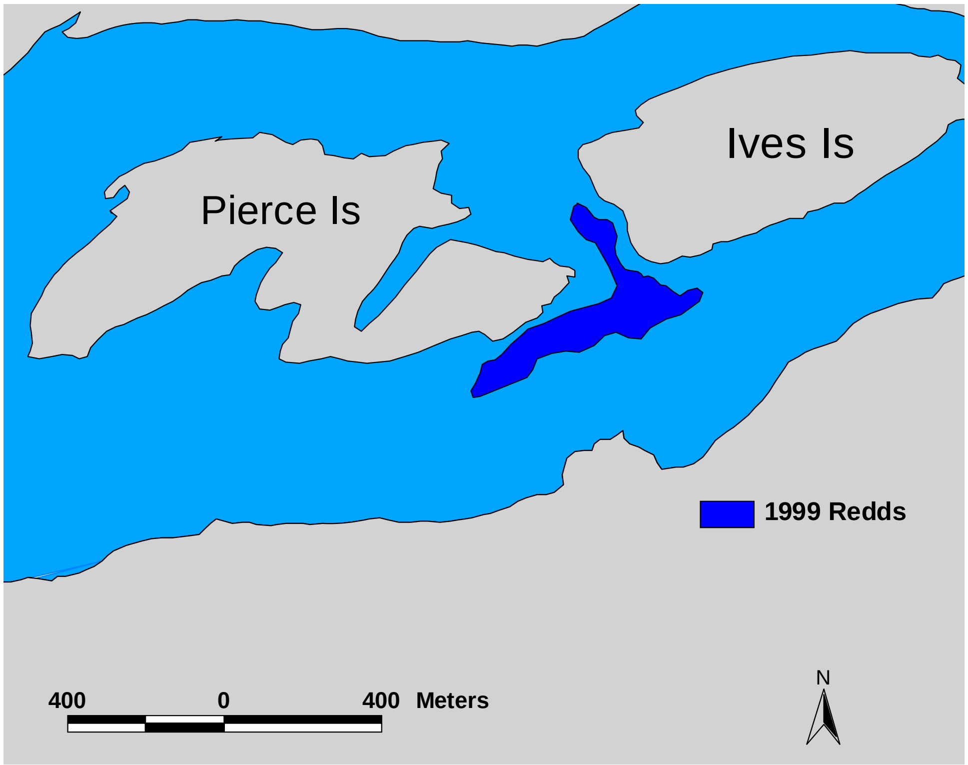
Appendix

Maps Illustrating Fall Chinook Salmon Redd Spawning Areas, 1999 Through 2004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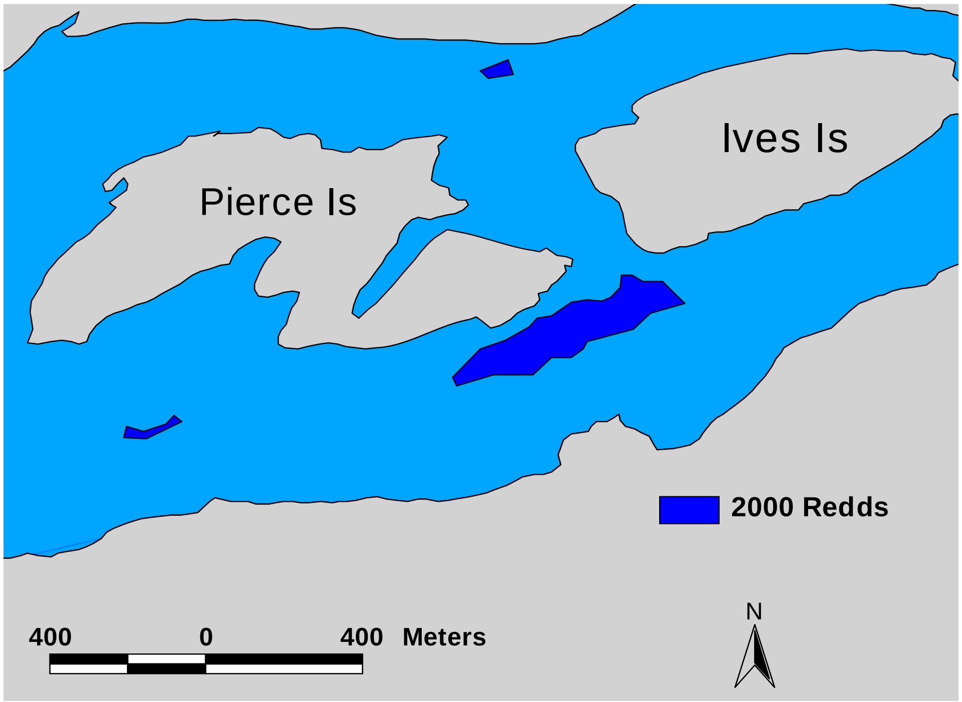
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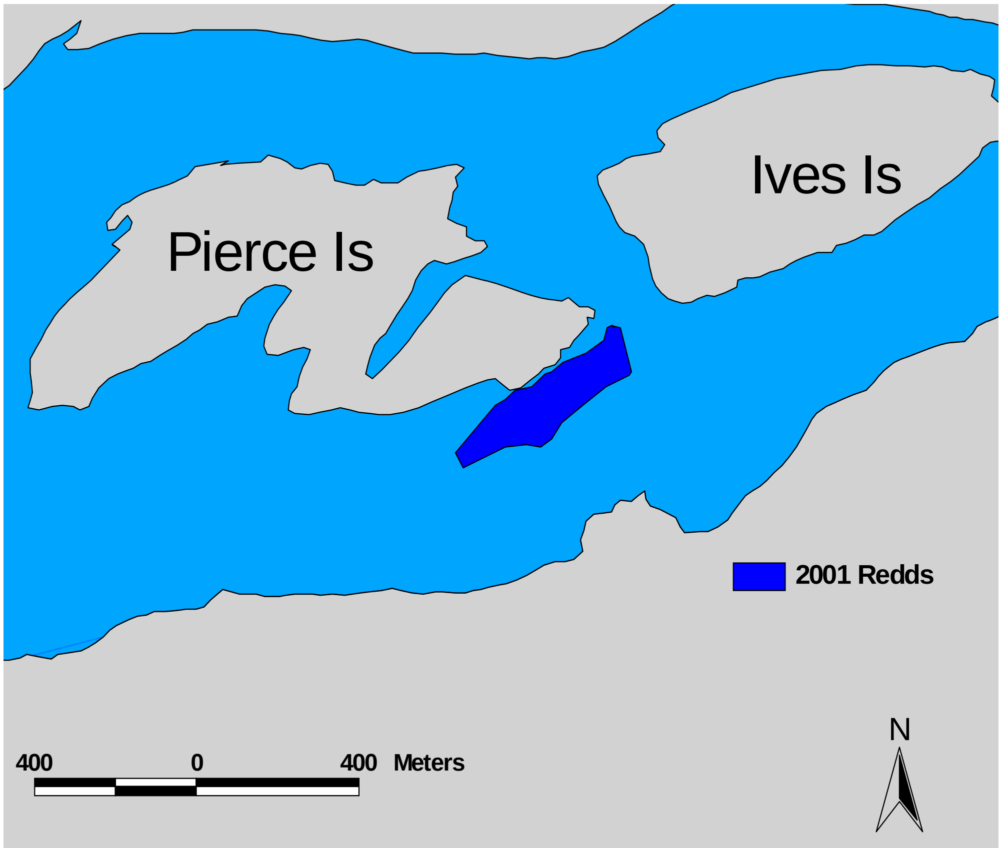
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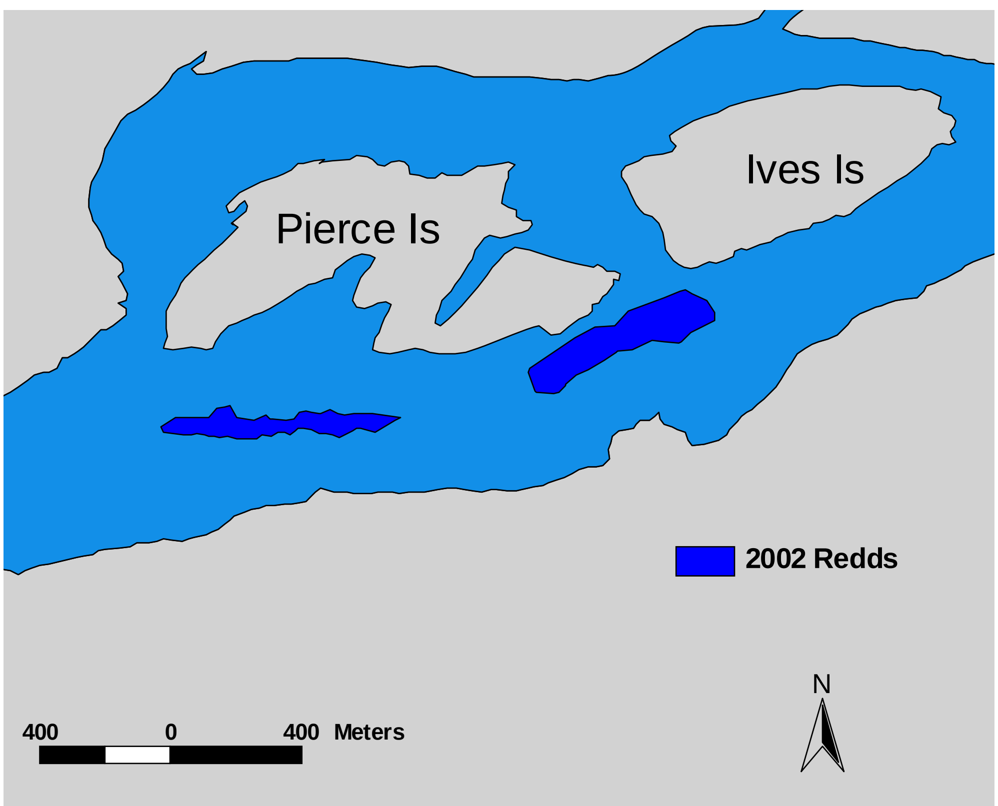
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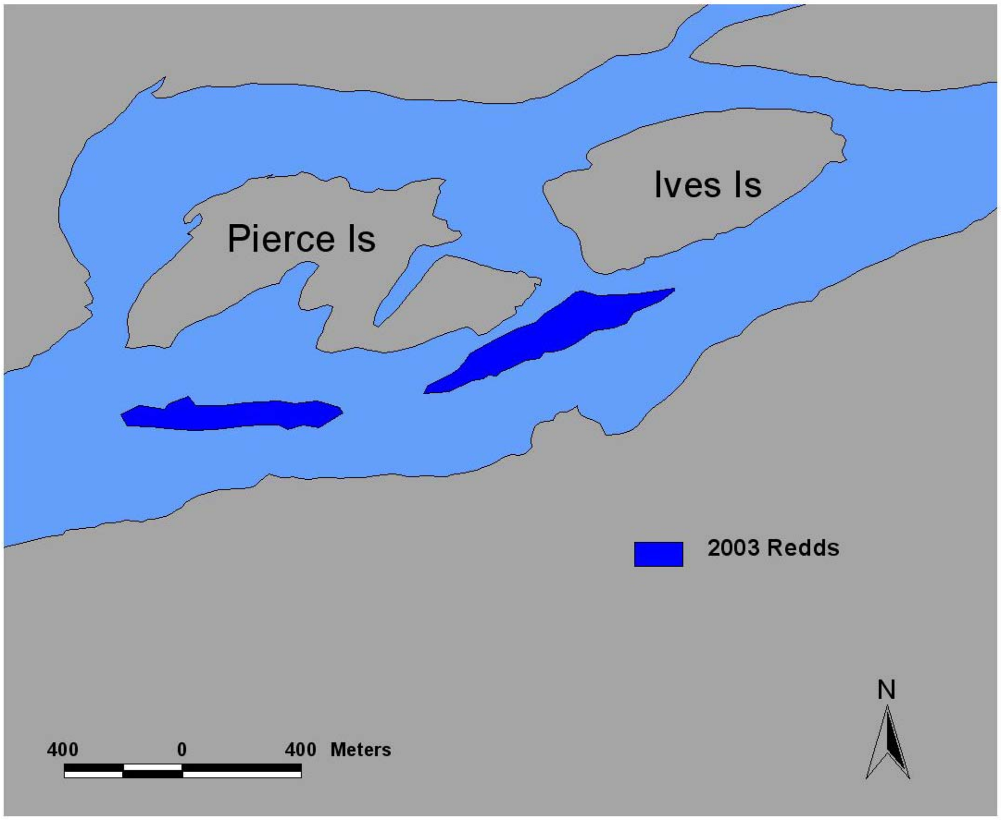
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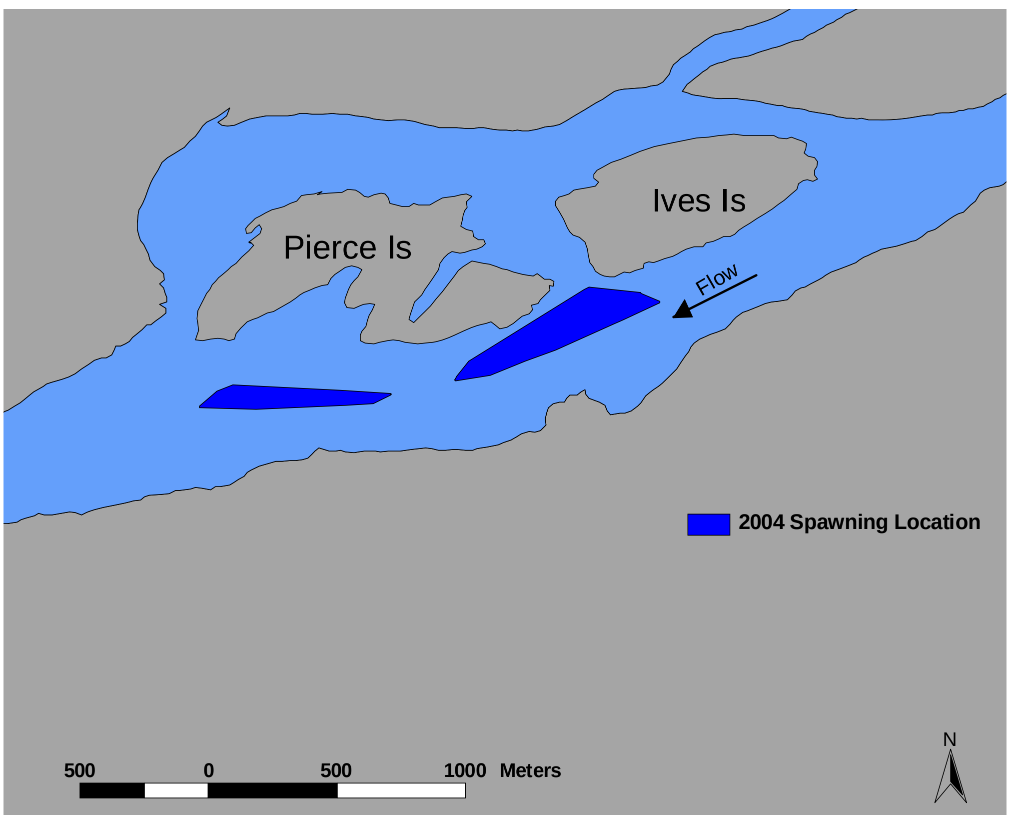
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Chapter 2

