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SNAKE RIVER FALL CHINOOK SALMON LIFE HISTORY INVESTIGATIONS

ANNUAL REPORT 2010

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Executive Summary

In 2010, we used radiotelemetry to evaluate the migratory behavior, delay, and relative mortality of subyearling fall Chinook salmon in the Clearwater River and Lower Granite Reservoir. We captured, tagged, and released a total of 100 run-at-large subyearlings in the Transition Zone of the lower Clearwater River in late July and monitored their downstream movement past fixed detection sites and by mobile tracking through the end of August. Median residence time of fish that passed through the Transition Zone, Confluence, and Upper Reservoir reaches was relatively short (8.8-25.6 h). However, for fish that remained in the Transition Zone that were detected by mobile tracking, median residence time was over 30 d (N=6). Median migration rates through the study reaches were variable but slow (range 2.9-17.2 km/d) compared to that of more active migrants indicating that subyearlings from the Clearwater River were not actively migrating during July and August. The fate of radio-tagged subyearlings was determined from mobile tracking records. A total of 37of the 71 fish detected during tracking were deemed to be dead, 22 were determined to be alive, and the fate of 16 was unknown. We also radio tagged 66 smallmouth bass in the Confluence reach and later detected 59 bass during mobile tracking. Predators were primarily located along shorelines in the Confluence reach, but a few fish did swim downstream into the Upper Reservoir reach. Most radio-tagged subyearlings that we determined to be dead were also located in shoreline areas suggesting that predation could account for some of the mortality we observed.

In 2011, we concluded a four-year effort to examine the number and distribution of juvenile Chinook overwintering in the lower Snake River. From October 2010 to March 2011, we used monthly mobile hydroacoustic surveys to estimate the number of juvenile fall Chinook salmon in Little Goose and Lower Granite reservoirs. Concurrent lampara seining was used to verify acoustic targets and to examine spatial and temporal density patterns. We examined seasonal and longitudinal density differences to help identify where holdovers overwinter in the lower Snake River. In 2010-2011, we also sampled the Ice Harbor and Lower Monumental forebays to determine the extent to which fish might overwinter in those areas. Lampara catch data indicated that holdovers were seasonally the most abundant in November in Little Goose and Lower Granite reservoirs and in December in Ice Harbor Reservoir. The hydroacoustic data indicated population peaks in October in Lower Granite Reservoir and in March in Little Goose Reservoir. Maximum population estimates in Little Goose Reservoir were 30,045 in March 2011 and in Lower Granite Reservoir the maximum population was 27,290 in October 2010. Spatial differences were primarily longitudinal with greater holdover abundances in the lower reaches of both reservoirs. Sampling downstream of Little Goose Reservoir revealed that large numbers of holdovers accumulated in Ice Harbor Reservoir by late December; however few holdovers were encountered in Lower Monumental Reservoir, the next upstream reservoir, during any month.

We analyzed the effects of various biological, environmental, and timing factors on survival parameters and travel time estimated from radio-tagged and acoustic-tagged subyearling fall Chinook salmon released in the Clearwater River in 2009. This effects analysis consisted of regression of the joint probability of migration and survival, and the joint probability of migration delay and survival, against covariates describing environmental conditions measured throughout the study period. Travel time was related to both biological and environmental covariates. Analysis focused on the reach from Potlatch on the Clearwater River to Red Wolf Bridge on the Snake River. The joint probability of migrating and surviving through the Transition Zone-Confluence tended to decrease as the difference in cross-sectional velocity between the free-flowing Clearwater River and the Confluence area increased. In contrast, the probability of delaying in the Transition Zone-Confluence tended to increase as the difference in cross-sectional velocity increased, suggesting that subyearling fall Chinook salmon smolts may delay migration when they encounter large changes in water velocity. Smolts were also seen to be more likely to delay migration within the Transition Zone-Confluence when the water was cold near the Confluence of the Clearwater and Snake rivers. Radio-tagged fish were observed to be more likely to migrate and less likely to delay within the Transition Zone-Confluence than acoustic-tagged fish. Among those smolts that moved through the Transition Zone-Confluence reach, radio-tagged smolts tended to move faster than acoustic-tagged smolts.

