SNAKE RIVER FALL CHINOOK SALMON LIFE HISTORY INVESTIGATIONS
ANNUAL REPORT 2008

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Executive Summary

This study was initiated to provide empirical data and analyses on the dam passage timing, travel rate, survival, and life history variation of fall Chinook salmon that are produced in the Clearwater River. The area of interest for this study focuses on the lower four miles of the Clearwater River and its confluence with the Snake River because this is an area where many fish delay their seaward migration. The goal of the project is to increase our understanding of the environmental and biological factors that affect juvenile life history of fall Chinook salmon in the Clearwater River. The following summaries are provided for each of the individual chapters in this report.

Chapter 1: Efforts to collect and tag in-river subyearling fall Chinook salmon from the Clearwater River in 2008 were hampered by mortality associated with collection and handling stress and gas bubble trauma (GBT). 2008 was the first year we ever attempted to collect fish from the Clearwater River. We used a 150' lampara seine to collect subyearlings in the lower Clearwater River at Lewiston, Idaho. Fish were held in net pens overnight prior to radio-tagging. High mortality from both holding and tagging prompted us to suspend all collection and tagging for the remainder of the year. Subsequent investigations revealed some fish showed signs of GBT. Data from the water quality gage at Lewiston showed a cyclic pattern of total dissolved gas (TDG) increasing from around 102% in the early morning to a peak of about 109% in late afternoon each day. We speculate that our holding fish in water <1 m deep did not allow them to compensate for elevated TDG by seeking deeper water and may have been responsible for the GBT and mortality we observed. Furthermore, fish residing in shallower parts of the river may be chronically exposed to low levels of elevated TDG, but do not suffer ill effects until they encounter added stressors such as collection and handling.

Chapter 2: In 2008, we collected, radio-tagged, and released 50 subyearling fall Chinook salmon in the Snake River near Asotin, Washington. The purpose of this release was to compare the migratory behavior of subyearlings released in both the Snake and Clearwater rivers to identify variables that could potentially explain life history differences between the two rivers. Detections of radio-tagged subyearlings released in the Snake River generally declined with distance from release as fish moved downstream. Detections ranged from 92% at Red Wolf Bridge to 46% in the forebay of Lower Granite Dam. Slightly more than half the fish were detected to have passed Lower Granite Dam. Median subyearling travel times within study reaches increased from release to Granite Point and then decreased as fish moved downstream to the tailrace. Migration rates decreased as fish moved through Lower Granite Reservoir but increase slightly as fish traveled from Lower Granite Dam to the tailrace detection sites in the relatively higher velocities found there. Median residence time in the forebay was 10.2 h.

Chapter 3: We conducted a sensitivity analysis to assess the effect of delayed migration on estimates of the joint probability of migration and survival (ϕ) to Lower Granite Dam in 2008. One method of exploring the size and nature of this bias is to compare estimates of survival to Lower Granite Dam using two sets of detections: one set from an "abbreviated" detection period that corresponds to the usual period when the PIT-tag system was operational, and a second set from an "extended" period that includes additional weeks of detections. This extended detection offers an opportunity to assess the possible bias in estimates of the joint probability of migration

and survival to Lower Granite based solely on the abbreviated detection period. Our sensitivity analysis found no evidence of bias arising from using abbreviated detection data in estimating the joint probability of migration and survival from release to Lower Granite Dam for fish released either in the Clearwater River or in the Snake River in the spring and summer of 2008. This is in contrast to a bias found in a similar analysis of data collected in 2007. However, it is important to note that the PIT-tagged fish used in this analysis were released (in 2008) in May, June, and July, whereas the acoustic-tagged fish used in the 2007 analysis were released in August, September, and October of 2007. It is possible that if we were to analyze PIT-tagged subyearlings released in the late summer and early fall of 2008, we might have found evidence of bias based on the abbreviated detection period.

Chapter 4: Estimation of the smolt-to-adult return (SAR) ratio from Lower Granite Dam for fall Chinook salmon is complicated by the alternative reservoir life history that is adopted by some fall Chinook. If SAR is to be estimated from Lower Granite Dam, then it is necessary to account for the proportion of fish that adopted the reservoir life history. This is true whether SAR is to be estimated for undetected fish alone or for all fish that reached Lower Granite Dam. Estimating SAR for the undetected group requires more data and more modeling assumptions than estimating SAR from Lower Granite for all fish. Both estimates may be calculated from either year-round PIT-tag detections, or summer, fall, and spring PIT-tag detections augmented by detections in the Lower Granite tailrace from long-lived acoustic tags. Estimating SAR for all fish that reached Lower Granite also requires PIT-tag detection at Lower Granite throughout the winter.

Estimating the SAR of fall Chinook from the release point is much simpler than estimating SAR from Lower Granite Dam. The SAR from the point of release is simply the ratio of the number of returning adults to the size of the release group. This SAR estimate is unbiased, and is robust to the effects of delayed migration exhibited by fall Chinook salmon.

Rather than using any of the estimators of SAR from Lower Granite that are described here to estimate transportation effects, we strongly recommend using the Ricker relative recovery method (Ricker 1975) to analyze transportation. The Ricker method uses pre-assigned transport and control groups, and is not dependent on the timing of the juvenile migration. This makes the Ricker method robust to the effects of delayed migration.

Chapter 5: We measured the hydrodynamic conditions and water quality of the lower Clearwater River and Lower Granite Reservoir in 2008 to better understand the causative mechanisms of juvenile fall Chinook salmon emigration delay and survival. Water temperatures were generally coolest ($<15^{\circ}\text{C}$) in the Clearwater River Arm and warmest ($>20^{\circ}\text{C}$) in the Snake River Arm of Lower Granite Reservoir in 2008/09. Temperatures in the Snake River Arm exceeded 20°C throughout the water column from the end of June through mid-October and only the uppermost five to seven meters of water at the confluence downstream boundary exceeded 20°C during the same time period. The Clearwater River Arm exceeded 20°C only from mid-September through mid-October. Thermal stratification of the Snake River at the confluence downstream boundary began in early July and dissipated by mid-October. Water particle travel time from Clearwater River rkm 7.5 to the Red Wolf Bridge (Snake rkm 221.1) gradually increased from about 2 hours in early June to about 35 hours by mid-September and remained relatively slow throughout a majority of the fall, winter, and early spring. We measured the proportion of the lower 13.3 km of the Clearwater River shallower than the compensation depths at total dissolved gas saturations

of 103% and 109%. These compensation depths were 0.3 m and 0.9 m, respectively. At 103% total dissolved gas saturation, 1.5% (0.4 ha) of the river would not allow for subyearling depth compensation, and at 109% saturation, 8.4% (2.4 ha) of the river would not allow for subyearling depth compensation.

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CHAPTER ONE

Summary of Juvenile Fall Chinook Salmon Collection, Mortality, and GBT in the Clearwater River, 2008

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In 2008, personnel of the U.S. Fish and Wildlife Service, Nez Perce Tribe Department of Fisheries Resources Management, and U.S. Geological Survey worked together to collect fall Chinook salmon subyearlings in the Clearwater River to accomplish work described in Bonneville Power Administration projects 200203200 and 1983350003. Past observations have shown that relatively large numbers of young fall Chinook salmon rear for extended periods of time in the lower 6 km of the Clearwater River, but little is known about this group of fish. Collections made in 2008 represent the first attempt to obtain run-at-large fish for radio, acoustic, and PIT tagging. The following time line describes results of these collections.

On 21 July 2008, we used a 150' x 10' lampara seine to collect approximately 275 fall Chinook salmon subyearlings in the lower 6 km of the Clearwater River at an average temperature of 14°C. After collection, the fish were visually graded into two groups. The “radio and PIT tag group” (project 200203200) comprised fish approximately 85 mm and larger. This group was transferred to a floating net pen (~ 1 m deep) secured to partially submerged log off shore. The “PIT-tag only” group (project 1983350003) comprised fish approximately 85 mm and smaller. This group ($N = 149$) was immediately PIT tagged. During PIT tagging, 4 fish died almost immediately (2.7%). Post-tagging mortality rate is usually close to zero over the course of a 3–4 month beach seining season when thousands of fish are tagged. A post-tagging mortality of 2.7% is inexplicably high. The remaining 145 newly PIT-tagged fish appeared to be healthy and were released after a 15-min recovery period.

On the morning of 22 July 2008, one dead fish was found in the net pen that held fish for subsequent radio tagging. The remaining fish were then transported by truck 8 kilometers upriver to Hog Island boat ramp where they were placed in a net pen for radio and PIT tagging the following day. The following morning (23 July 2008), there were 17 dead fish in the net pen. The surviving fish in the net pen were lethargic and did not exhibit a fright response. We postponed surgery and released the survivors.