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, Christopher J. Murray, Yi-Ju Bott, Jennifer L. Panther,
David R. Geist, and Timothy P. Hanrahan

Summary

From 1999 through 2005, 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 2006, PNNL collected temperature and water surface elevation data from the Ives Island area as well as additional temperature data from newly identified chum salmon spawning locations near Multnomah Falls and the Interstate 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 2006 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 newly identified chum salmon spawning locations at 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 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 the Multnomah Falls and I-205 chum salmon spawning areas. Samples were collected for each position occupied, enabling development of riverbed temperature distribution maps representing a single point in time. 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 11.6°C in Ives Island areas and 10.3°C in I-205 locations, compared to 8.8°C in Ives Island fall Chinook salmon spawning locations. Temperature mapping results showed that bed temperatures were significantly warmer than river temperatures at all chum salmon sites mapped, including Multnomah Falls, 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, run sizes of chum salmon (*Oncorhynchus keta*) and fall Chinook salmon (*O. tshawytscha*) to the Columbia River 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* (National Marine Fisheries 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 [USFWS] and ODFW, 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 to the present, the Bonneville Power Administration (BPA) has 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 located approximately 4 km downstream from Bonneville Dam.

During 1999, Pacific Northwest National Laboratory (PNNL) 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., unpublished manuscript[a]). During 2004, the USFWS and WDFW confirmed the presence

(a) Geist DR, EV Arntzen, CJ Murray, KE McGrath, Y-J Chein, and TP Hanrahan. "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* (in review).

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 bridge near Vancouver, Washington. The third, known as Rivershore, is on the north bank approximately 3 km east of the I-205 bridge. In the 2005–2006 study year, we included those additional sites. Also in 2005, PNNL conducted a preliminary investigation to determine whether hyporheic temperatures were elevated at the additional chum salmon spawning locations and, if so, to determine the distribution of warm upwelling water at each site.

During FY 2006, 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 newly identified chum salmon spawning locations at 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. A major incentive for riverbed temperature mapping is to improve habitat use models by incorporating hyporheic variables (Garland et al. 2003). 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 2005–2006 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). A preliminary analysis of the effect of hydrosystem operation on hyporheic zone characteristics was prepared separately and submitted for publication (Geist et al., unpublished manuscript[a]).

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.

(a) Geist DR, EV Arntzen, CJ Murray, KE McGrath, Y-J Chein, and TP Hanrahan. "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* (in review).

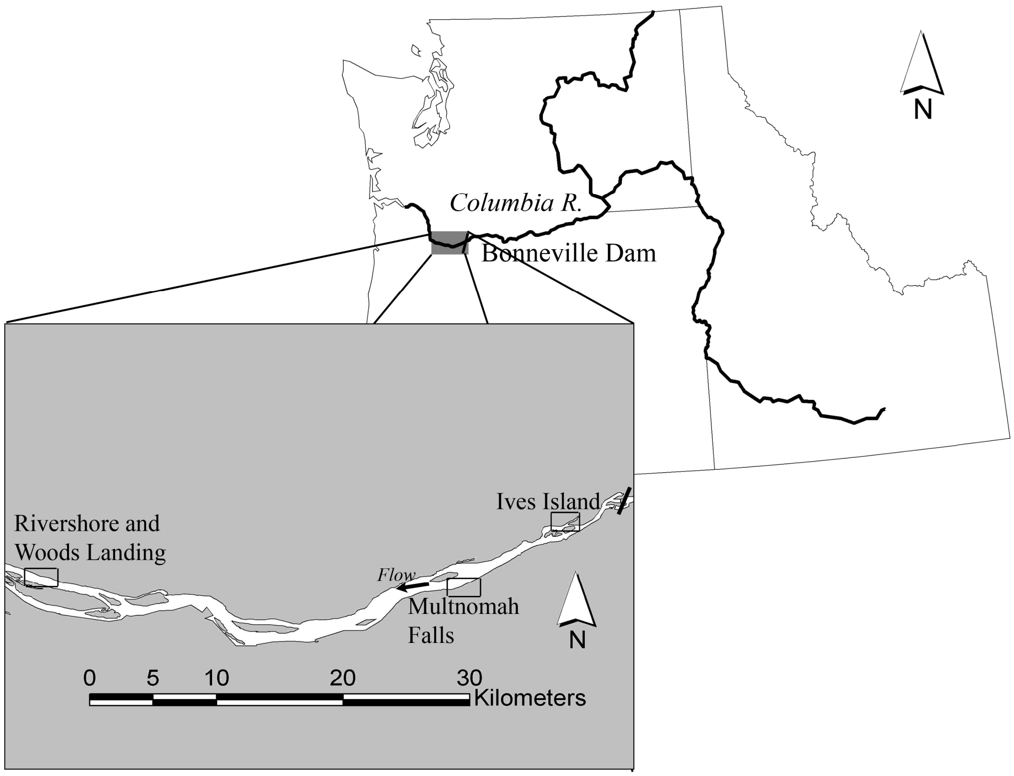


Figure 2.1. Ives Island, Multnomah Falls, and Interstate 205 Rivershore and Woods Landing Spawning Areas

Methods

Temperature and Water Surface Elevation Monitoring

We used 11 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, T1MC, 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 2005–2006, locations T2RB, T4LB, T4MC, T4RB, and T5MC were refurbished and 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) or Onset Optic Stowaway loggers (Onset Computer Corp., Pocasset, Massachusetts; temperature accuracy ±0.2ºC). We installed one additional piezometer and deployed one Solinst temperature logger in the mouth of Hamilton Creek. On October 11, 2005, we installed one new pair of piezometers each at Multnomah Falls, Rivershore, and Woods Landing (Figure 2.1). The hyporheic piezometers were screened at egg pocket depth within the

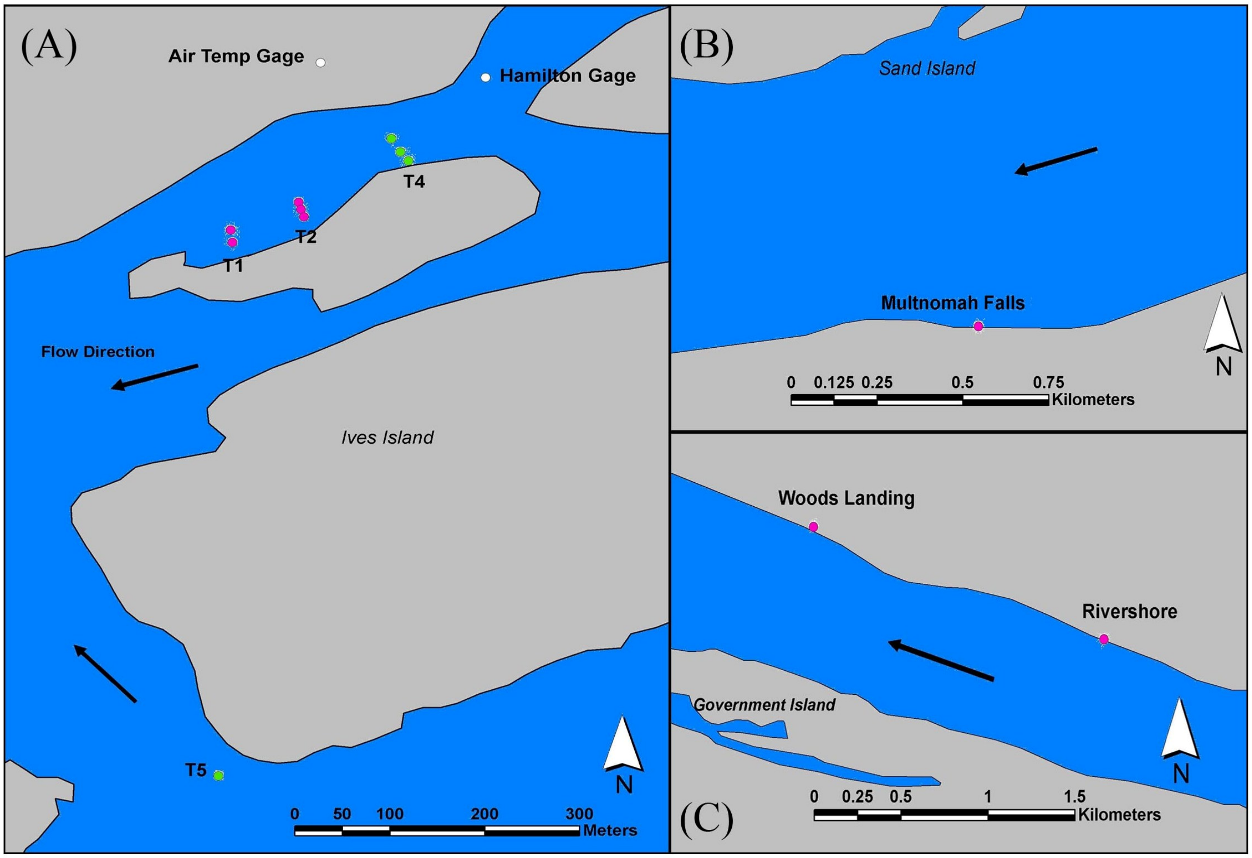


Figure 2.2. Piezometer Locations in Chum Salmon Spawning Areas (red circles) and Fall Chinook Salmon Spawning Locations (green circles) at A) Ives Island, B) Multnomah Falls, and C) Woods Landing and Rivershore Sites

riverbed, and the river piezometers were screened above the riverbed. In each piezometer, we deployed a Solinst Model 3001 LT levelogger to collect hourly temperature data. 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 from sensors at the Ive4s, Multnomah Falls, and I-205 sites are included in Appendix C.

Two-Dimensional Riverbed Temperature Mapping

Water temperatures of the river and riverbed were mapped at Multnomah Falls and the I-205 sites during December 5–6, 2005. Our methodology was similar to previous work done to map river and riverbed temperatures in the Ives Island area (Geist et al. 2002). A total of 54 transects were spaced 10 to 20 m apart throughout the study site (Figure 2.3), for a total of 177 sampling locations. At points spaced approximately every 10 m along each transect, a post-pounder was used to drive a customized temp-erature 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

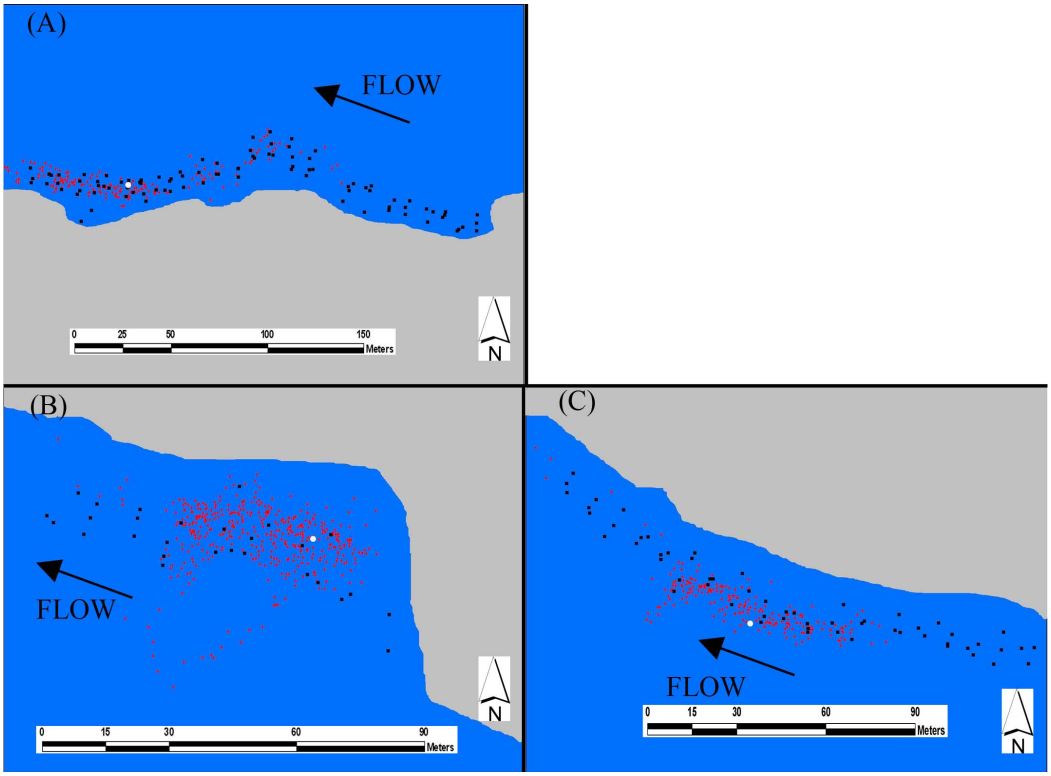


Figure 2.3. Chum Salmon Redd Locations from 2003–2004 (red circles), Piezometer Locations (white circles), and Temperature Mapping Points (black squares) at A) Multnomah Falls, B) Woods Landing, and C) Rivershore Sites

(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.