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CHAPTER ONE

Migration Delay of Juvenile Fall Chinook Salmon in the Vicinity of the Confluence of the Snake and Clearwater Rivers

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Introduction

The Snake River upper reach, Snake River lower reach, Grande Ronde River, and Clearwater River are recognized as the four major spawning areas of Snake River Basin natural fall Chinook salmon *Oncorhynchus tshawytscha* upstream of Lower Granite Reservoir (Figure 1; ICTRT 2007). Though treated as one population, temperature during incubation and early rearing fosters life history diversity among the juveniles produced in these major spawning areas (Connor et al. 2002, 2003). Young fall Chinook salmon in the Snake River upper reach emerge and begin seaward movement earliest in the year followed by fish from the Snake River lower reach, Grande Ronde River, and Clearwater River. Of the four spawning areas, young fall Chinook salmon from the Clearwater River have the most diverse life history. Some of the juveniles meet the seasonal requirements to become actively migrating subyearling smolts and enter the ocean in their first summer of life. Others move downstream gradually, increase their downstream movement rate in the fall, pass Bonneville Dam, and then winter in freshwater or the Columbia River Estuary (Figure 1). A portion of the Clearwater River juveniles begin seaward migration as subyearlings, but eventually lose their disposition to actively migrate and winter in reservoirs formed by the Federal Columbia River Power System. The fish that winter in reservoirs grow to fork lengths >170 mm and enter the ocean as yearlings. They are referred to as reservoir-type juveniles (Connor et al. 2005).

Understanding the juvenile life history diversity of Clearwater River fall Chinook salmon juveniles is critical to the recovery of the Snake River Basin fall Chinook salmon population. In 2007, Arnsberg et al. (2010; hereafter Arnsberg et al.) collected data that exemplified the life history diversity of young fall Chinook salmon in the Clearwater River. During June through the first week of August, Arnsberg et al. seined subyearlings rearing along the shorelines of the free-flowing Clearwater River. All subyearlings 60-mm fork length and longer (N = 943) were implanted with passive integrated transponders (PIT tags; Prentice et al. 1990) and released back to the river. Subyearlings that were PIT-tagged had a mean fork length of 68 ± 8 mm. A total of 11 of the PIT-tagged fish were eventually recaptured in the free-flowing reaches. The mean residence time (i.e., the number of days that elapsed between initial tagging and recapture) was 6 ± 4 d. This suggests that after growing to 60 mm the fish spent about one week in the free flowing reaches before moving downstream. After moving downstream, the subyearlings traverse a 6-km long reach where the river transitions from a free-flowing to an impounded state. We refer to this area as the "Transition Zone" that includes both riverine and impounded habitat. The impounded portion makes up the Clearwater River arm of Lower Granite Reservoir. Arnsberg et al. sampled the Transition Zone from the last week of July to the end of August 2007. In contrast to the free-flowing river, the seine was set at starting points well off shore. A total of 743 subyearlings were captured in the Transition Zone at an average fork length of 103 ± 12 mm. Of these, four had been initially tagged and released from 26 to 40 d earlier in the free-flowing reaches upstream. Three of the subyearlings were recaptured 29 d after they were