On 29 July 2008, we took several steps to reduce handling stress. We moved our tagging trailer from Hog Island to the north Lewiston boat ramp, which is located within the lower 6 km of the Clearwater River. We replaced the battery powered aerators in holding containers on the seining boat with regulated oxygen. We added salt and Polyproaqua (i.e., artificial slime) to the holding containers. We reduced the amount of time between capture and transfer to the net pens from about an hour down to 15 min. We stationed two net pens offshore at the north Lewiston boat ramp in about 1 m of 12.8°C water. This reduced fish density during overnight holding. As previously described, the fish were visually graded after seining. The larger fish were placed evenly into the two net pens. The smaller fish ($N = 10$) were PIT-tagged immediately. After a 15-min recovery period, all of these newly PIT tagged fish were released alive.

On 30 July 2008, we surgically implanted 67 fish with radio and PIT tags. After surgery, the fish were transferred to recovery tanks supplied continuously with 13.1°C river water. Six of the tagged fish died within a few hours of surgery, which is an unusually high short-term mortality rate. Typically, mortality is about 1 fish/500 fish tagged.

On the morning of 31 July 2008, water temperature averaged 12.8°C. A total of 34 of the remaining 61 radio- and PIT-tagged fish had died bringing the post-tagging mortality rate up to

60%. Post-tagging mortality rate is usually close to zero, even when we tag fish at Lower Granite Dam at temperatures above 17°C. To help explain the high level of mortality, the surviving tagged fish and 10 untagged fish from the net pen were transported live to Dworshak National Fish Hatchery (DNFH). DNFH fish health personnel euthanized the fish in un-buffered MS-222 and immediately examined 10 of the tagged fish and 10 of the untagged fish. Glistening elongated emboli were observed in the gill lamellae of all 20 fish. The first diagnosis was that these emboli were indicative of gas bubble trauma (GBT). Viral samples were also taken, but results were negative.

On 5 August 2008, 10 fish were collected by hook-and-line at 13.2°C in the lower 6 km of the Clearwater River. They were immediately taken to DNFH for examination. The fish were euthanized with un-buffered MS-222 at the hatchery. All 10 fish had gill emboli. Bacterial samples were also taken but did not show anything unusual. At this point, we indefinitely postponed all surgery and tagging under project 200203200.

On 7 August 2008, we beached seined in the lower 6 km of the Clearwater and captured 30 Chinook salmon subyearlings. Half of the fish were PIT tagged and half were held in a holding tub to assess their condition. After an hour, one of the non-PIT tagged fish died. When visually examined, it had emphysema around the eye (a conclusive symptom of GBT). The rest of the fish were behaving normally and were released. We indefinitely postponed all PIT tagging associated with project 1983350003.

On 12 August 2008, we participated in a conference call to update Fish Passage Advisory Committee (FPAC) members on the delayed mortality and its potential association with GBT. During the call, we emphasized that this issue was perplexing. The total dissolved gas (TDG) levels during our sampling were only averaging around a 104 to 105% (Figure 1); well below levels generally associated GBT-related mortality. Hourly TDG levels in the lower Clearwater River fluctuated between about 101% and 109% each day with the peak occurring in late afternoon. We formed the following hypothesis about subyearling exposure to TDG and their development of GBT. The fish had been chronically exposed to elevated TDG levels in shallow rearing areas just upstream of our sampling site, sounded to below the compensation depth when not feeding, were netted at the surface while feeding, were transferred to a shallow live well or held in net pens stationed in shallow water where they could not sound to the compensation depth. Some of the participants agreed that the net-pen experience induced the emboli. It was also noted that emboli composed of lipids were commonly misidentified as gas emboli during the early years of GBT monitoring in the Federal Columbia River Power System. A review of the criteria for gas emboli confirmation (Elston et al. 1997) coupled with immediate on-site examination were recommended. After receiving suggestions on continued monitoring, we proposed to cooperatively collect subsamples of fish in the lower Clearwater River to further evaluate the emboli. The fish would be transported to DNFH under ID Live Fish Import/Transport/Release Permit #HQ-08-145. Mortalities would be applied to allowed take permitted under ESA Hydro Determination 22-08 USGS34.

On 13 August 2008, we collected 20 subyearlings in the lower 6 km of the Clearwater River using hook-and-line. Of these; 10 were immediately euthanized with a lethal dose of un-

Figure 1.—Hourly total dissolved gas (%) readings measured at the Lewiston gage in the Clearwater River from 21 July to 20 August 2008

buffered MS-222, fixed in Davidson’s solution, and transported directly to DNFH. The remaining 10 were placed in a net pen. The following day (14 August 2008), the 10 fish in the net pen were immediately euthanized with a lethal dose of un-buffered MS-222, fixed in Davidson’s solution, and transported to DNFH.

On 18 August 2008, our fish health personnel found that their tissue sampler (required for histopathology) had been irreparably damaged by a recent power surge. To overcome this problem, they arranged for the samples to be examined by an independent professional fish pathologist. If emboli were present at the time the fish were fixed in Davidson’s solution, “ghost shapes” of the emboli might be observed (Elston pers. comm.). The absence of ghost shapes in the 10 fish euthanized on 13 August, combined with the presence of ghost shapes in the 10 fish held overnight in net pens and euthanized on 14 August, would confirm net pen holding as a causal factor for the emboli.

On 20 August 2008, we were contacted by Margaret Filardo of the Fish Passage Center. Margaret informed us that un-buffered MS-222 might be a factor for gill emboli. In response,

we equipped the tagging trailer at the north Lewiston boat ramp with microscope and viewing monitor. We fished for fall Chinook salmon on 21 August in the lower 6 km of the Clearwater River. When the first fish was caught, it was immediately euthanized in buffered MS-222. DNFH health personnel extracted its gills and examined them for glistening, elongated, and rapidly diffusing emboli (20-30 min; Elston et al. 1997). Emboli that diffused slightly over 30 min were observed, but they did not completely dissipate. Furthermore, these emboli were smaller and more nebulous than the emboli observed on 31 July. We did not observe emphysema in the fins of this first fish, but they could have dissipated during the time it took to examine the gills. A second fish was captured, euthanized, and transferred to the trailer. At that time, Dr. Ken Cain (professor of fish health, University of Idaho) arrived to offer his assistance. The second fish examined had emphysema at the base of the dorsal fin (Figure 2) and in the pectoral fin. The examination for gas emboli in the gills of the second fish was inconclusive. In the time it took to examine the fish externally, any gas emboli would have dissipated. The third fish examined also had emphysema in the pectoral fins. Its gill examination was also inconclusive due to time limitations. Two additional fish were collected and preserved in Davidson's solution for subsequent histopathology.

In conclusion, a portion of the ESA-listed juvenile fall Chinook salmon population of the Clearwater River experienced GBT in 2008. Holding in net pens stationed overnight in shallow gas supersaturated water along with cumulative stress from capture and surgery resulted in unprecedented levels of post-tagging mortality. However, we also observed a fish with GBT (ocular emphysema) die during beach seining on 7 August. This fish represented 3% of that particular sample, had never been held in a net pen, never been anesthetized, had not been PIT tagged, and it had only been in a shallow tub of river water for 1 h after capture. It is probable that chronic exposure to gas super saturation in 2008 diminished the resilience of some portion of the juvenile fall Chinook salmon population in the Clearwater River. Examination of Lewiston gage data from past years indicates that elevated TDG levels in the 100-109% range may be a common occurrence in the Clearwater River during July and August. Fish may be able to cope with these levels provided they do not incur any additional stress.

In 2009, we intend to collect fish from the lower Clearwater River as in 2008, but fish will be transported to the Nez Perce Tribal Hatchery where they will be held in degassed water to eliminate any GBT and allow them to recover from handling stress prior to tagging. Hans et al. (1999) showed that GBT symptoms in juvenile salmon can dissipate relatively rapidly if fish are held in degassed water. Regular monitoring of TDG levels will be conducted in the lower Clearwater River as well.

Figure 2.—Emphysema at the base of the dorsal fin observed on a juvenile fall Chinook salmon collected in the lower 6 km of the Clearwater River on 21 August 2008. Note that the tear in the dorsal fin resulted from the forceps and was not a result of the emphysema.