Comparison of the river and hyporheic temperature data for each site was performed using a series of paired hypothesis tests. The Bonferroni correction was used to account for multiple t-tests. The paired hypothesis tests were performed using SYSTAT 11 (Systat Software, Inc., San Jose, California). 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. Ordinary kriging is a geostatistical method based on a generalized form of linear regression that allows one to incorporate an explicit model of the spatial variability of a variable in the interpolation process. Variogram analysis (Isaaks and Srivastava 1989) provides a method for estimating the spatial variability of random variables and fitting a model to their spatial variability. Because of the directionality of the spatial variability of both bed and river temperature data found during the variogram modeling, we applied an elliptical search pattern with a radius of approximately 80 m along the river and approximately 40 m across the river in the kriging interpolation.

We calculated the distances between chum salmon redds at the three sites (Figure D.2) and determined that the maximum distance between chum salmon redds was approximately 12 m. We then chose spawning and non-spawning grid nodes from the ordinary kriging grid of bed and river temperatures and the grid of temperature differences for each of the three sites. The spawning grid nodes were the grid nodes that were closest to 35 randomly chosen chum salmon redds at each site. We randomly chose 35 grid nodes that were at least 12 m from the nearest chum salmon redd and designated those as non-spawning nodes. The temperature distributions for the spawning and non-spawning nodes were compared using SYSTAT 11 to calculate the summary statistics, plot box plots of temperature, and apply two-sample t-tests on the mean of the temperature of spawning compared to non-spawning grid nodes.

Temperature mapping data and their statistical summaries from the Multnomah Falls 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 58 Onset data loggers (HOBO Water Temp Pro) deployed from October 12 through December 7, 2005, in Ives chum salmon and fall Chinook salmon spawning areas. Four sensors were removed by the river or by other causes; we recovered a total of 54 Onset loggers (Figure 2.4). Onset sensors were spaced 10 m apart along transects labeled N1–N9 (Figure 2.4). Sensors within each transect were labeled alphabetically (N1A, N1B, N1C, and so on) from left bank to right bank. Sensors on transect N9 were placed at only locations N9C and N9D; sensors at locations N2C, N2D, N4E, and N6G were lost.

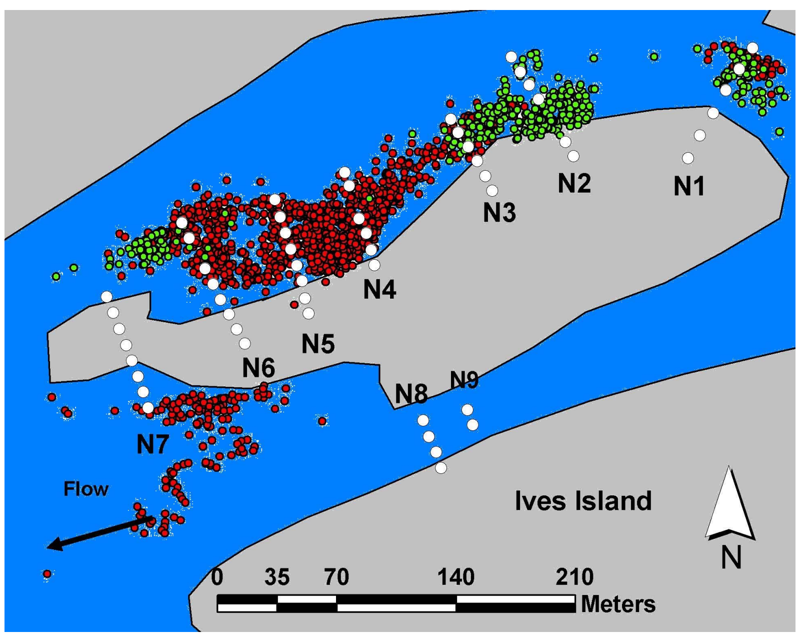


Figure 2.4. Onset Sensors (white circles) As Spaced on Transects. Along each transect, sensor locations were labeled A, B, C, and so on, progressing from left bank toward the right bank. Redd locations for chum salmon (red circles) and fall Chinook salmon (green circles) are based on redd surveys conducted during 2000–2005.

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 2.5. 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. We first established a control point at the end of each transect. We then used a Leica automatic level (Model NA730) to determine the elevation change between each rebar stake (with Onset sensor attached) and its associated survey stake (at the end of each transect). The automatic level was then used to survey the elevation change between the control point at the end of each transect and the USFWS survey stake. Once the vertical elevation of each rebar stake was determined, we subtracted the distance of the sensor tip (20 cm) from the top of the stake to determine the vertical elevation of each sensor. All elevations were surveyed at least two times so the most probable elevation, most probable error, and degree of accuracy could be computed (Fogiel 1983).

Survey results and associated accuracy are included in Appendix E.1.

Following data collection, it was necessary to evaluate time periods during which the sensors were dewatered and therefore when the temperature data were not representative. We compared the vertical elevation of each sensor to Ives area water-surface elevations (WSE) recorded at T2MC bed (these WSE data were collected as part of Objective 1 using a PT2X sensor). The elevation of the sensor within the riverbed at T2MC was 4.79 ft (NGVD 29). This elevation was lower than any of the Onset sensors, suggesting the WSE data there could be used to evaluate dewatering. Additionally, the sensor at T2MC was centrally located (as compared to most of the Objective 3 Onset sensor locations), further suggesting that using T2MC WSE data were appropriate for evaluating dewatering. We assumed that T2MC WSE was sufficiently representative to be used to evaluate dewatering at transects N3 through N9. Transects N1 and N2 were located upstream of a riffle, and it is known that the riverbed elevation is higher there. This meant that, although we could determine periods when N1 and N2 sensors were below the water line, there were periods during which our technique would erroneously conclude that the sensors were dewatered when in fact they were below the water line. To demonstrate how we used T2MC WSE to determine periods of dewatering, an example from several sensors on transect N6 is provided (Figure 2.6). Figure 2.6 shows that sensors near the deeper part of the north Ives Island channel (e.g., N6h) were located at an elevation lower than the WSE elevation for the entire time period (Figure 2.6).[a] However, at locations higher on the riverbank (e.g., N6c), there were periods during which the WSE dropped below the sensor elevation (Figure 2.6).[b] The influence of dewatering on the temperature response is evident during these periods (e.g., N6c from approximately November 19 to November 29, 2005). Some sensors (e.g., N6a) were dewatered for most of the time period, as is reflected by their temperature profile (Figure 2.6).[c] We present all the data collected for Objective 3 in Appendix E.2.

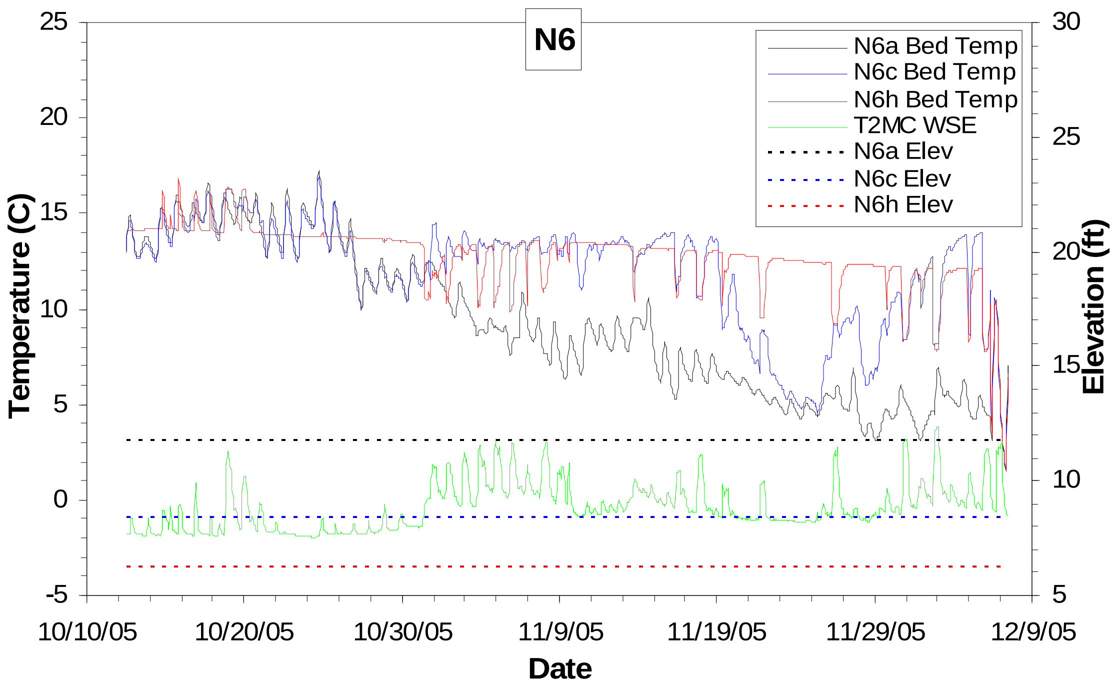


Figure 2.6. Water Surface Elevation (at location T2MC, solid green line) Used To Determine Time Periods During Which Onset Temperature Sensors Were Dewatered (e.g., at N6a). Other solid lines represent the temperature at N6a (black), N6c (blue), and N6h (red). Dashed lines represent elevations of sensors at N6a (black), N6c (blue), and N6k (red).

(a) This is apparent in Figure 2.6 by the dashed red line, representing the elevation of sensor N6h, which is always below the T2MC WSE line.

(b) This is apparent in Figure 2.6 by the dashed blue line, representing the elevation of sensor N6c, which is sometimes above and sometimes below the T2MC WSE line.

(c) This is apparent in Figure 2.6 by the dashed black line, representing the elevation of sensor N6a, which is always above the T2MC WSE line.

However, we used WSE to provide descriptive flags describing all the temperature data (Appendix E.2). The flags suggest one of two possibilities: 1) a flag of “1” indicates the sensors were below the water line, or 2) a flag of “-1” indicates the sensors were above the water line and therefore dewatered.

Our goal was to collect data that could be later used in conjunction with the USGS to evaluate whether spawning behavior is influenced by hyporheic temperature cues during surface water elevation fluctuations. In this chapter, we present the data, suggest time periods when they should not be used (due to sensor dewatering), and discuss general trends. We have not statistically summarized the data or attempted to evaluate their influence on spawning behavior.

We used Tecplot to generate an animation of the temperature data recorded using the onset sensor network (Appendix E.3). 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.

Results and Discussion

Temperature and Water Surface Elevation Monitoring

The time period during which bed and river data were successfully collected varied, as did the type of sensors used to collect the data. Data among sensor types are comparable, within the accuracy limits of the sensors. 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 2005 through September 2006 are presented in Appendix C. During 2005 through 2006, riverbed and river water temperatures were provided to the ODFW, WDFW, and the Fish Passage Center to assist federal and state agencies in estimating chum and fall Chinook salmon emergence timing, and to help determine time periods when 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 Figure 2.7, data from partial records were not used in statistical comparisons. Comparative statistics are provided as general descriptions; more rigorous analyses should be conducted by, and are the responsibility of, data users. 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 2000–2005 (USFWS, ODFW, unpublished data) and piezometer locations within a geographic information system. 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.

Data may be unavailable or missing at a location for a variety of reasons. The most common sources of data loss were data logger malfunction and data logger loss. Several data loggers were found at the bottom of their piezometers with the cable suspending them severed. High discharge during spring runoff 2006 caused riverbed scouring and subsequent damage to the river sensor at T2MC, where the damaged sensor was unable to collect data from mid May 2006 through mid September 2006 (when the sensor was repaired).

In the Ives Island area, temperature patterns observed during October 2005 through June 2006 were generally similar to those observed during previous years by Arntzen et al. (2006). Mean (SD) bed temperatures in Ives chum salmon spawning areas ranged from 10°C (2.8°C) at T2RB to 12.7°C (3.1°C) at T2MC (Figure 2.7). Composite mean bed temperature in Ives chum salmon areas was 11.6°C (3.1°C). Composite mean (SD) river temperature in chum salmon spawning areas was 10°C (4.08°C) (Figure 2.6). Mean (SD) temperatures in Ives fall Chinook salmon spawning areas ranged from 8°C (4.3°C) at T4LB to 10°C (4.1°C) at T5MC (Figures 2.7 and 2.8). The composite mean (SD) bed temperature in Ives fall Chinook salmon spawning areas was 8.8°C (4.3°C), while the composite mean (SD) river temperature in Ives fall Chinook salmon spawning areas was 8.8°C (4.4°C). Mean (SD) surface water temperature in the mouth of Hamilton Creek was 8.6°C (3.8°C).

In other lower Columbia River chum salmon spawning locations (i.e., Multnomah Falls, Rivershore, and Woods Landing), mean (SD) bed temperatures ranged from 9°C (2.3°C) at Rivershore to 10.9°C (0.04°C) at Woods Landing (Figure 2.9). Most of the bed temperature data at Multnomah Falls were lost due to sensor failure. Composite mean (SD) bed temperature for Rivershore and Woods Landing was 10.3°C (1.5°C). The mean river temperature was not representative of the entire study period at the Multnomah Falls and Rivershore locations, where only partial river data sets were available (Figure 2.9). At Woods Landing, mean (SD) river temperature was 10.1°C (1.5°C).

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 2.7). 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), bed temperatures were several degrees centigrade warmer than adjacent surface water temperatures (Figure 2.7). This was in contrast to fall Chinook salmon spawning locations (i.e., T4RB, T4LB, and T5MC), where riverbed temperatures remained relatively similar to surface water temperatures (Figures 2.7 and 2.8). In general, surface water temperatures were more variable than bed temperatures in Ives chum salmon spawning areas during high-water periods (i.e., January through February and April through June at T1LB and T2LB). During lower-water periods (i.e., October through December and March), the bed temperatures were more variable in chum salmon spawning areas than the river temperatures. This suggests that, during periods of relatively low water, the interaction between groundwater and surface water is more strongly influenced by river discharge/stage. Despite river stage fluctuations during periods of generally high water, the bed temperatures at chum salmon spawning locations seem relatively unaffected. The variability of bed temperature and river temperature in Ives fall Chinook salmon spawning areas (i.e., T4LB, T4RB, and T5MC) remains similar throughout the seasons.

Multnomah Falls river temperature data were similar to those collected in the Ives Island area (Figure 2.9). At Multnomah Falls, bed temperature data were largely not available (due to sensor failure). At Rivershore, river data were limited; however, bed temperatures were similar to river responses from upstream locations in the Ives Island area (Figure 2.9). At Woods Landing, bed temperatures were elevated and stable (Figure 2.9). The Woods Landing chum salmon spawning location is adjacent to a spring where subsurface water can be observed discharging into the Columbia River during relatively low river stage. The bed temperature there was extremely stable, despite large fluctuations in the river temperature during October through December, suggesting a zone of nearly constant groundwater discharge into the river. Two bed locations were monitored at Woods Landing at different riverbed

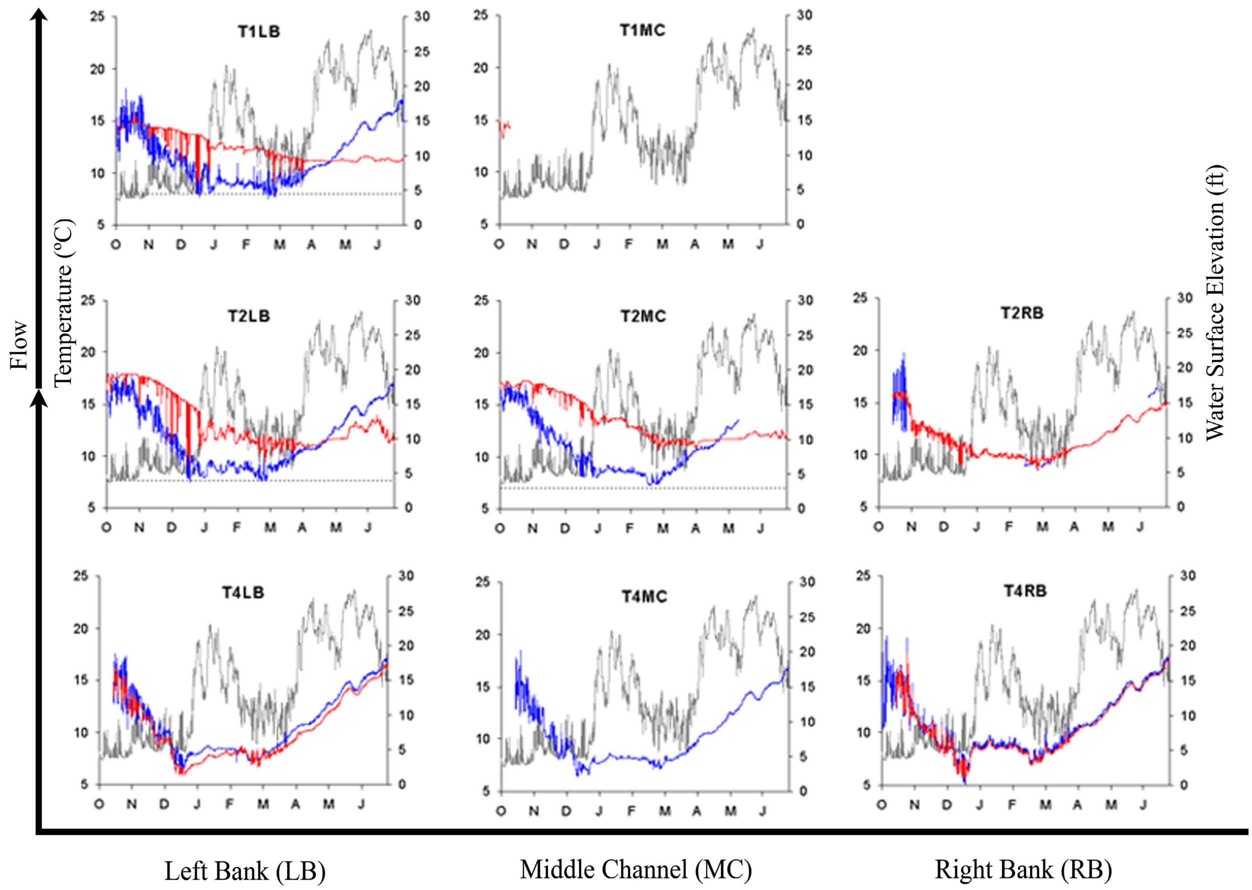


Figure 2.7. Temperature for River (blue) and Hyporheic (red) Sensors Within Channel North of Ives Island. The grey line is water surface elevation (recorded at T2MC). Plots are arranged according to sensor location, with plots at the top farthest downstream and plots on the left along the left bank.

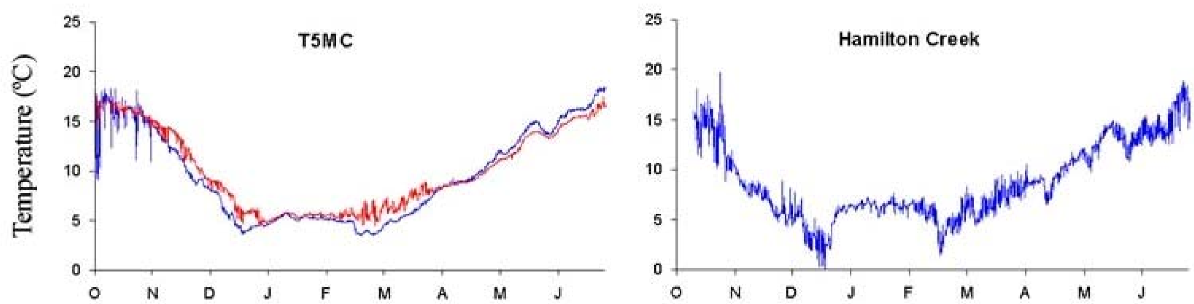


Figure 2.8. Temperature for River (blue) and Hyporheic (red) Sensors for Other Ives Island Locations

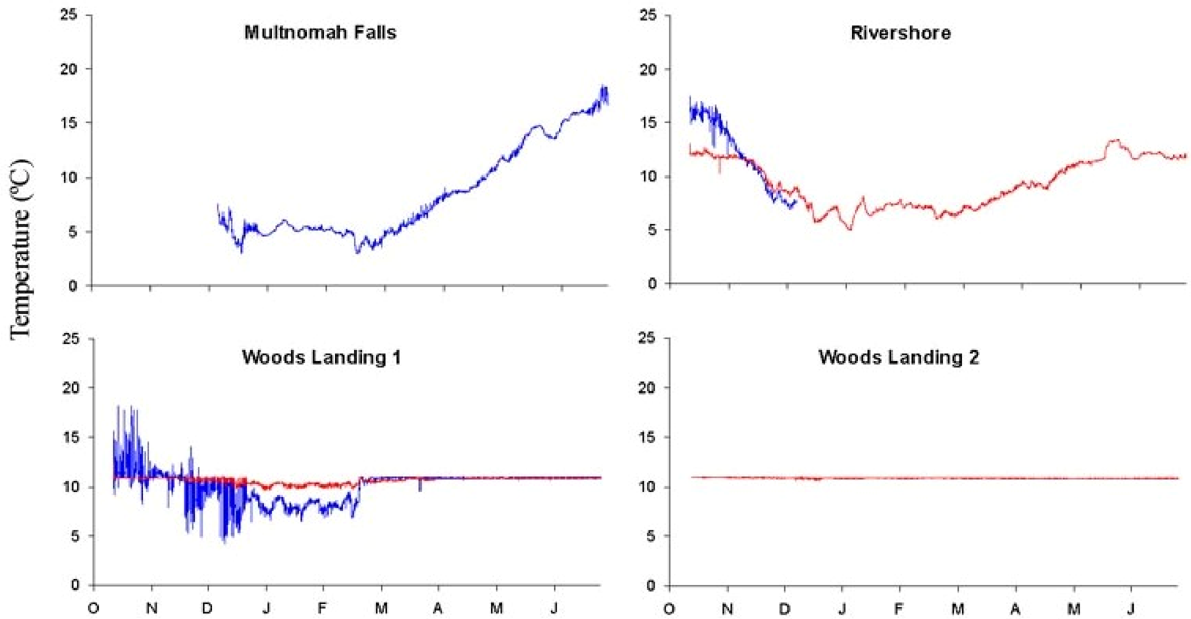


Figure 2.9. Temperature for River (blue) and Hyporheic (red) Sensors at Multnomah Falls, Rivershore, and Woods Landing Sites

elevations. The lower elevation (Woods Landing 1) showed some minor temperature fluctuation during November through February, apparently due to the increased influence of surface water level fluctuations. However, the response was still very stable compared to other chum salmon spawning locations and very similar to the other Woods Landing temperature profile (Woods Landing 2; Figure 2.9).

Two-Dimensional Riverbed Temperature Mapping

We summarized the hyporheic and river temperature data for each site and for the three sites taken together (Appendix D, Tables D.2 and D.3). Comparison of the hyporheic and river temperature found significant differences at all three sites ($P < 0.0005$). The largest mean temperature difference between the hyporheic zone and the river was 1.7°C at Multnomah Falls, with differences of 0.8°C at Rivershore and 0.6°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 12 m at Rivershore and Woods Landing, and 50 m at Multnomah Falls (Appendix D, Table D.4). 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. A visual analysis of the ordinary kriging maps of temperature for the three sites (Figures 2.10 through 2.12) indicates that chum salmon redds tend to be found in areas with high hyporheic temperatures. Examination of the temperature data associated with randomly selected nodes from the temperature grid confirmed this hypothesis (Figures 2.13 through 2.15). At all three sites, the temperatures for randomly selected chum salmon and non-spawning locations were significantly different from one another (Appendix D, Tables D.5 through D.7). The means of the distributions of all of the temperature data at the 35 spawning and non-spawning locations are significantly different ($P < 0.005$) except for river temperature at the Rivershore site (Table D.6).

The results confirm those found by Geist et al. (2002) for chum salmon redds at the Ives Island study area, with the location of chum salmon redds associated with significantly higher hyporheic temperatures than non-spawning areas and temperature differences between hyporheic and river temperatures. The river temperatures at two of the lower Columbia River sites, Multnomah Falls and Woods Landing, are also significantly different between spawning and non-spawning redd locations. This may be due to the shallow river depths and large input of warm spring water at the sites, which appears to have increased the temperature of the river water relative to river water in nearby non-spawning areas. The river temperature map is much more homogeneous at the Rivershore site than it is at the other two sites; compare Figure 2.11 with Figures 2.10 and 2.12.