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CHAPTER TWO

Migration Behavior of Juvenile Fall Chinook Salmon in the Snake River, 2008

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Introduction

Understanding the juvenile life history diversity of Snake River basin fall Chinook salmon juveniles is critical to the recovery of this ESA-listed population (National Marine Fisheries Service 1992). Snake River fall Chinook salmon *Oncorhynchus tshawytscha* display two juvenile life history types. Fish with an ocean-type life history (Healey 1991) emerge as fry in the spring, exhibit rapid growth, emigrate seaward during the summer, and enter the ocean as subyearlings (Connor et al. 2002, 2003; Connor and Burge 2003). In contrast, fish with a reservoir-type life history (Connor et al. 2005) emerge later in the spring, grow slower, and do not complete their seaward migration as subyearlings. Instead, they over-winter in reservoirs of the Columbia River hydropower system and resume their seaward migration the following spring as yearlings.

Water temperature is one determinant of juvenile fall Chinook salmon life history in the Snake River basin. The Snake River above its confluence with the Salmon River is the warmest contemporary spawning and incubation area (Figure 1; Connor et al. 2002) and generally produces fish that exhibit an ocean-type life history. Fry emergence is earliest in this reach and fish migrate seaward under relatively high flows. Less than 2% of the juveniles produced in this reach from brood years 1994 to 1999 adopted a reservoir-type life history (Connor et al. 2005). The Clearwater River by comparison is the coolest, least productive contemporary spawning area. Fry emergence generally lags about 50 d behind that of the Snake River (Connor et al. 2002). Growth of fish is further slowed with the release of cold (6°C), hypolimnetic water from Dworshak Reservoir (Figure 1) for summer flow augmentation, which is intended to improve migratory and temperature conditions in the lower Snake River. The percentage of fish produced in the Clearwater that adopt a reservoir-type life history can be significant (e.g., an average of 53% from brood years 1992 to 1998; Connor et al. 2005).

Although both environmental and physiological factors contribute to life history strategies, there is likely a behavioral component as well. In 2008, we intended to use radio telemetry to compare the migratory behavior of subyearlings released in both the Snake and Clearwater rivers to identify variables that could potentially explain life history differences. We collected run-of-river fish at the head of Lower Granite Reservoir for tagging for the first time in 2008. This worked well for collecting fish from the Snake River, but unforeseen problems associated with elevated levels of total dissolved gas prevented us from tagging and releasing fish in the Clearwater River (see Chapter One). Therefore, this chapter only summarizes data collected from a small release of radio-tagged subyearlings in the Snake River.

Methods

We collected 50 run-of-river subyearlings with a beach seine near Asotin, Washington on 2 June 2008. Collected fish were held over night in a net pen before being tagged the following day. Fish were surgically implanted with coded radio tags (Lotek Wireless, Inc., Newmarket, Ontario) following the methods of Adams et al. (1998). The tags we used (model NTC-M-2) measured 12.0 mm long, 4.5 mm wide, weighed 0.43 g in air, had a burst rate of 20 s, and had a life expectancy of 42 d. Fish also were implanted with an 8.5 mm PIT tag. For all tagged fish, the ratio of tag weight to fish weight did not exceed 5%. Tagged fish were held for

Figure 1.—The lower Snake River (top panel) showing the Salmon River, Clearwater River, and dams relevant to this study. The bottom panel shows locations of radio telemetry detection sites (solid circles) and the release site at Asotin, Washington (open circle) in 2008.

24 h after tagging to monitor short-term delayed mortality then released in the middle of the river channel at river kilometer (rkm) 235.7 on June 4, 2009.

We monitored the movement of radio-tagged fish by using arrays of antennas and receivers located at various detection sites between the release site and Lower Granite Dam forebay (Figure 1). Detection sites were located at Red Wolf Bridge over the Snake River (rkm 221.0), Silcott Island (rkm 210.8), Blyton (rkm 192.3), Granite Point (rkm 182.8), the forebay of Lower Granite Dam (rkm 174.5), Lower Granite Dam (rkm 173.0), the upper tailrace (rkm 172.0) and lower tailrace (rkm 170.2) of Lower Granite Dam (Figure 1).

The monitoring equipment at each detection station consisted of a 6- and/or 3-element Yagi antenna and a Lotek SRX400 receiver powered by a solar charged 12-V battery. At most sites, receivers and antennas were deployed on each side of the river to increase detection efficiency and protect against data loss in the event of equipment failure or vandalism. At Granite Point, a detection site was established on only one side of the river. At the Red Wolf Bridge, a single receiver and three pairs of 3- and 6-element antennas were used. At Lower Granite Dam, three arrays of antennas monitored the powerhouse, spillway, and earthen dam, respectively. Each receiver continuously scanned for transmitters, which were all on one frequency and channel thus eliminating gaps in scan time. Receivers were usually downloaded twice a week through the end of July.

Detection records from each site were analyzed to examine travel times, migration rates, and relative detection efficiencies. Subyearling travel times were calculated as the elapsed time between release and first detection at a site, or between first detection at a site and the first detection at the next downstream site. Migration rates were calculated as the distance between two sites divided by fish travel time between the two sites. Travel times and migration rate calculations only used data from fish detected at consecutive sites. For each site, we divided the number of unique fish detected by the total number released to determine the relative detection efficiency. We refer to the areas between detection sites as reaches. Reaches are named by their downstream ends. For example, the “Silcott” reach would comprise the area between the Red Wolf Bridge and Silcott Island. Residence time in the forebay of Lower Granite Dam was calculated as the elapsed time between first detection in the forebay and last detection at the dam or first detection at a tailrace site.

Results

During our study, flows at Lower Granite Dam peaked at 161 kcfs on June 3 and declined to about 41 kcfs by late July (Figure 2). Water temperatures measured in the forebay of Lower Granite Dam increased from about 10.1°C in early June to almost 19°C by the end of July (Figure 2).

We radio tagged 50 subyearlings that had a mean fork length of 100.4 mm (range = 90-112 mm, SD = 5.3 mm) and a mean weight of 10.9 g (range = 8.3-14.9 g, SD = 1.6 g). No fish died during our 24-h post-tagging holding period.

Figure 2.—Flows (solid line) and temperatures (dashed line) at Lower Granite Dam during our study in 2008.

Detections of radio-tagged subyearlings released in the Snake River generally declined with distance from release as fish moved downstream (Figure 3). Detections ranged from 92% at Red Wolf Bridge to 46% in the forebay of Lower Granite Dam (Figure 3). Slightly more than half the fish were detected to have passed Lower Granite Dam. The antennas located on either side of the reservoir at Silcott and Blyton performed almost equally as well at detecting the same fish (Table 1). The antennas on the north shore of the forebay of Lower Granite Dam detected more fish than the south-side antennas. At Lower Granite Dam, the spillway antennas detected the most fish followed by the earthen dam and powerhouse antennas. In the upper tailrace of Lower Granite Dam, the detection site on the south side of the river was far more effective than the site on the north side of the river, but in the lower tailrace, more fish were detected by antennas located on the north side of the river (Table 1). Of the 26 fish detected in the tailrace as a whole, the upper detection sites missed three fish and the lower detection sites missed one fish.

Median subyearling travel times within reaches increased from release to Granite Point and then decreased as fish moved downstream to the tailrace (Figure 4, Table 2). Fish generally traveled from release to Red Wolf Bridge in about 6 h, but took about 73 h to travel from Blyton

Figure 3.—Detections of radio-tagged subyearlings at various sites in Lower Granite Reservoir on the Snake River in 2008.

Table 1.— Detections of radio-tagged subyearlings on different antennas at various sites in Lower Granite Reservoir on the Snake River in 2008.

Detection site	Antenna location	Number detected	Total detected
Red Wolf Bridge	Bridge	41	41
Silcott	North shore	35	38
	South shore	38	
Blyton	North shore	32	35
	South shore	34	
Granite Point	South shore	30	30
Forebay	North shore	23	23
	South shore	18	
Lower Granite Dam	Earthen Dam	19	28
	Spillway	26	
	Powerhouse	16	
Upper Tailrace	North shore	5	22
	South shore	19	
Lower Tailrace	North shore	24	25
	South shore	15

Figure 4.—Box plots of travel times of radio-tagged subyearlings within reaches of Lower Granite Reservoir in 2008. The bottom of each box represents the 25th percentile, the horizontal line represents the median, and the top of each box represents the 75th percentile. The maximum travel time through each site is shown above each box and the minimum is represented by the stem and whisker extending from the bottom of each box.

Table 2.—Travel times (hours) of radio-tagged subyearlings between detection sites in Lower Granite Reservoir in 2008.