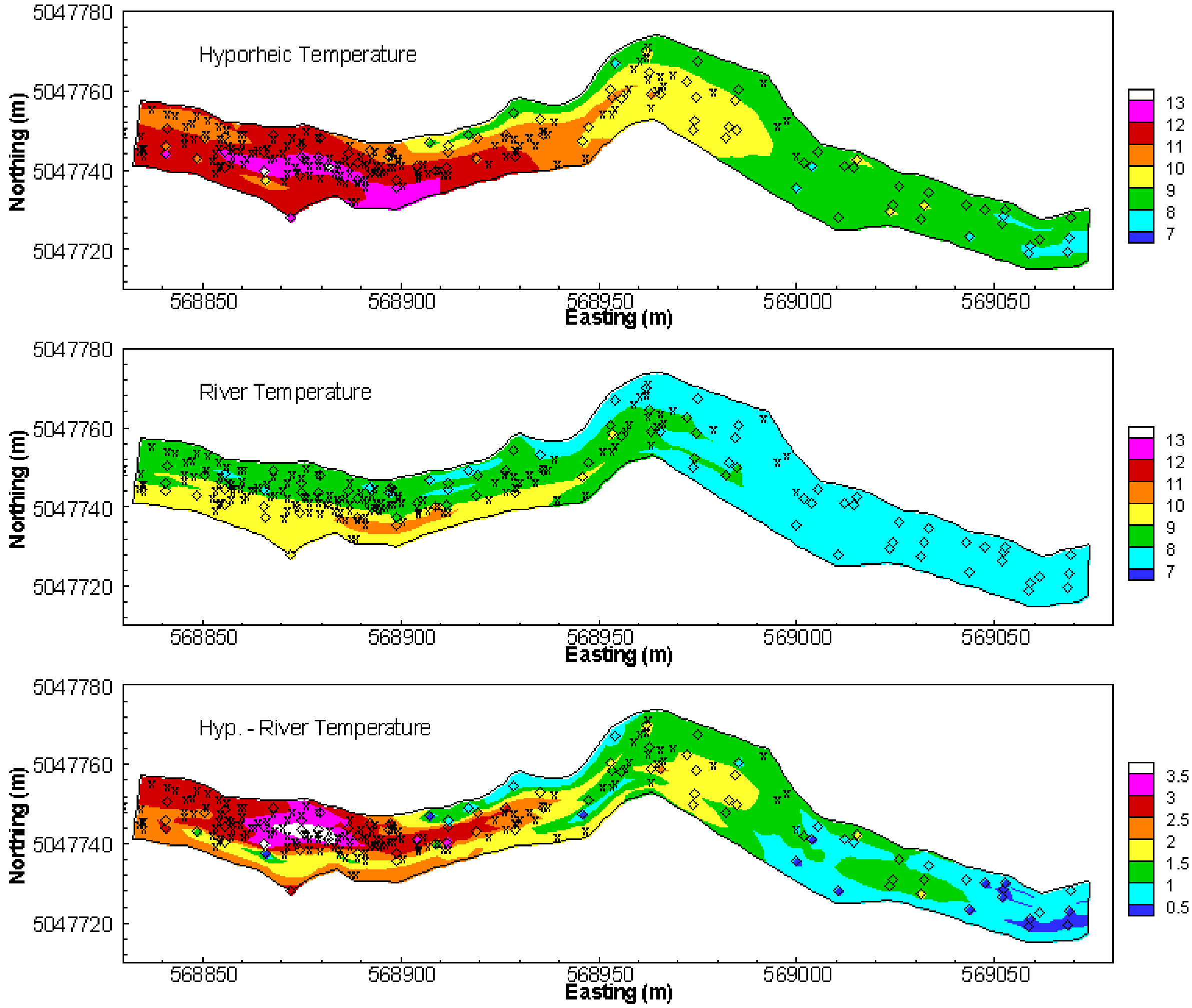


Figure 2.10. Kriging-Estimated Hyporheic Temperature (top), River Temperature (middle), and Calculated Temperature Difference (bottom) at Multnomah Falls Site. Diamonds indicate sample locations; Xs denote chum salmon spawning locations.

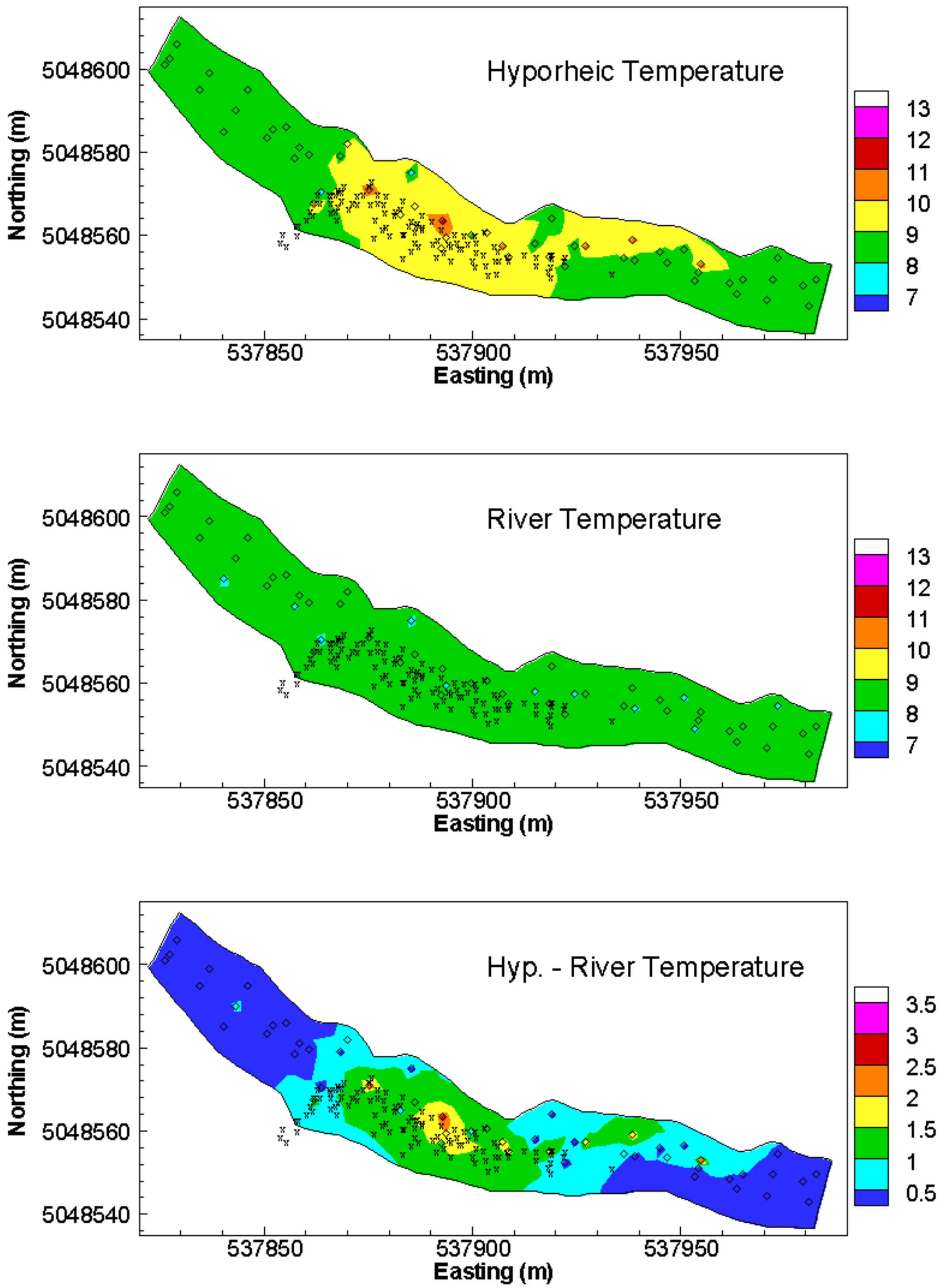


Figure 2.11. Kriging-Estimated Hyporheic Temperature (top), River Temperature (middle), and Calculated Temperature Difference (bottom) at Rivershore Site. Diamonds indicate sample locations; Xs denote chum salmon spawning locations.

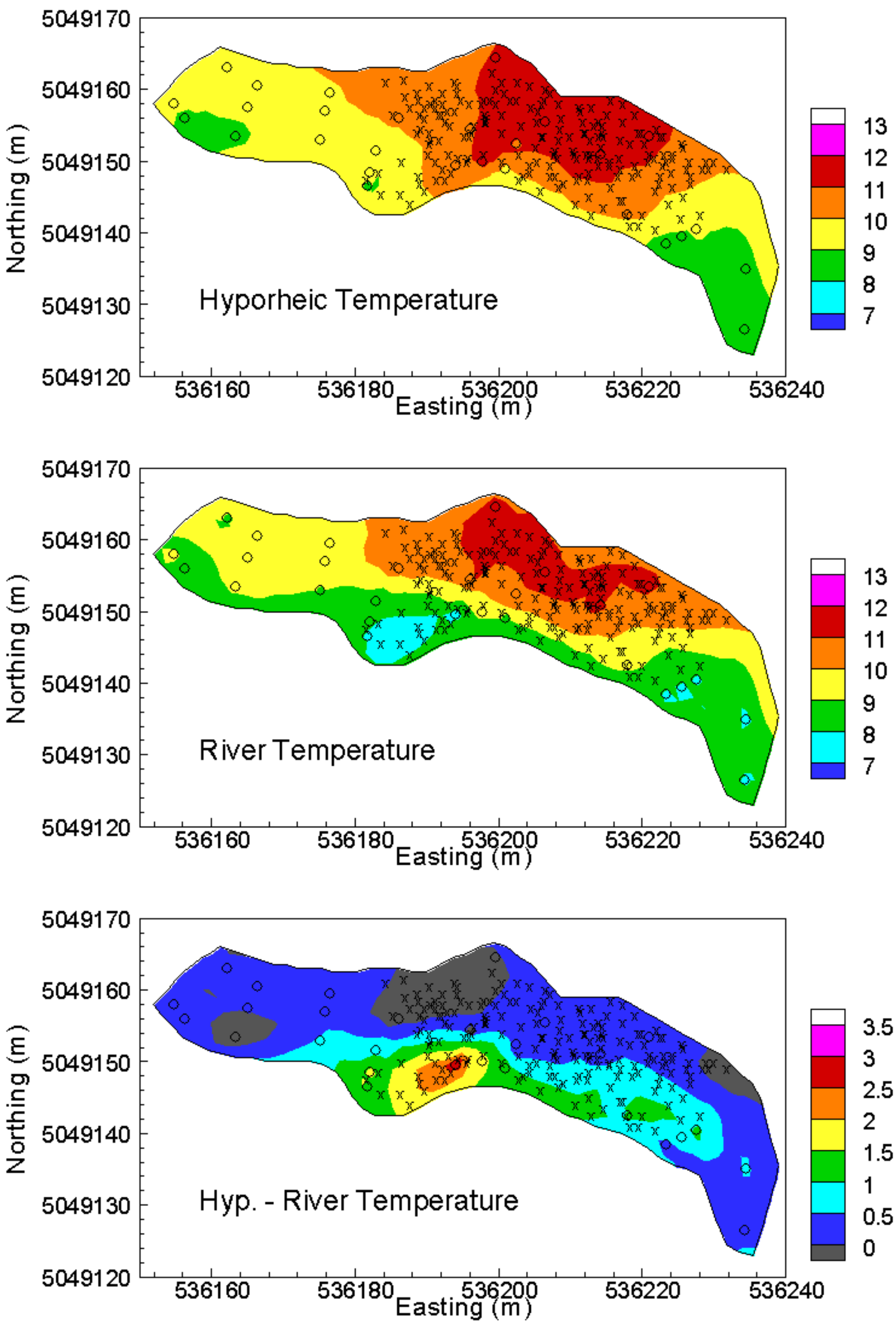
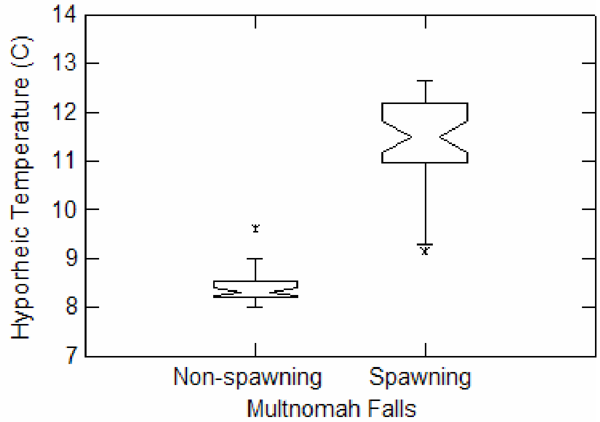
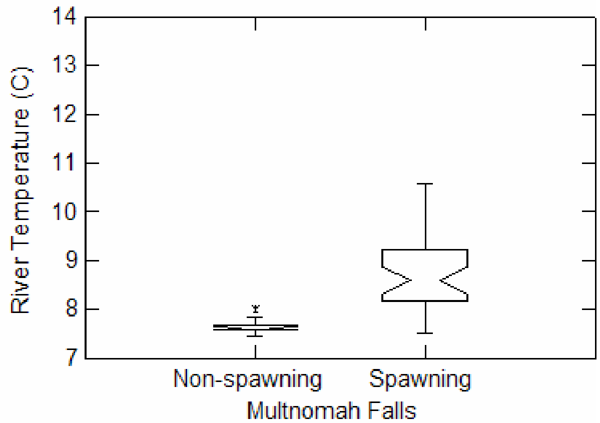


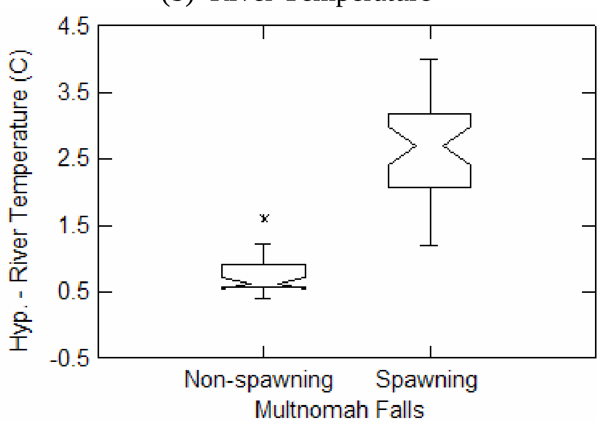
Figure 2.12. Kriging-Estimated Hyporheic Temperature (top), River Temperature (middle), and Calculated Temperature Difference (bottom) at Woods Landing Site. Diamonds indicate sample locations; Xs denote chum salmon spawning locations.



(a) Hyporheic Temperature

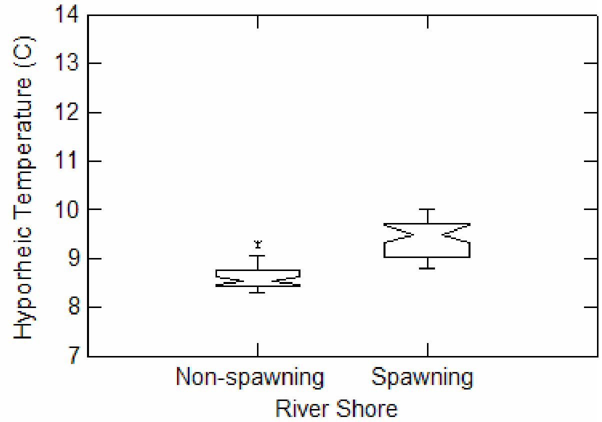


(b) River Temperature



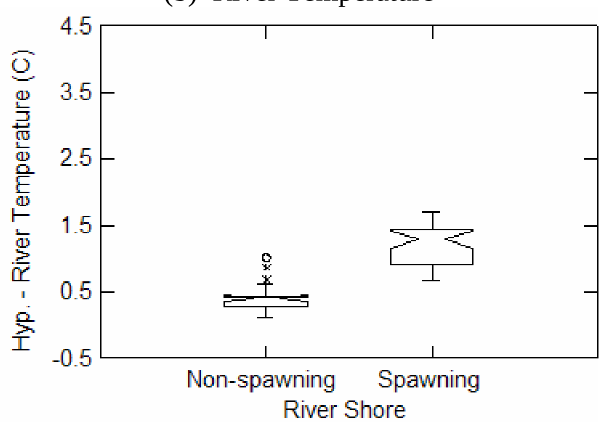
(c) Temperature Differences

Figure 2.13. Temperature Data from 35 Randomly Selected Chum Salmon Spawning and Non-Spawning Locations at the Multnomah Falls Site



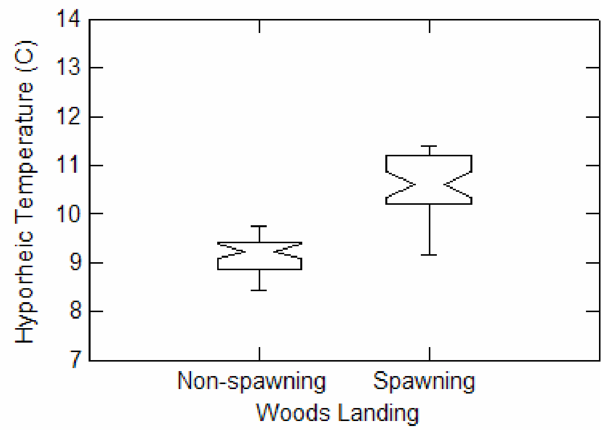
(a) Hyporheic Temperature

(b) River Temperature

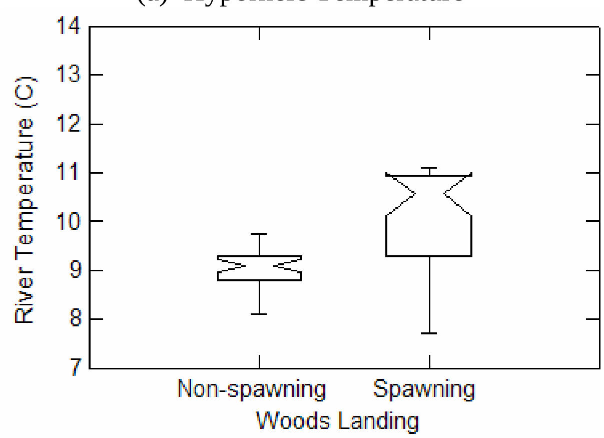


(c) Temperature Differences

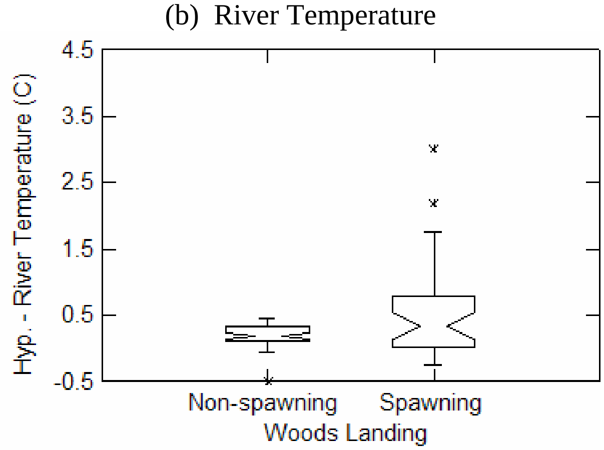
Figure 2.14. Temperature Data from 35 Randomly Selected Chum Salmon Spawning and Non-Spawning Locations at the Rivershore Site



(a) Hyporheic Temperature



(b) River Temperature



(c) Temperature Differences

Figure 2.15. Temperature Data from 35 Randomly Selected Chum Salmon Spawning and Non-Spawning Locations at the Woods Landing Site

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 when sensors were below the water line). During periods of low river stage, relatively warm hyporheic water was present at sensor depth below the riverbed (Figure 2.16) near chum salmon spawning locations (e.g., N6). During periods of high river stage, hyporheic water temperatures more closely resembled the surface water temperature (Figure 2.17). This effect can be further examined in a time-series plot of temperature data from sensors on transect N6, a chum salmon spawning location (Figure 2.18). During late November and early December, the bed temperature at N6h and other nearby temperature sensors remained relatively stable at approximately 12°C when the river stage remained stable at a WSE of between 9 and 9.5 ft (Figure 2.18). On December 1 and 3, 2005, the stage increased by approximately 3 ft, causing bed temperatures to decrease to between 8°C and 9°C (Figure 2.18). These changes were consistent with the temperature response of other N6 temperature sensors that remained below the water line (i.e., N6c–h), although the exact magnitude of the response varied depending on the elevation of the sensor. Sensors that were located above the water line most of the time (i.e., N6a, N6b, and N6i) reflected colder surface air temperature during periods of low river stage and warmed up to temperatures similar to surface water temperatures as they were flooded during high stage periods (Figure 2.18). Despite stage fluctuations during earlier time periods (i.e., late October and early November) that were almost as large, bed temperatures often did not fluctuate as widely during this early time period as they did during late November and early December. This is likely due to the similarity between river and bed temperatures during the early time period (Figure 2.7).

In fall Chinook salmon spawning areas, temperature profiles were generally less influenced by changes in river stage (Figures 2.16 and 2.17), suggesting the predominance of downwelling surface water as has been previously noted (Arntzen et al. 2006). Using an example of time-series hyporheic temperature data from a fall Chinook salmon spawning location (N2) during late November to early December, it is apparent that temperatures (within the wetted channel) of fall Chinook salmon spawning areas were lower than chum salmon areas (Figure 2.19). During this period at N2, hyporheic temperatures ranged from approximately 5°C to 9°C. At N2, there was a lack of warm hyporheic water. This, combined with the relatively high elevation where sensors were placed, caused bed sensor responses to be influenced by cold air temperatures (Figure 2.19). During fluctuations in river stage (i.e., when stage increased), bed temperatures at N2 often increased in response, more closely reflecting river temperatures between 8°C and 9°C (Figure 2.19).

Onset temperature data from each of the 54 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–N9 in response to changes in water surface elevation. The visualization was created for the week of November 29 through December 6, 2005. That visualization is included as a digital file in Appendix E (E.3).

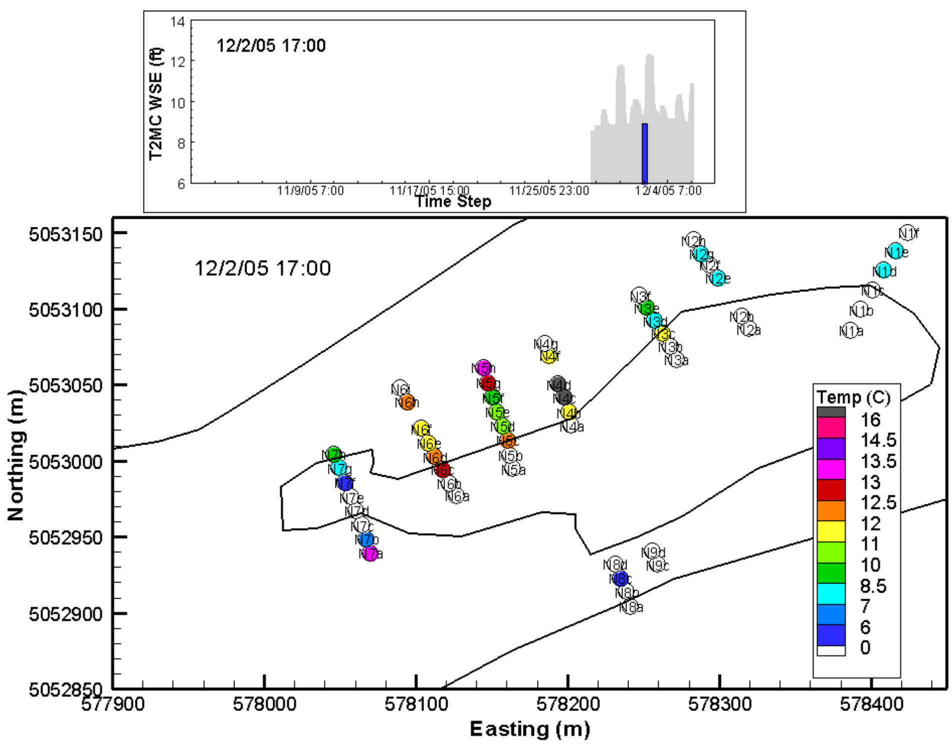


Figure 2.16. Distribution of Onset Temperature Data at Relatively Low River Stage (WSE = 8.884 ft)

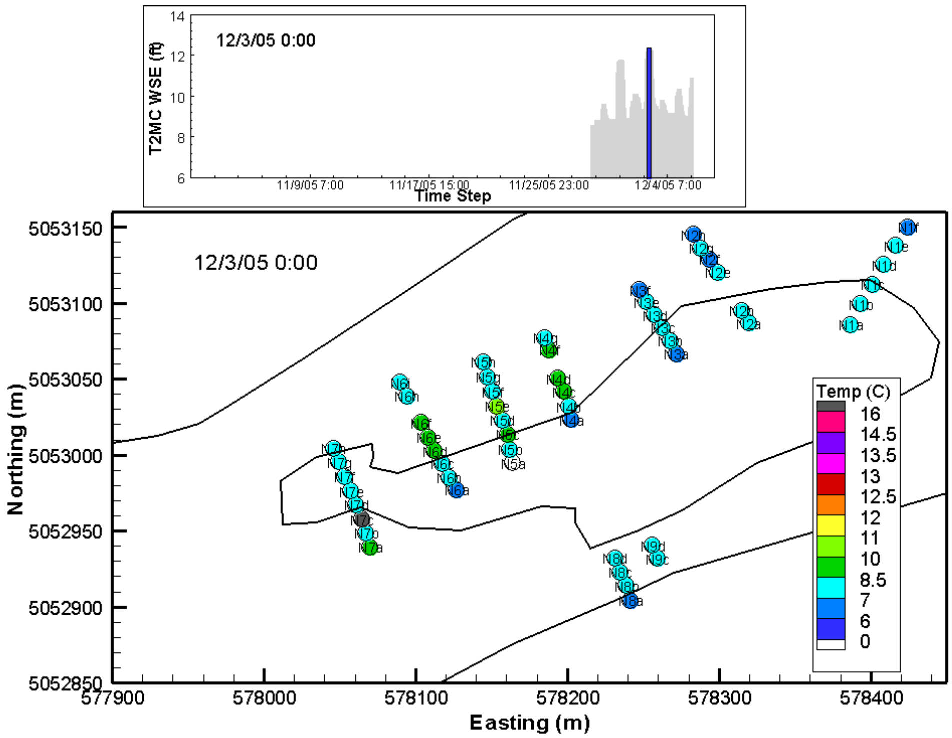


Figure 2.17. Distribution of Onset Temperature Data at Relatively High River Stage (WSE = 12.37 ft)

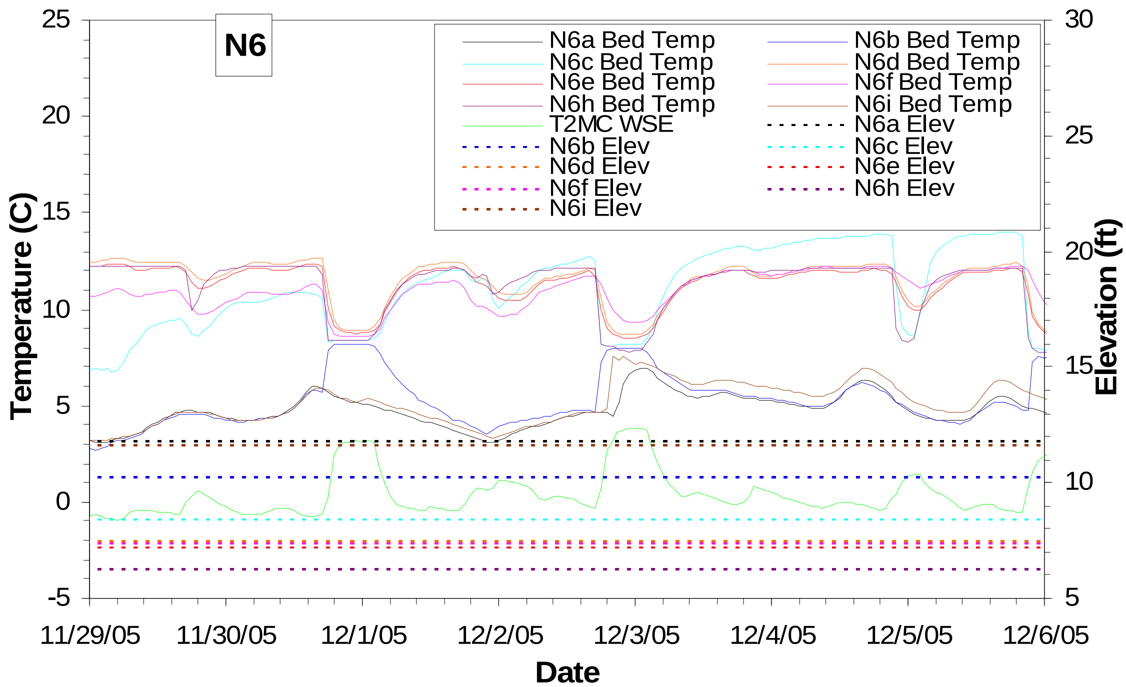


Figure 2.18. Temperature Profile of Buried Onset Sensors in Chum Salmon Spawning Location N6 During River Stage Fluctuation for a One-Week Period During the Chum Salmon Spawning Season