Reach	<i>N</i>	Minimum	25 th percentile	Median	75 th percentile	Maximum
Red Wolf Bridge	41	2.2	2.6	5.9	14.7	140.9
Silcott	35	2.7	10.3	13.8	41.1	418.4
Blyton	30	5.9	20.7	32.0	75.7	384.4
Granite Point	27	11.6	40.7	72.6	102.4	306.8
Forebay	19	7.7	12.4	20.6	32.7	291.7
Lower Granite Dam	17	1.2	3.0	5.0	25.5	61.6
Tailrace	21	0.2	0.4	1.2	17.5	144.7

to Granite Point. In each reach, some subyearlings showed considerable delay. In individual reaches between Red Wolf Bridge and the forebay, maximum travel times ranged from 12 to 17 days (Table 2). Median residence time in the forebay was 10.2 h and ranged from 2.5 to 170.6 h ($N = 19$).

Median migration rates were highest from release to Red Wolf Bridge (60 km/d), decreased to a low of 3.1 km/d between Blyton and Granite Point, then increased slightly as fish moved to the forebay and dam (Figure 5, Table 3). Subyearling migration rates increased from Lower Granite Dam to the tailrace detection sites in the relatively higher velocities found there. Subyearling migration rates were generally less than 20 km/d in Lower Granite reservoir, but some fish did move at high rates in the upper reaches of the reservoir (Figure 5, Table 3).

A total of four subyearlings made upstream excursions between detection sites. One fish traveled downstream to Granite Point and then swam back upstream to Blyton. The total time for this round-trip excursion was almost 6 d. Another fish reached the forebay and then swam upstream to Granite Point before returning to the forebay almost 20 d later. This same fish had spent over 17 d in the reach between Red Wolf Bridge and Silcott before continuing downstream, and was also the last fish detected in the study—July 28 in the forebay. The last two fish initiated upstream excursions from Lower Granite Dam to the forebay. One fish made five round-trip excursions and finally passed Lower Granite Dam on July 4.

Discussion

We collected run-of-river subyearlings from the Snake River for radio-tagging for the first time in 2008. Our past efforts on this project have relied on using hatchery fish (Tiffan 2008; Tiffan et al. 2009a), and collecting fish from the river was intended to better represent the

Figure 5.—Box plots of migration rates of radio-tagged subyearlings within reaches of Lower Granite Reservoir in 2008. The bottom of each box represents the 25th percentile, the horizontal line represents the median, and the top of each box represents the 75th percentile. The vertical bars represent minimum and maximum travel times.

Table 3.—Migration rates (km/d) of radio-tagged subyearlings within reaches of Lower Granite Reservoir in 2008.

Reach	<i>N</i>	Minimum	25 th percentile	Median	75 th percentile	Maximum
Red Wolf Bridge	41	2.5	24.0	59.7	138.1	162.6
Silcott	35	0.6	6.0	17.7	24.0	91.9
Blyton	30	1.2	5.6	13.9	21.4	74.9
Granite Point	27	0.7	2.2	3.1	5.7	19.7
Forebay	19	0.7	6.1	9.7	16.0	25.9
Lower Granite Dam	17	0.6	1.4	7.2	11.9	29.9
Tailrace	21	0.1	1.4	20.2	65.4	107.6

population at large. As such, the fish we tagged were likely a mix of wild fish and unmarked hatchery fish. The fish we tagged in 2008 were detected at rates similar to those of fish from comparable releases made in 2006. The general decline in detection rates as fish moved downstream was likely the result of mortality, decreased detection efficiency if fish inhabited deeper water, and tag expiration before a fish moved completely through the study area.

The subyearlings we tagged behaved similarly to those we tagged in 2006 and 2007. Migration rates were highest from release to Red Wolf Bridge as this portion of the reservoir contained the highest velocities. Migration rates declined with increasing impoundment in Lower Granite Reservoir. These results are similar to those of Tiffan et al. (2009b) who found that migration rate of subyearlings through Lower Granite Reservoir was directly related to water velocity, which in turn was influenced by impoundment (e.g., greater cross-sectional area). Our fish displayed a large range in travel times and migration rates as did the subyearlings tagged by Tiffan et al. (2009b). More active migrants had fast travel rates through reservoir reaches indicating that some of these fish were likely actively swimming downstream. In contrast, some fish delayed in some reaches in excess of 17 days and consequently had very slow downstream movement rates. Furthermore, some fish took a month or more to pass Lower Granite Dam. This coupled with upstream excursions illustrates the migratory behavior that can lead to some fish adopting a reservoir-type life history. We speculate that a combination of physiological, behavioral, and environmental factors contribute to this life history strategy.

We intended to make releases of radio-tagged subyearlings in the Clearwater River in 2008 for comparison and to investigate the migratory behavior, survival, mortality, and timing of delay because fish produced there have a greater tendency to adopt a reservoir-type life history. Unfortunately, fish experienced high mortality following collection and handling due to gas bubble trauma. In 2009, fish will be collected from the Clearwater River and held in degassed water to alleviate the problems encountered in 2008.

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CHAPTER THREE

Assessment of the Effect of Delayed Migration on Estimates of the Joint Probability of Migration and Survival of Juvenile Fall Chinook Salmon to Lower Granite Dam

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Introduction

The objective of this sensitivity analysis was to assess the effect of delayed migration on estimates of the joint probability of migration and survival (ϕ) to Lower Granite Dam in 2008. The joint probability of migration and survival is estimated because some fish delay migration and are not detected at Lower Granite Dam. Therefore, survival to Lower Granite Dam represents both migrating and surviving to the dam. Large-scale monitoring studies typically use PIT-tag detections to measure migration and survival. In the presence of delayed migration to Lower Granite Dam that results in smolt passage occurring after the end of PIT-tag operations, migration and survival estimates based on PIT-tag detections will be biased. One method of exploring the size and nature of this bias is to compare estimates of survival to Lower Granite Dam using two sets of detections: one set from an “abbreviated” detection period that corresponds to the usual period when the PIT-tag system was operational, and a second set from an “extended” period that includes additional weeks of detections. In most years, PIT-tag detections are available at Lower Granite Dam until 1 November. However, in 2008, PIT-tag detections were available at Lower Granite and at dams downriver through mid-December. This extended detection offers an opportunity to assess the possible bias in estimates of the joint probability of migration and survival to Lower Granite based solely on the abbreviated detection period. For this analysis, we used 1 November 2008 as the end of the abbreviated period, and 18 December 2008 as the end of the extended detection period.

Because PIT-tag detections were not available at Lower Granite Dam and at the lower dams throughout the winter, the estimate of the joint probability of migration and survival to Lower Granite based on the extended period may itself be biased. In particular, it will be biased if PIT-tagged juveniles passed Lower Granite after the end of the extended detection period. However, it will be a more reasonable estimate of the joint probability of migrating and surviving to Lower Granite than the comparable estimate from the abbreviated period if significant numbers of fish pass Lower Granite after the end of the abbreviated period and before the end of the extended period. Furthermore, if the estimates of the joint probability of migration and survival to Lower Granite Dam differ between the abbreviated and the extended detection periods, then we can conclude that estimates based solely on the abbreviated detection period are biased.

Methods

Data

Because no fish were tagged for this study in 2008, we used PIT-tag detection data from surrogate fall Chinook salmon smolts tagged at Dworshak Dam in 2008 and released either in the Clearwater River or the Snake River. Release groups were classified by their release site: Clearwater River (“CLR”, released at Big Canyon Creek Acclimation Pond on the Clearwater River) or Snake River (“SNK”, released in the Snake River between the Clearwater and Salmon rivers). Three weekly releases were made for both the CLR fish and the SNK fish, with weekly release sizes ranging from 28,656 for the first week of CLR releases, to 70,582 for the second week of SNK releases, after accounting for recovered tags (Tables 1 and 2). PIT-tag release,

Table 1.—Tagging and release information for surrogate fall Chinook salmon tagged at Dworshak in 2008 and released at Big Canyon Creek Acclimation Pond on the Clearwater River (CLR). After accounting for recovered tags, the weekly release groups had sizes 28,656 (week 1), 32,310 (week 2), and 38,951 (week 3).

Group	Week	Release Date (2008)	Tagging Files	Number Released
CLR	1	23 June	DMM08175.DW1	6,535
CLR	1	24 June	DMM08176.DW1	6,533
CLR	1	25 June	DMM08177.DW1	6,550
CLR	1	26 June	DMM08178.DW1	6,564
CLR	1	27 June	DMM08179.DW1	6,897
CLR	2	29 June	DMM08181.DW1	6,558
CLR	2	30 June	DMM08182.DW1	6,552
CLR	2	1 July	DMM08183.DW1	6,802
CLR	2	2 July	DMM08184.DW1	6,495
CLR	2	3 July	DMM08185.DW1	6,629
CLR	3	7 July	DMM08189.DW1	6,585
CLR	3	8 July	DMM08190.DW1	7,457
CLR	3	9 July	DMM08191.DW1	9,194
CLR	3	10 July	DMM08192.DW1	8,391
CLR	3	11 July	DMM08193.DW1	7,701

Table 2.—Tagging and release information for surrogate fall Chinook salmon tagged at Dworshak in 2008 and released in the Snake River (SNK) between the Clearwater and the Salmon rivers. After accounting for recovered tags, the weekly release groups had sizes 64,928 (week 1), 70,582 (week 2), and 64,500 (week 3).