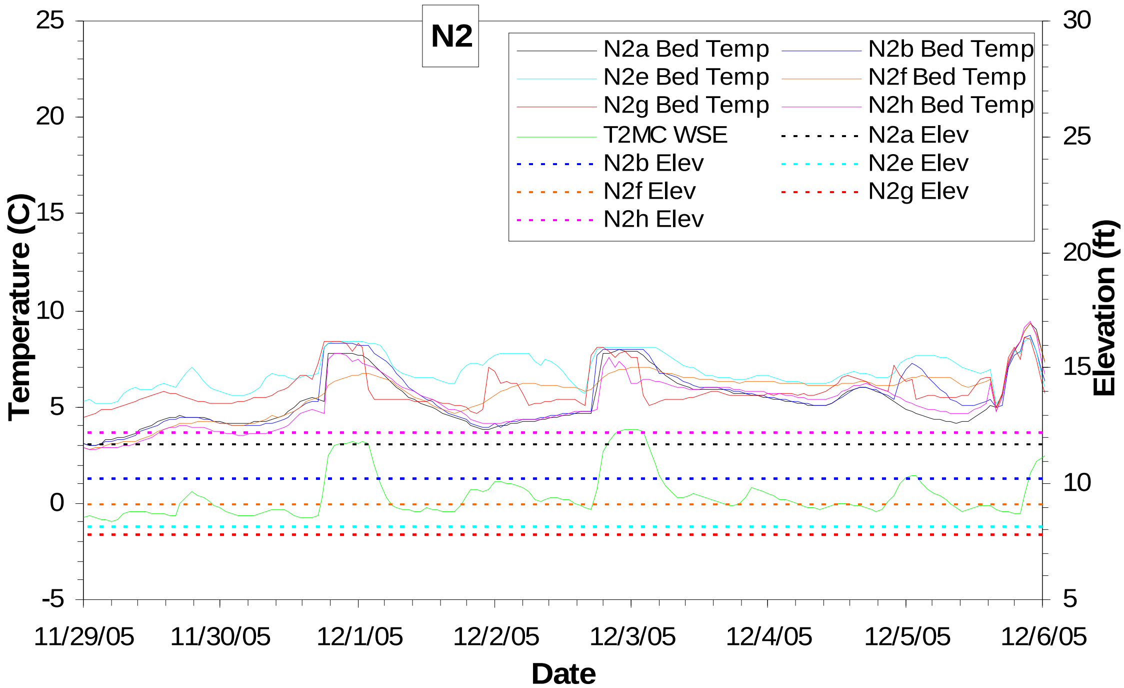


Figure 2.19. Temperature Profile of Buried Onset Sensors in Fall Chinook Salmon Spawning Location N2 During River Stage Fluctuation

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Appendix A

Temperature Sensor Location Information

Name	△L[a] (cm)	X[b]	Y[b]
Rivershore	50.0	537888	5048557
Multnomah Falls	55.5	568891	5047743
Woods Landing 1	50.0	536217	5049153
Woods Landing 2	36.0	536217	5049153
T1LB	30.0	578126	5053019
T1LB	58.0	578121	5053018
T1MC	30.0	578119	5053032
T2LB	58.4	578197	5053041
T2MC	31.0	578193	5053055
T2MC	58.0	578193	5053055
T2RB	30.0[c]	578190	5053064
T4LB	35.5[d]	578306	5053111
T4MC	36.0[e]	578298	5053121
T4RB	30.0[f]	578288	5053136
T5MC	30.0[g]	578106	5052412

(a) △L= depth of riverbed sensor below the riverbed.
(b) Horizontal coordinate system UTM Zone 10 North, Datum NAD 83.
(c) △L changed to 37.0 cm on 10/13/05.
(d) △L changed to 36.0 cm on 10/13/05.
(e) △L changed to 35.0 cm on 10/13/05.
(f) △L changed to 38.0 cm on 9/7/03. △L changed to 36.0 cm on 10/13/05.
(g) △L changed to 24.2 cm on 10/10/02. △L changed to 36.5 cm on 10/13/05.

Appendix B

Temperature Data Collected Downstream from Bonneville Dam in the Ives Island Area, FY 2006

Location	Vpos	Type	2005			2006								
			10	11	12	1	2	3	4	5	6	7	8	9
T1LB	B	PT												
	B	OS												
	R	PT												
T1MC	B	SOL												
	R	SOL												
T2LB	B	PT												
	R	PT												
T2MC	B	PT												
	B	OS												
	R	PT												
T2RB	B	SOL												
	R	SOL												
T4LB	B	SOL												
	R	SOL												
T4MC	B	SOL												
	R	SOL												
T4RB	B	SOL												
	R	OS												
	R	SOL												
T5MC	B	SOL												
	R	SOL												
Air temp	NA	PT												
Hamilton Creek	R	SOL												
Rivershore	B	SOL												
	R	SOL												
Multnomah Falls	B	SOL												
	R	SOL												
Woods Landing 1	B	SOL												
	R	SOL												
Woods Landing 2	B	SOL												

Legend:
- hyporheic - all data available
- river - all data available
- partial data
- no data available
- air temperature available

Location: see text for piezometer naming convention and location description

Vpos = position of piezometer screen: B=riverbed, R=river

Type = sensor type: SOL=Solinst, PT=PT2X, OS=Onset

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 Multnomah Falls, Rivershore, and Woods Landing

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

Table D.2. Summary Statistics for Hyporheic Temperature Data for Multnomah Falls (MF), Rivershore (RS), and Woods Landing (WL), and for the Combination of the Three Sites

Hyporheic Temperature (˚C)	All Sites	MF	RS	WL
Mean	9.63	9.98	8.98	9.82
Standard Error	0.10	0.16	0.11	0.20
Median	9.30	9.70	8.70	9.65
Mode	8.20	9.30	8.20	9.10
Standard Deviation	1.35	1.52	0.87	1.06
Sample Variance	1.81	2.31	0.76	1.12
Kurtosis	-0.48	-0.95	0.56	-1.25
Skewness	0.64	0.27	1.14	0.25
Range	6.20	6.20	3.70	3.30
Minimum	7.40	7.40	7.90	8.20
Maximum	13.60	13.60	11.60	11.50
Count	178	92	58	28
Confidence Level of Mean (95.0%)	0.20	0.31	0.23	0.41

Table D.3. Summary Statistics for River Temperature Data for Multnomah Falls (MF), Rivershore (RS), and Woods Landing (WL), and for the Combination of the Three Sites

River Temperature (˚C)	All Sites	MF	RS	WL
Mean	8.39	8.24	8.22	9.23
Standard Error	0.06	0.08	0.03	0.24
Median	8.20	8.10	8.25	9.20
Mode	8.30	7.40	8.30	9.40
Standard Deviation	0.86	0.81	0.20	1.28
Sample Variance	0.73	0.65	0.04	1.65
Kurtosis	2.80	0.88	-0.56	-1.18
Skewness	1.58	1.03	-0.15	0.45
Range	4.20	3.90	0.80	3.60
Minimum	7.10	7.10	7.80	7.70
Maximum	11.30	11.00	8.60	11.30
Count	178	92	58	28
Confidence Level of Mean (95.0%)	0.13	0.17	0.05	0.50

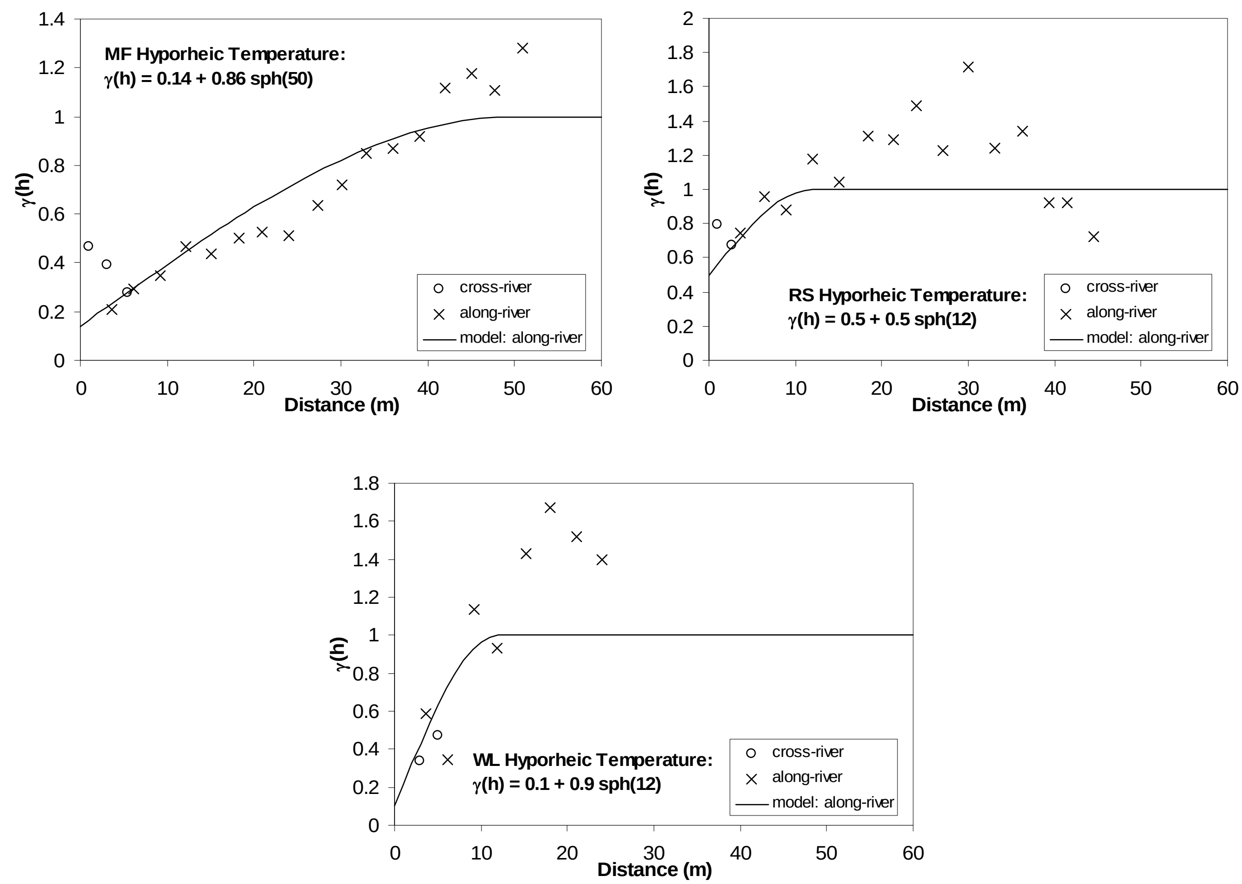

Figure D.1. Experimental Variogram Results (X) and Models (solid black lines) Fit to the Data for the Three Sites