Group	Week	Release Date (2008)	Tagging Files	Number Released
SNK	1	19 May	DMM08140.DW1, DMM08140.DW2	15,350
SNK	1	20 May	DMM08141.DW1, DMM08141.DW2	15,355
SNK	1	21 May	DMM08142.DW1, DMM08142.DW2	15,415
SNK	1	22 May	DMM08143.DW1, DMM08143.DW2	19,380
SNK	2	26 May	DMM08147.DW1, DMM08147.DW2	15,371
SNK	2	27 May	DMM08148.DW1, DMM08148.DW2	15,354
SNK	2	28 May	DMM08149.DW1, DMM08149.DW2	15,399
SNK	2	29 May	DMM08150.DW1, DMM08150.DW2	14,356
SNK	2	30 May	DMM08151.DW1, DMM08151.DW2	10,682
SNK	3	2 June	DMM08154.DW1, DMM08154.DW2	17,029
SNK	3	3 June	DMM08155.DW1, DMM08155.DW2	15,382
SNK	3	4 June	DMM08156.DW1, DMM08156.DW2	15,353
SNK	3	5 June	DMM08157.DW1, DMM08157.DW2	17,511

detection, recapture, and mortality data for these release groups were downloaded from the PTAGIS database on 3-4 March, 2009.

Statistics

For each PIT-tagged release group and for both the abbreviated and extended detection periods, University of Washington software PitPro was used to convert the PTAGIS release and observation data to detection histories. Detection sites included Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, Bonneville, and the estuary towed array (TWX). For each release group, the joint probability of migrating and surviving from the release point to Lower Granite Dam was estimated for both the abbreviated detection period (ϕ_A) and for the extended detection period (ϕ_E) using the Cormack-Jolly-Seber (CJS; Cormack 1964; Jolly 1965; Seber 1965) release-recapture model. A one-sided z -test was used to test the hypothesis that the migration and survival probability from the extended period was greater than the corresponding probability from the abbreviated period, i.e., $H_A : \phi_E > \phi_A$.

Results

Estimates of the joint probability of migration and survival from the release point to Lower Granite Dam for the abbreviated period ranged from $\hat{\phi}_A = 0.1900$ ($\widehat{SE} = 0.0159$) for the third release of Clearwater fish, to $\hat{\phi}_A = 0.6888$ ($\widehat{SE} = 0.0166$) for the first release of Snake River fish (Table 3). For the extended period, estimates ranged from $\hat{\phi}_E = 0.1932$ ($\widehat{SE} = 0.0081$) for the third release of Clearwater fish to $\hat{\phi}_E = 0.6883$ ($\widehat{SE} = 0.0166$) for the first release of Snake River fish (Table 3). In general, estimates for Clearwater fish (released at Big Canyon Creek Acclimation Pond on the Clearwater River) were much lower than for Snake River fish (released in the Snake River between the Clearwater and Salmon rivers). In most cases, the point estimate of the joint probability of migration and survival to Lower Granite was slightly larger for the extended detection period than for the abbreviated period, but in no case was the difference statistically significant at the 10% level (Table 3). This sensitivity analysis found no evidence of bias arising from using abbreviated detection data in estimating the joint probability of migration and survival from release to Lower Granite Dam for fish released either in the Clearwater River or in the Snake River in the spring and summer of 2008.

Table 3.—Estimated joint probability (and standard error) of migrating and surviving from release to the Lower Granite tailrace for the abbreviated detection period ($\hat{\phi}_A$) and the extended detection period ($\hat{\phi}_E$), for each weekly release group. CLR = Clearwater fall Chinook subyearlings. SNK = Snake River fall Chinook subyearlings. “A” = abbreviated detection period (ending 1 November 2008), and “E” = extended detection period (ending 18 December 2008). P-value is based on one-sided z-test.

PIT-Tag Release Group	Abbreviated Detection Period		Extended Detection Period		$P(\phi_E > \phi_A)$
	$\hat{\phi}_A$	$\widehat{SE}(\hat{\phi}_A)$	$\hat{\phi}_E$	$\widehat{SE}(\hat{\phi}_E)$	
CLR week 1	0.2131	0.0140	0.2363	0.0124	0.1074
CLR week 2	0.2099	0.0140	0.2250	0.0107	0.1957
CLR week 3	0.1900	0.0159	0.1932	0.0081	0.4288
SNK week 1	0.6888	0.0166	0.6883	0.0166	0.5085
SNK week 2	0.6094	0.0145	0.6108	0.0145	0.4728
SNK week 3	0.5696	0.0144	0.5697	0.0144	0.7980

Discussion

This sensitivity analysis is a follow-up to the sensitivity analysis performed using acoustic-tag detections from fall Chinook subyearlings tagged and released in the Clearwater River as part of the 2007 study. In that study, we found strong evidence of bias in estimates of migration and survival to Lower Granite Dam based on the abbreviated detection period (ending 1 November 2007), with estimates available during the extended detection period only for fish released in September and October. This contrasts with the results presented here based on detections from the 2008 PIT-tagged release groups, which showed no evidence of bias using the abbreviated detection period. However, it is important to note that the PIT-tagged fish used in this analysis were released (in 2008) in May, June, and July, whereas the acoustic-tagged fish used in the previous analysis were released in August, September, and October of 2007. It is possible that if we were to analyze PIT-tagged subyearlings released in the late summer and early fall of 2008, we might have found evidence of bias based on the abbreviated detection period.

The extended detection period used here (ending 18 December 2008) did not include the entire time when these PIT-tagged fish may have been passing Lower Granite Dam. For this reason, the estimate of migration and survival generated for the extended detection periods may yet be negatively biased. A more definitive sensitivity analysis would use detections at Lower

Granite Dam and further downriver throughout the fall, winter, and spring seasons. Such studies would need to be repeated over multiple years to estimate the average degree of bias and the amount of interannual variability in the bias. This type of analysis would provide guidance in refining the temporal component of definitions of SAR and T/I (transport/inriver ratio) for fall Chinook salmon.

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CHAPTER FOUR

Fall Chinook Salmon SAR Estimation and Bias Correction

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Introduction

The SAR (smolt-to-adult return ratio) is the probability of a salmonid returning to a particular site as an adult, conditional on reaching a given site as a juvenile. It is a measure of the overall migration success for a release group or brood year, and is an important performance measure used in fishery and hydrosystem management. For salmonids released upstream of Lower Granite Dam, SAR is often measured from reaching Lower Granite as a juvenile back to Lower Granite as an adult, but may also be measured from release back to either Lower Granite or a hatchery or spawning ground. If SAR is measured from release back to Lower Granite, it is estimated simply as the ratio of the counts of adults observed at Lower Granite to the number of smolts initially released. If SAR is measured from Lower Granite Dam, juvenile survival to Lower Granite must be accounted for. Additionally, if measured from Lower Granite, SAR may be estimated for different groups of fish, including the undetected group (i.e., the group of juveniles that passed through the hydrosystem without detection at transport dams) and the entire collection of juveniles that reached Lower Granite, regardless of downstream detections. If SAR is to be used to assess transportation effects, then it is necessary to account for transportation at dams downstream of Lower Granite. The Comparative Survival Study (CSS; Schaller et al. 2007) attempts to do this by estimating SAR for the undetected group, because only fish that enter the bypass system at transport dams (and are detected, if PIT-tagged) are transported. The CSS approach requires estimating survival from Lower Granite to the downstream dams where fish may be transported or otherwise removed from the migrating population.

Fall Chinook salmon exhibit a flexible life history, with most juveniles migrating to the ocean in the summer or fall of their first year (“ocean life history,” or OLH), and others entering the ocean as yearlings (“reservoir life history,” or RLH). Fish exhibiting the reservoir life history may begin their seaward migration in the summer or fall of their first year (i.e., as subyearlings), and then delay the completion of their migration until the following winter or spring. If PIT-tagged fall Chinook salmon pass Lower Granite Dam in winter when the PIT-tag detection system is non-operational, then the estimate of the number of juveniles passing Lower Granite will be too low, and the resulting SAR estimate from Lower Granite will be too high. This will be the case regardless of whether SAR is estimated for the undetected group or for all fish that reached Lower Granite, unless the count of returning adults is limited to fish that were detected at Lower Granite in the fall of their release year.

It is possible to calculate an unbiased estimate of SAR from Lower Granite for fall Chinook salmon, either for the undetected group or for all fish that reached Lower Granite. However, both these types of SAR estimates require more tagging data than are currently available. The purpose of this chapter is to describe unbiased SAR estimators for both the undetected group and the entire group of fish at Lower Granite, and to identify the tagging requirements for calculating these estimates. Alternatively, a simpler SAR measure from the release point back to Lower Granite may be estimated as the ratio of the number of adults observed at Lower Granite to the initial release size.

Estimators of SAR from Lower Granite Dam

The SAR from Lower Granite is typically estimated as the ratio of the number of adults detected at Lower Granite (A) to the number of juveniles that passed Lower Granite (J), for a given release group:

$$\widehat{SAR} = \frac{A}{J}.$$

In general, A is a tally of adults detected at Lower Granite, while it is typically necessary to estimate J using PIT-tag detection data. Different SAR estimators are used for inference to different groups of fish.

SAR for the Undetected Group

The CSS estimator of SAR for the undetected group ($\widehat{SAR}_{CSS}$) has the form

$$\widehat{SAR}_{CSS} = \frac{A_0}{\hat{J}_0},$$

where A_0 is the number of adults detected at Lower Granite that were not detected at transport dams during their juvenile migration, and $\hat{J}_0$ is the estimated number of juveniles that were present at Lower Granite and were “destined” to pass through the hydrosystem without detection at transport dams or other removal from the migrating population. For fall Chinook, A_0 includes both adults that passed through the hydrosystem as subyearlings in the summer or fall of their release year, and adults that migrated as juveniles through part or all of the hydrosystem in winter, when the PIT-tag detection system is typically not operational, or in the following spring. If J_0 is estimated using only PIT-tag detections from the summer and fall of the release year, then $\widehat{SAR}_{CSS}$ will be biased because the denominator will exclude juveniles that exhibited the reservoir life history, while the numerator will include adults with that life history.

It is possible to estimate a bias-correction factor, β , to generate an unbiased estimate of SAR for the undetected group, $\widehat{SAR}_{ADJ}$:

$$\widehat{SAR}_{ADJ} = \widehat{SAR}_{CSS} \hat{\beta}.$$

The bias-correction factor (β) is a complex function of numerous parameters representing the probability of migratory delay, reinitiation of migration, and survival upstream of Lower Granite, as well as PIT-tag detection probabilities at all transport dams. Details on the definition and estimation of β are given in a previous report (Buchanan and Skalski 2008). Some parameters can be estimated from PIT-tag detection data that are available from the usual operation of the bypass system. In particular, the joint probability of migrating and surviving from the release site to Lower Granite Dam in the summer or fall of the release year, or separately in the following spring, can be estimated using the CJS model to analyze detection histories that are restricted to the summer/fall or spring, respectively. The necessary detection probabilities can be estimated concurrently. Other necessary parameters require additional data, either from extended operation of the bypass and PIT-tag detection systems, or else from acoustic telemetry

studies using long-lived acoustic tags. The key parameter necessary for estimating β and SAR_{ADJ} that is unavailable from current PIT-tag detection data is the joint probability of delaying migration upstream of Lower Granite Dam until the winter following release, and then migrating and surviving from the release site to Lower Granite in the winter (ϕ_{1w}). This parameter may be estimated using acoustic-tag detections from a large release group of subyearlings tagged with long-lived acoustic tags, and a double array of acoustic receivers in the tailrace of Lower Granite Dam. Alternatively, it is possible to estimate ϕ_{1w} from PIT-tag detections if the bypass and PIT-tag detection systems are operational year-round (i.e., throughout the winter). A specialized release-recapture model that accounts for the seasonal timing of passage at Lower Granite Dam and downstream dams would be required in this case.

SAR for all Fish at Lower Granite Dam

If SAR is to be estimated for all fish that arrive at Lower Granite Dam, without restriction to undetected or nontransported fish, then it may be estimated as

$$\widehat{SAR}_{LGR} = \frac{A_{LGR}}{J_{LGR}},$$

where J_{LGR} is the number of juveniles detected at Lower Granite, and A_{LGR} is the number of adults returning to Lower Granite that were detected there as juveniles. If juvenile PIT-tag detection probabilities at Lower Granite vary during the times when tagged fish passed Lower Granite, then $\widehat{SAR}_{LGR}$ will be biased toward the periods with higher detection probabilities. In particular, if fall migrants have a higher detection probability than spring migrants, then $\widehat{SAR}_{LGR}$ will be biased toward the fall migrants, regardless of the proportion of the release group that migrated to Lower Granite in fall. Without winter detections, $\widehat{SAR}_{LGR}$ will be biased toward the SAR of the fall and spring migrants.

It is possible to avoid this bias by calculating the SAR separately for each season or migration period, and then computing a weighted sum of the period-specific SAR estimates, with weights corresponding to the passage distribution at Lower Granite through time. Analytically, this is $SAR_{LGR(Adj)}$:

$$SAR_{LGR(Adj)} = \sum_x \alpha_x SAR_x,$$

where x is the migration period, α_x is the proportion of all juvenile arrivals at Lower Granite that arrived during period x , and SAR_x is the SAR of fish that arrived at Lower Granite in period x . Migration periods should be identified so that the PIT-tag detection probability at Lower Granite is fairly constant throughout each individual migration period. The SAR for period x is estimated as $\widehat{SAR}_x = A_x/J_x$, where J_x is the number of juveniles detected at Lower Granite in period x , and A_x is the number of returning adults that were detected at Lower Granite in period x . The proportion α_x may be estimated as

$$\hat{\alpha}_x = \frac{m_x / \hat{p}_x}{m_x / \hat{p}_x + \sum_{y \neq x} m_y / \hat{p}_y},$$

where m_x and m_y are the numbers of tagged juveniles detected at Lower Granite in periods x and y with detection probabilities p_x and p_y , respectively ($y \neq x$). The detections used in m_x and m_y may come from PIT tags, in which case $m_x = J_x$ and $m_y = J_y$, or from long-lived acoustic tags. If PIT tags are used to estimate α_x , then PIT-tag detection must be possible at Lower Granite and at one or more dams downstream of Lower Granite Dam in each migration period, in order to estimate the PIT-tag detection probability at Lower Granite. If long-lived acoustic tags are used to estimate α_x , then a double array of acoustic receivers must be located in the tailrace of Lower Granite. In either case, estimation of $SAR_{LGR(Adj)}$ requires PIT-tag detection at Lower Granite during all migration periods (including winter), in order to estimate SAR_x for all migration periods.

Design Implications

Our 2007 report (Buchanan and Skalski 2009) lists detailed estimation and design requirements to estimate the bias-correction factor β for the SAR estimate from Lower Granite for undetected fish. In summary, a large release of PIT-tagged subyearling fall Chinook salmon is required, with detections available at all transport dams in the summer and fall of the migration year, and in the following spring. Estimation of β also requires one of the following:

1. Winter PIT-tag detections at Lower Granite Dam and downstream dams, or
2. A large release of subyearlings tagged with long-lived acoustic tags released upstream of Lower Granite Dam, with a double array of acoustic receivers in the tailrace of Lower Granite throughout the winter.

Conclusions

It is possible to estimate unbiased SAR from Lower Granite for fall Chinook salmon, either for all fish that arrived at Lower Granite Dam, or for the undetected group in terms of “Lower Granite equivalents.” However, the complex life history of juvenile fall Chinook requires estimating additional parameters that relate to the temporal nature of the juvenile migration, compared with SAR estimation for spring and summer Chinook salmon. Large release groups of PIT-tagged subyearlings are required, along with either year-round operation of the bypass and PIT-tag detection systems at Lower Granite and downstream dams, or else large releases of subyearlings tagged with long-lived acoustic tags. It is expected that the size of the bias-correction factor will vary annually. Thus, such studies will need to be repeated over several years to determine the interannual variability in the bias-correction factor or migration timing parameters. A much simpler, unbiased, and less expensive SAR can be measured from the release point back to Lower Granite using the ratio of the number of adults at Lower Granite to the size of the initial release group. This SAR from release is robust to the effects of delayed migration, and its estimation requires less intensive tagging studies.

The standard CSS estimator of SAR for the undetected group (SAR_{CSS}) should not be used to estimate transportation effects (e.g., T/I or T/C ratio) for fall Chinook salmon, because it is biased. The bias-corrected SAR estimator for the undetected group (SAR_{ADJ}) may be used for estimating the SAR from Lower Granite for undetected fall Chinook salmon. Using SAR_{ADJ} to also estimate transportation effects implicitly compares the return rate of transported fish to the return rate of fish that had no chance of transportation, because they reached the transport dams after the end of transport operations. A more robust approach to analyzing transportation effects is the Ricker relative recovery method (Ricker 1975), which uses preassigned transport and control groups and is not dependent on the timing of the juvenile migration. Additionally, the Ricker relative recovery method has lower data requirements, and does not depend on modeling assumptions.