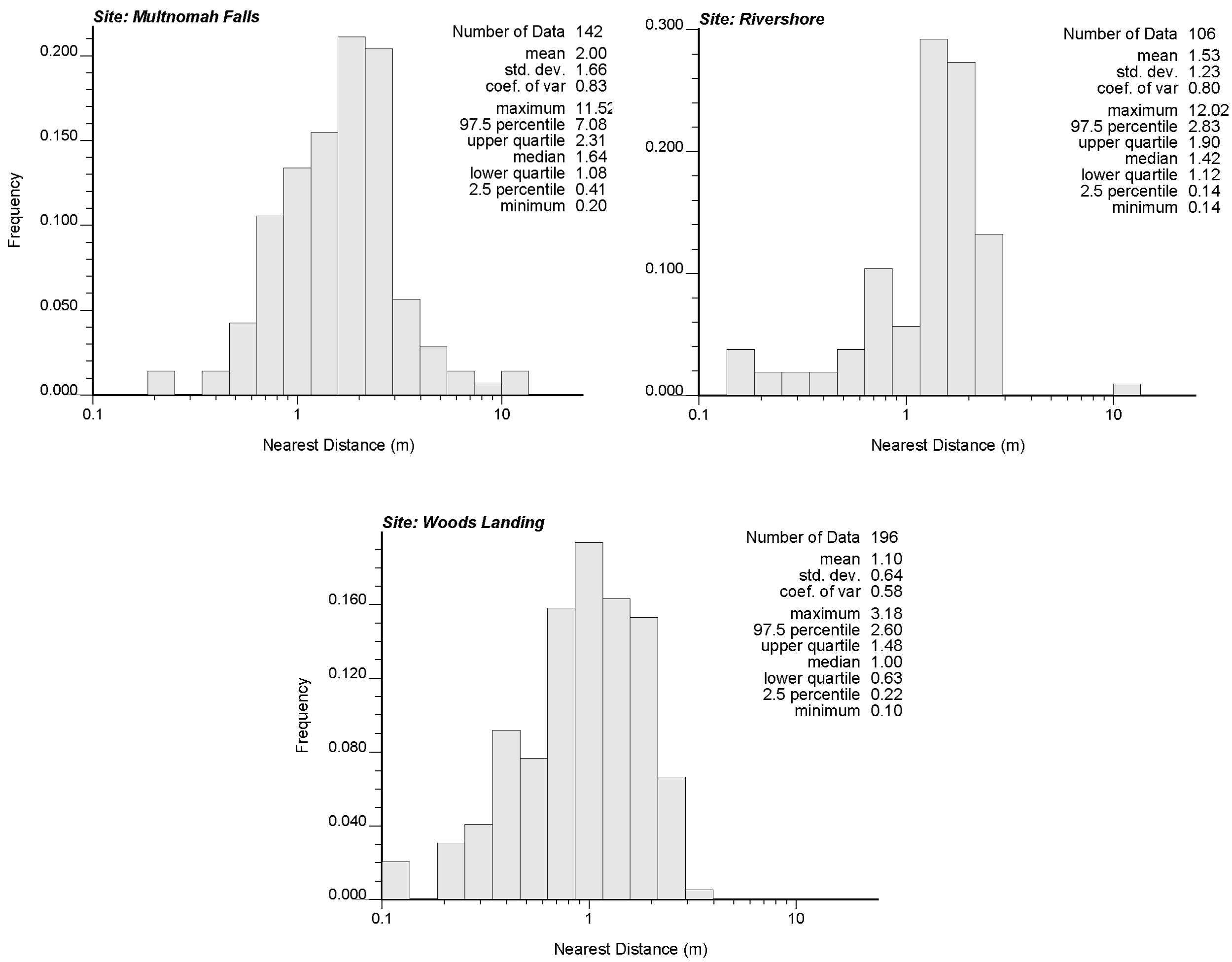

Figure D.2. Distance from Each Chum Salmon Redd to the Nearest Chum Salmon Redd. Distances were plotted using a logarithmic scale.

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

Site	Temperature	Nugget	Sill	Range (transformed unit)	
				Along-River	Cross-River
Multnomah Fall (MF)	Hyporheic	0.14	0.86	50	7.5
	River	0.14	0.45	15	1
			0.41	50	7
Rivershore (RS)	Hyporheic	0.5	0.5	12	7.5
	River	0.5	0.5	10	7
Woods Landing (WL)	Hyporheic	0.1	0.9	12	7.5
	River	0.2	0.8	8	5

Table D.5. Summary Statistics of Temperature and Temperature Differences at the 35 Randomly Selected 2004 Chum Salmon Spawning and Non-Spawning Locations at Multnomah Falls Site

Multnomah Falls	Hyp. Temperature (˚C)		River Temperature (˚C)		Hyp. – River Temp. (˚C)		River – Hyp. Temp. (˚C)	
	Non-Spawning	Spawning	Non-Spawning	Spawning	Non-Spawning	Spawning	Non-Spawning	Spawning
N of cases	35	35	35	35	35	35	35	35
Minimum	8.00	9.13	7.46	7.50	0.40	1.20	-1.60	-4.00
Maximum	9.60	12.63	8.00	10.59	1.60	4.00	-0.40	-1.20
Range	1.60	3.50	0.54	3.09	1.20	2.80	1.20	2.80
Median	8.32	11.50	7.62	8.60	0.63	2.70	-0.63	-2.70
Mean	8.40	11.35	7.63	8.76	0.77	2.59	-0.77	-2.59
95% CI Upper	8.51	11.68	7.67	9.03	0.86	2.84	-0.67	-2.35
95% CI Lower	8.28	11.03	7.60	8.49	0.67	2.35	-0.86	-2.84
Std. Error	0.06	0.16	0.02	0.14	0.05	0.12	0.05	0.12
Standard Dev	0.34	0.94	0.11	0.80	0.28	0.71	0.28	0.71
Variance	0.11	0.88	0.01	0.64	0.08	0.51	0.08	0.51
C.V.	0.04	0.08	0.01	0.09	0.37	0.27	-0.37	-0.27
Two-sample t-test on Mean	$P < 0.000005$		$P < 0.000005$		$P < 0.000005$		$P < 0.000005$	

Table D.6. Summary Statistics of Temperature and Temperature Differences at the 35 Randomly Selected 2004 Chum Salmon Spawning and Non-Spawning Locations at Rivershore Site

Rivershore	Hyp. Temperature (˚C)		River Temperature (˚C)		Hyp. – River Temp. (˚C)		River – Hyp. Temp. (˚C)	
	Non-Spawning	Spawning	Non-Spawning	Spawning	Non-Spawning	Spawning	Non-Spawning	Spawning
N of cases	35	35	35	35	35	35	35	35
Minimum	8.30	8.80	8.06	8.08	0.10	0.66	-1.01	-1.70
Maximum	9.29	10.00	8.41	8.41	1.01	1.70	-0.10	-0.66
Range	0.99	1.20	0.35	0.33	0.91	1.04	0.91	1.04
Median	8.54	9.50	8.20	8.23	0.40	1.28	-0.40	-1.28
Mean	8.61	9.44	8.21	8.23	0.40	1.21	-0.40	-1.21
95% CI Upper	8.69	9.57	8.25	8.26	0.46	1.31	-0.34	-1.10
95% CI Lower	8.53	9.31	8.18	8.20	0.34	1.10	-0.46	-1.31
Std. Error	0.04	0.06	0.02	0.02	0.03	0.05	0.03	0.05
Standard Dev	0.23	0.38	0.10	0.10	0.18	0.31	0.18	0.31
Variance	0.05	0.14	0.01	0.01	0.03	0.09	0.03	0.09
C.V.	0.03	0.04	0.01	0.01	0.44	0.25	-0.44	-0.25
Two-sample t-test on Mean	$P < 0.000005$		$P = 0.42$ (adj. $P = 1.0$ or 0.88)		$P < 0.000005$		$P < 0.000005$	

Table D.7. Summary Statistics of Temperature and Temperature Differences at the 35 Randomly Selected 2004 Chum Salmon Spawning and Non-Spawning Locations at Woods Landing Site

Woods Landing	Hyp. Temperature (˚C)		River Temperature (˚C)		Hyp. – River Temp. (˚C)		River – Hyp. Temp. (˚C)	
	Non-Spawning	Spawning	Non-Spawning	Spawning	Non-Spawning	Spawning	Non-Spawning	Spawning
N of cases	35	35	35	35	35	35	35	35
Minimum	8.43	9.17	8.10	7.70	-0.50	-0.25	-0.44	-3.00
Maximum	9.75	11.38	9.74	11.10	0.44	3.00	0.50	0.25
Range	1.32	2.22	1.64	3.40	0.94	3.25	0.94	3.25
Median	9.24	10.62	9.09	10.56	0.18	0.34	-0.18	-0.34
Mean	9.16	10.60	8.97	10.08	0.18	0.52	-0.18	-0.52
95% CI Upper	9.30	10.81	9.13	10.45	0.24	0.77	-0.12	-0.27
95% CI Lower	9.02	10.39	8.82	9.71	0.12	0.27	-0.24	-0.77
Std. Error	0.07	0.10	0.08	0.18	0.03	0.12	0.03	0.12
Standard Dev	0.40	0.60	0.45	1.07	0.18	0.73	0.18	0.73
Variance	0.16	0.36	0.20	1.15	0.03	0.53	0.03	0.53
C.V.	0.04	0.06	0.05	0.11	0.96	1.39	-0.96	-1.39
Two-sample t-test on Mean	$P < 0.000005$		$P < 0.000005$		$P = 0.01$ (adj. $P = 0.04$)		$P = 0.01$ (adj. $P = 0.04$)	

Appendix E

54 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]	S1 (cm)[b]	S2 (cm)[b]	Probable Error	Degree of Accuracy
T1A	11.804	80.5	78.25	0.479	0.000
T1B	10.468	121.25	119	0.479	0.000
T1C	9.381	154.5	152	0.486	0.017
T1D	7.909	199.25	197	0.479	0.000
T1E	7.770	203.5	201.25	0.479	0.000
T1F	12.087	72	69.5	0.486	0.013
T2A	11.681	59.5	61.25	0.347	0.000
T2B	10.168	105.5	107.5	0.357	0.015
T2C	7.848	176.25	178.25	0.357	0.017
T2D	7.155	197.5	199.25	0.347	0.000
T2E	8.131	167.75	169.5	0.347	0.000
T2F	9.082	138.75	140.5	0.347	0.000
T2G	7.729	180	181.75	0.347	0.000
T2H	12.186	44	46	0.357	0.015
T3A	11.735	60	62.25	0.268	0.017
T3B	9.102	140.25	142.5	0.268	0.018
T3C	7.667	184	186.25	0.268	0.018
T3D	6.273	226.5	228.75	0.268	0.018
T3E	6.085	232.25	234.5	0.268	0.016
T3F	10.500	97.5	100	0.305	0.031
T4A	12.022	30	32.5	0.248	0.016
T4B	8.434	139.5	141.75	0.234	0.000
T4C	6.540	197.25	199.5	0.234	0.000
T4D	6.105	210.5	212.75	0.234	0.000
T4E	5.851	218.25	220.5	0.234	0.000
T4F	7.270	175	177.25	0.234	0.000
T4G	11.435	48	50.25	0.234	0.000
T5A	12.727	74.5	93.5	0.308	0.013

E.1 (contd)

Location	Elevation[a]	S1 (cm)[b]	S2 (cm)[b]	Probable Error	Degree of Accuracy
T5B	10.591	139.5	158.75	0.296	0.000
T5C	7.630	229.75	249	0.296	0.000
T5D	6.942	250.75	270	0.296	0.000
T5E	6.790	255.5	274.5	0.308	0.013
T5F	7.061	247.25	266.25	0.308	0.012
T5G	6.790	255.5	274.5	0.308	0.012
T5H	7.889	222	241	0.308	0.011
T6A	11.714	N/A	61.5	0.682	0.000
T6B	10.197	90.75	108	0.382	0.026
T6C	8.336	147.5	164.75	0.382	0.027
T6D	7.417	175.5	192.75	0.382	0.027
T6E	7.204	182	199.25	0.382	0.026
T6F	7.302	179	196.25	0.382	0.025
T6G	6.618	200	217	0.353	0.012
T6H	6.183	212.5	231	0.682	0.081
T6I	11.603	48	65	0.353	0.011
T7A	7.188	247	255	0.438	0.033
T7B	8.873	195.25	204	0.413	0.018
T7C	10.496	146	154.25	0.413	0.019
T7D	10.439	147.75	156	0.413	0.020
T7E	9.984	161.5	170	0.404	0.000
T7F	8.856	196	204.25	0.413	0.018
T7G	7.339	242.25	250.5	0.413	0.016
T7H	5.917	285.5	294	0.404	0.000
T8A	11.960	72.25	66.75	0.493	0.000
T8B	9.475	148	142.5	0.493	0.000
T8C	8.819	168	162.5	0.493	0.000
T8D	9.439	149.25	143.5	0.500	0.023
T9C	8.901	165.5	160	0.493	0.000
T9D	9.303	153.25	147.75	0.493	0.000

(a) Elevation is of the sensors tip, NGVD 29, feet.
(b) Two surveys were conducted to determine the difference between each location and a previously occupied control point. S1 and S2 represent the differences in elevation between each location and the control point for two separate surveys.

E.2 Temperature Data Collected from 54 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, appendixE_2_N2, appendixE_2_N3, 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

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

Chapter 3

Stranding and Entrapment Evaluation

Christopher J. Murray

Summary

During FY 2006, we completed Work Elements G, H, and I from the PNNL Statement of Work Report for BPA Project 1999-003-01. This work scope provides technical support to Pacific States Marine Fisheries Commission (PSMFC) for assessment of stranding of juvenile chum, fall Chinook, and coho salmon in the area below Bonneville Dam. We discussed the current sampling plan used for assessment of loss due to stranding and entrapment with PSMFC and looked at the possibility of improving that plan. Given the lack of a real-time model for prediction of water levels at specific locations in the study area, we suggested that it would be necessary to continue with the current sampling plan.

As part of its work on the three work elements, PNNL performed a statistical analysis of fork length data for each of the three salmon species to determine whether or not there was a statistically significant difference between the fork length of entrapped and stranded juvenile salmon. This work was performed using a series of two-sample t-tests, and the results were included within the report that was being prepared by PSMFC.

The main work performed for the three work elements included providing detailed evaluations and comments for the report produced by PSMFC describing the field sampling of salmon stranding and entrapment for all three species as well as analysis of those data. Several drafts were reviewed and evaluated, and we provided both technical and editorial comments for each of the drafts. The final report on 2005 stranding and assessment was accepted by BPA and is available as

Wilson, Jeremy, and Reed Duston, "2005 Evaluation of Chum, Chinook, and Coho Salmon Entrapment near Ives Island in the Columbia River," 2004-05 Annual Report, Project No. 199900301, 70 electronic pages, (BPA Report DOE/BP-00004287-4). Accessed electronically on 1/3/2006 at http://www.efw.bpa.gov/Publications/I00004287-4.pdf.