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CHAPTER FIVE

Hydrodynamic Conditions and Water Quality of the Lower Clearwater River and Lower Granite Reservoir, 2008

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Introduction

Assessment of the hydrodynamic conditions and water quality of the lower Clearwater River and Lower Granite Reservoir is needed to understand the causative mechanisms of juvenile fall Chinook salmon emigration delay and survival. Cold hypolimnetic water releases from Dworshak Reservoir on the North Fork of the Clearwater River cool Lower Granite Reservoir during summer in an attempt to improve environmental conditions and increase survival rates of emigrating juvenile salmon through the lower Snake River. Consequently, changes in water quality (e.g., temperature) and hydrodynamic conditions (e.g., velocity) between the Clearwater River and Lower Granite Reservoir on the Snake River may impact juvenile salmon migration rates by increasing migration delay and facilitating the reservoir-type life history (Connor et al. 2005). Understanding the effects of these environmental variables on juvenile salmon migration behavior and survival is a needed component for fisheries managers working to restore threatened Snake River fall Chinook salmon.

Results from the 2007/08 pilot (first) year of study indicate that juvenile salmon delayed their migration and had the lowest probabilities of migrating and surviving in the transition zone and confluence zone of the Snake and Clearwater rivers during July and August (Tiffan et al. 2009a). Hydrodynamic and water quality data collected in 2007/08 suggest that fish delayed their migration during late summer when water temperatures between the Snake and Clearwater rivers differed by as much as 10-14°C (Tiffan et al. 2009a). Although relationships between water temperatures and fish behavior were only superficially examined during the pilot year, it is possible that the large variation in temperature between the free-flowing Clearwater River and Lower Granite Reservoir may have influenced juvenile salmon migration delay at the confluence. Other hydrodynamic variables (e.g., changes in water velocity at the confluence) may have also affected juvenile salmon migration behavior in the pilot year, but were not thoroughly investigated.

Hydrodynamic data collection continued during the 2008/09 (second) year of study; however, data on juvenile salmon were not collected due to the discovery of gas bubble trauma in fall Chinook salmon subyearlings captured in the lower Clearwater River. Although comparisons between hydrodynamic information and fish behavior were not possible in 2008/09, hydrodynamic data are useful in determining a baseline of environmental conditions for this multi-year study. Additional years of empirical hydrologic data also help to validate the hydrologic model for Lower Granite Reservoir and the lower Clearwater River and ensure that is applicable to varying hydrologic conditions. Further, hydrodynamic data collected in 2008/09 combined with the hydrodynamic and fish behavioral data collected during the pilot year allows the formation of hypotheses about how subyearling Chinook salmon may have behaved in 2008/09 and how they may behave in the future.

Methods

Hydrodynamic Data Collection

Hydrodynamic and water quality monitoring data were collected during the 2008/09 field season using the same methods as in the 2007/08 pilot season (Tiffan et al. 2009a). Temperature logger strings were deployed at the same locations as the previous field season throughout Lower Granite Reservoir on the Clearwater and Snake rivers (Figure 1). The open water strings (LGR4, LGR5, and LGR6) and the Clearwater site (LGR1) were deployed on 27 May 2008 and began measurements on 28 May 2008. The other two bridge site strings (LGR2 and LGR3) were deployed 28 June 2008. Deployment prior to that date was too dangerous due to high river discharges. The temperature logger strings were retrieved in early January 2009. All of the strings, with the exception of LGR6, operated until that time. The buoy for the subsurface string at LGR6 failed in mid-October and the loggers sank to the bottom.

One-hundred and four mobile acoustic Doppler current profiler (ADCP) transects and 74 conductivity-temperature-depth (CTD) casts were made from May to September 2008 and in January 2009 throughout Lower Granite Reservoir (Figure 2 and Figure 3). Additionally, Clearwater River stage was measured with a pressure sensor deployed near the north shore, just upstream of the North Lewiston pump station near river kilometer 7.5 (Figure 4). The location was just upstream of a well-defined riffle, which was chosen to minimize the potential for Lower Granite backwater to affect the gauge. The sensor was deployed on 29 July 2008 and retrieved 5 March 2009; stage was measured every 20 minutes.

Figure 1.—Temperature logger string locations for the 2008/09 field season.

Figure 2.—Mobile acoustic doppler current profiler (ADCP) transect locations in the 2008/09 field season.

Figure 3.—Locations of conductivity-temperature-depth (CTD) casts performed in the 2008/09 field season.

Figure 4.—Location of stage gauge deployed on the Clearwater River during the 2008/09 field season.

Water Particle Travel Time

Water particle travel times were used to integrate estimated local velocity over space and time. This information answers questions such as “How long did it take a particle of water to travel to the LGR2 nodes after it passed the LGR1 nodes at 8:30 pm on August 30?” The river velocity in the study area varies considerably over time due to variation in discharge, and in space, due to the variation of cross-sectional area. Particle travel times provide an aggregate velocity from one point to another while accounting for the temporal and spatial variation of river velocity.

Particle travel time was computed through the confluence zone from river kilometer 7.5 in the Clearwater River to Red Wolf Bridge (Snake rkm 221.1). For this reach, a simulated particle was released at the upstream location every hour from 1 June 2008 through 1 March 2009. The downstream progress of the particle was computed at 5-min intervals using a linearly interpolated velocity (in both space and time) from the MASS1 hydrologic model (Richmond and Perkins 2009) simulation results. The particle position was saved at 15-min intervals.

Bathymetry Data Collection

A bathymetric survey of the Clearwater River from river kilometer 5.6 (river mile 3.5) to river kilometer 13.3 (river mile 8.3) was conducted by PNNL during March 2009. All depth data were collected using an Innerspace 455 single-beam, survey-grade, echo sounder with an 8-degree transducer, operating at 208 KHz, and a manufacturer’s stated vertical accuracy of 3.05 cm.

A bathymetric surface was developed which fused this new survey data with existing data, including the 2002 survey conducted by Cook et al. (2003) and various sediment range surveys either collected or contracted by the Walla Walla District of the U.S. Army Corps of Engineers. The final bathymetric surface had a raster cell resolution of 10-feet. To produce the surface, bathymetric data were processed using a combination of Golden Software's Surfer 7, ESRI's ArcGIS v. 9.2, and Australia University's ANUDEM v. 5.2. Using Surfer, these data were processed using anisotropic kriging while tuning angle and radial dimensionality parameters. This technique generated a stream-wise varying surface grid from the irregular set of point data. Anisotropic kriging has been found to minimize typical sinkhole and hillock effects commonly found when processing irregular spaced bathymetric data. When necessary, suspect or clearly anomalous data points were eliminated and data were reprocessed. The individual stream-sections were exported out of Surfer as DXF contours and imported to ArcGIS where data was pre-processed for final surface processing in ANUDEM (Hutchinson 1989, 1996). This method produces a raster-based terrain surface that can be imported into ArcGIS.

TDG Compensation Depths

Fish compensation depths during total dissolved gas levels exceeding 100% were calculated using typical July environmental conditions in the most downstream 13.3 km of the Clearwater River (river area of approximately 28 ha). A water surface profile was simulated using the MASS1 hydrologic model (Richmond and Perkins 2009) and average July river discharges for the Snake and Clearwater Rivers (29.8 and 14.2 kcfs, respectively) and a Lower Granite Reservoir stage of 733.5 ft. Compensation depths were computed assuming a barometric pressure of 741 mm Hg, the July average for the LEWI fixed monitor (USACE gauge in Clearwater River near Lewiston, ID).

Results

Hydrodynamic Conditions

Hydrodynamic conditions were generally similar between 2007/08 and 2008/09. Water temperatures were generally coolest in the Clearwater River Arm and warmest in the Snake River Arm in 2008/09 (Figure 5). Temperatures in the Snake River Arm exceeded 20°C throughout the water column from the end of June through mid-October and only the uppermost five to seven meters of water at the confluence downstream boundary exceeded 20°C during the same time period. The Clearwater River Arm exceeded 20°C only from mid-September through mid-October (Figure 5). Thermal stratification of the Snake River at the confluence downstream boundary began in early July and dissipated by mid-October. The 2008 spring freshet on both the Snake and Clearwater Rivers was larger and longer than in 2007 (Figure 6). Dworshak discharges were about 2000 kcfs higher in 2008 than 2007 during the summer (Figure 7). During the freshet until about mid-August 2008, temperatures in the Snake River were cooler than in 2007 (Figure 8). Additionally, water temperatures in the Clearwater River were slightly warmer in 2008 than 2007. This combination resulted in a much smaller temperature difference between the two rivers in 2008 until about 1 September (Figure 8).

Figure 5.—Measured water temperature in the Clearwater River Arm of Lower Granite Reservoir (LGR1 temperature logger string, top panel), Snake River Arm at the US12 bridge (LGR2 temperature logger string, middle panel), and the Snake and Clearwater Rivers Confluence Downstream Boundary at the Red Wolf Bridge (LGR3 temperature logger string, bottom panel) from May 2008 to January 2009.

Figure 6.—Comparison of 2007 and 2008 discharge in the Clearwater River near Spalding, ID (USGS gauge #13342500, left panel) and the Snake River near Anatone, WA (USGS gauge #13334300, right panel).

Figure 7.—Comparison of 2007 and 2008 discharge from Dworshak Dam (USGS gauge #13341000).

Figure 8.—Snake and Clearwater River temperatures measured in 2007 (left) and 2008 (right) collected from the LGR2 (Snake River) and LGR1 (Clearwater River) temperature logger strings. Temperature difference between the two rivers is also plotted.

Water Particle Travel Time

Water particle travel time from Clearwater River rkm 7.5 to the Red Wolf Bridge (Snake rkm 221.1) gradually increased from about two hours on 1 June 2008 to about 10 hours on 7 September 2008 and quickly increased to about 35 hours in mid-September (Figure 9). Travel times remained relatively long throughout a majority of the fall, winter, and early spring; however, travel times were shorter during a couple periods in mid-November 2008 and for a few weeks in mid-January 2009. Water particle travel time was generally similar in 2008 as in 2007; however, travel time in the summer of 2007 was slightly longer than in the summer 2008 and travel time in spring 2008 was longer than in 2009.

Figure 9.—Water particle travel time (h) and apparent speed (km/h) through the study area from Clearwater rkm 7.5 to the Red Wolf Bridge (LGR3 temperature loggers, Snake rkm 221.1) for the 2007/08 and 2008/09 study seasons.

TDG Compensation Depths

Total dissolved gas saturations of 103% and 109% yielded compensation depths of 0.3 m and 0.9 m (Table 1). The proportion of the river shallower than the compensation depth increased with increased total dissolved gas saturation and varied from a low of 1.5% (0.4 ha) at 103% saturation (Figure 10) to a high of 8.4% (2.4 ha) at 109% saturation (Figure 11).

Table 4.—Compensation depths for several levels of total dissolved gas (TDG) saturation. This assumes a barometric pressure of 741 mm Hg, which is the long term July average at the LEWI fixed TDG monitor.

TDG Saturation %	ΔP mm Hg	ΔP ft H ₂ O	ΔP m H ₂ O
103	22.2	1.0	0.3
109	66.7	3.0	0.9

Figure 10.—Map showing where the Clearwater River bottom is shallower or deeper than compensation depth when the TDG saturation is 103%. Clearwater river kilometers (rkm) are delineated by pink circles overlayed on the river channel; rkm 5 and 10 are labeled.

Figure 11.—Map showing where the Clearwater River bottom is shallower or deeper than compensation depth when the TDG saturation is 109%. Clearwater river kilometers (rkm) are delineated by pink circles overlayed on the river channel; rkm 5 and 10 are labeled.

Discussion

Water temperature was generally similar between the 2008/09 and 2007/08 study years despite a few minor differences. The duration of thermal stratification at the Clearwater-Snake river confluence downstream boundary was similar in 2008/09 as in 2007/08 and lasted from about 30 June to 30 September. The Clearwater River Arm was also thermally stratified in September 2008 as it was in 2007. The Snake River Arm, which stratified in August 2007 due to cool Clearwater River water moving upstream into the Snake River, did not stratify in 2008. Cooler water likely did not move upstream into the Snake River Arm in 2008 because of higher river discharge, which caused the Clearwater River water to move downstream into the reservoir. Additionally, the temperature difference between the Clearwater River and Snake River at the confluence was less in July and August 2008 (5-12°C) than in 2007 (10-14°C). This water temperature difference indicates that fall Chinook salmon subyearlings actively migrating through the confluence experienced less dramatic water temperature changes in 2008 than in

2007, which may have affected their migration delay if temperature is an influential factor. Quantifying the effect (if any) of the temperature difference between the two rivers on subyearling Chinook salmon delay and survival will be an objective of analyses in the 2009/10 study year.

The spring freshet discharge in the Clearwater and Snake rivers was less in 2007 than in 2008 and water particle travel time through the confluence was generally longer in summer 2007/08 than in 2008/09. Water particle travel time in 2008/09 was about 5 hours slower during summer and up to about 20 hours slower during January and February than in 2007/08. Based on the difference in discharge and water particle travel times between study years, the travel time and migration speed of fall Chinook salmon subyearlings may have been faster in 2008/09 than 2007/08. River flow is known to be a significant factor contributing to emigration speed of fall Chinook salmon subyearlings migrating through John Day Reservoir (Tiffan et al. 2000; Connor et al. 2003) and likely applies also to Clearwater-origin subyearling Chinook salmon migrating through Lower Granite Reservoir. However, it is currently unknown whether migration delay of Clearwater River subyearlings is related to river flow. This question will hopefully be addressed in the 2009/10 study year to determine the effect, if any, of discharge and water particle travel time on fall Chinook salmon subyearling emigration rates and delay.

Total dissolved gas compensation-depth models indicate that a majority of the lower Clearwater River is deep enough for fish to depth-compensate at TDG saturations up to 109%. Within the lower 13.5 km of the Clearwater River, the river reach near Potlatch Mill (rkm 7.5) has the least available compensation depths (i.e., the shallowest water) and could potentially contribute to gas bubble disease in subyearling Chinook salmon if migration delay occurs within this reach. Although actively emigrating salmonids and resident salmonids are known to depth-compensate to avoid TDG supersaturation (Weitkamp et al. 2003; Beeman and Maule 2006), further research may be needed to understand how fall Chinook salmon subyearlings behave if they delay their migration in a TDG-supersaturated river reach such as the lower Clearwater River, especially if habitat allowing depth-compensation is not readily available. Assuming that subyearlings in the Clearwater River will avoid TDG-supersaturated water, there is sufficient area available for fish to depth compensate and avoid gas bubble trauma. However, if total dissolved gas levels exceed 109%, or if other changes in environmental conditions (e.g., an increase in barometric pressure or a decrease in river discharge) affect compensation depth, the amount of river available for fish to escape TDG supersaturation would likely decrease.

The relationships between hydrodynamic variables and subyearling migratory behavior in the Clearwater River are currently undefined, but some hypotheses regarding these relationships can be constructed. Water velocity and turbulence have been proposed as the underlying mechanisms that affect fish migration (Coutant 2001; Coutant and Whitney 2006), and Tiffan et al. (2009b) recently demonstrated a direct link between these variables and subyearling migration rate in the Snake River. However, providing high velocities does not always translate to increased migration rates. Tiffan et al. (2009b) showed that subyearlings entering Lower Granite Reservoir from the free-flowing Snake River slowed their migration rate in this transition area in spite of velocities being relatively high. This supports the concept of a behavioral component to active downstream migration (Soloman 1982; Peake and McKinley 1998), which could possibly be overridden if hydrodynamic thresholds (e.g., velocity and

turbulence) are not met. It is possible that this situation exists in the Clearwater River. Radio tagged subyearlings released at monthly intervals from May through October at river kilometer 53 in the Clearwater River in 2007, had relatively fast migration rates through the free-flowing river during all months (Tiffan et al 2009a). However, upon entering the transition zone where impoundment begins, migration rates slowed substantially and some fish exhibited significant delay. In this situation, velocities may have declined to a point that subyearlings did not find it profitable to continue active migration. Identifying the extent to which velocity might affect subyearling migratory behavior in the Clearwater River will determine the effectiveness of current flow management strategies at reducing migratory delay.

Water temperature is another environmental variable that may be influencing subyearling migratory behavior in the Clearwater River. Fry emergence begins in June under increasing temperatures and photoperiod. With the implementation of flow augmentation from Dworshak Reservoir in early July, water temperatures can decline up to 5°C. This cool water may retard growth and interrupt smoltification thereby reducing migratory disposition. If so, then fish that enter Lower Granite Reservoir and stay in cooler temperatures (Tiffan et al. 2009c) means they may not regain their migratory disposition. It is not known whether physiological development will progress in fish that use warmer temperatures in Lower Granite Reservoir particularly under a decreasing photoperiod. The interaction between water temperature, growth, physiological development and migratory disposition remains an area of future research.

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