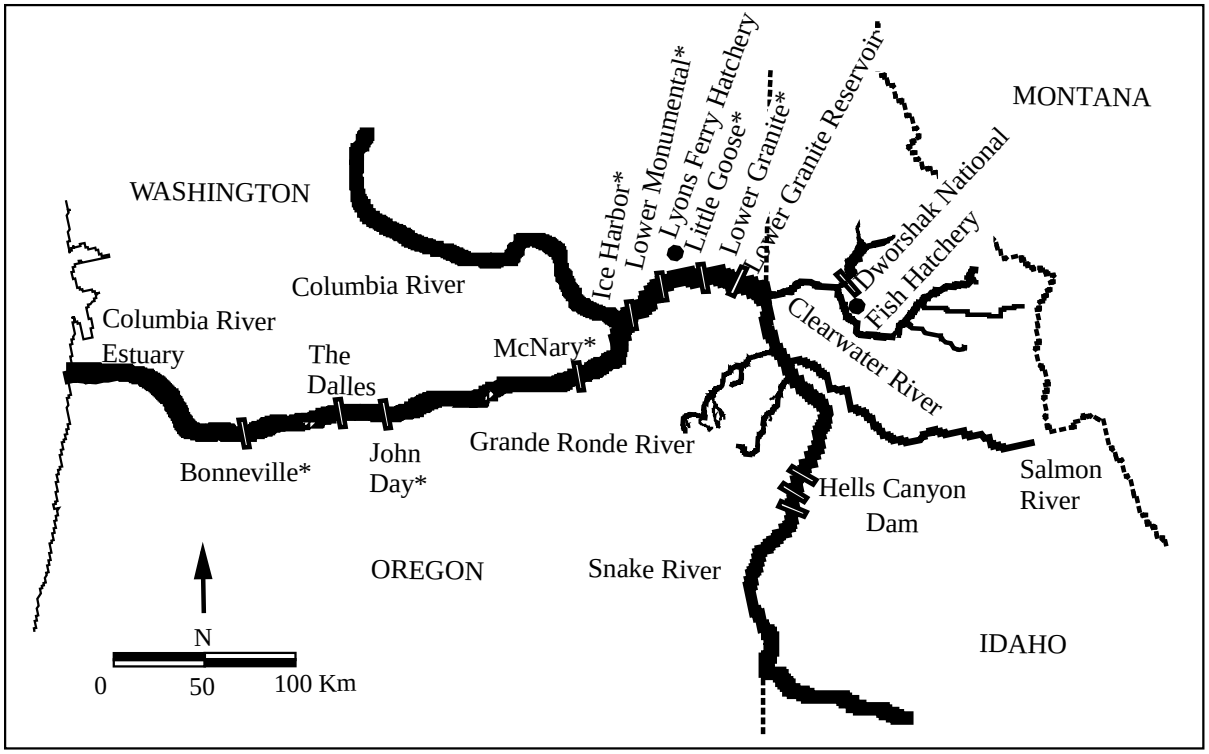

Figure 1.—The Snake River upper reach (Hells Canyon Dam to the Salmon River), Snake River lower reach (Salmon River to upper end of Lower Granite Reservoir), Grande Ronde River, and Clearwater River where fall Chinook salmon spawn. The Federal Columbia River Power System including the dams equipped with juvenile fish bypass and PIT-tag detection systems (denoted by asterisks) as well as the location of Lyons Ferry Hatchery where the hatchery fall Chinook salmon used for the study were initially cultured are also shown.

initially captured and tagged in the Transition Zone. These findings confirmed that some subyearlings dispersed from the free-flowing reaches and then spent up to one month or more in the Transition Zone where they continued to grow.

In 2007 and 2009, we used radio and acoustic telemetry to more fully evaluate the migratory behavior, survival, mortality, and delay of subyearling fall Chinook salmon in the Clearwater River and Lower Granite Reservoir. Monthly releases of radio- and acoustic-tagged hatchery subyearlings made from May through October (2007) showed that fish traveled relatively rapidly in the free-flowing river (>50 km/d), but then slowed substantially (<5 km/d) and delayed in the Transition Zone and Confluence (Tiffan et al. 2009a; Figure 2). In both years, this delay was most prevalent during July and August and mortality of tagged fish during these months was high (Tiffan et al 2010). Although fish eventually moved out of the Transition Zone and into Lower Granite Reservoir, they did not resume active downstream migration but

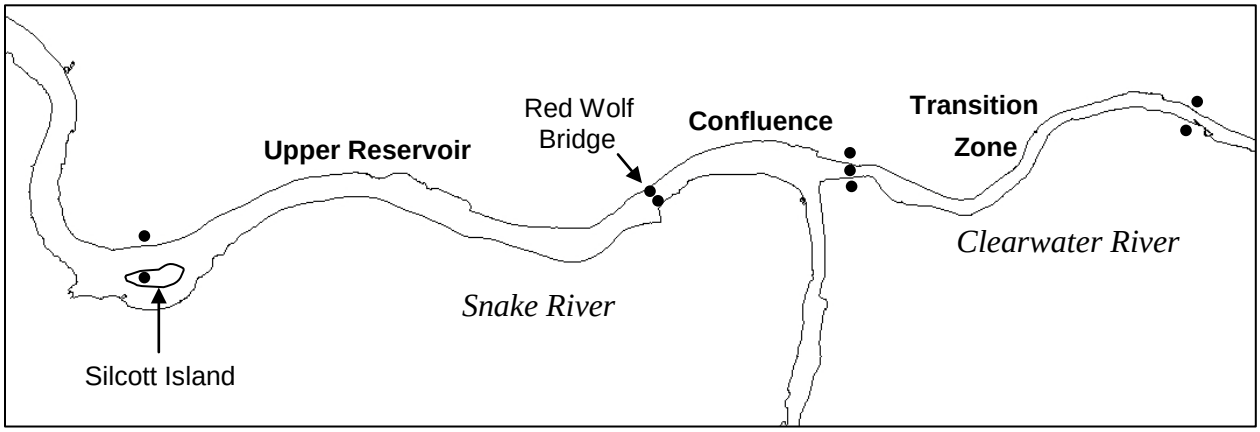

Figure 2.—A map of the study area in 2010 showing locations of radiotelemetry detection sites (black circles) and study reaches.

remained in the reservoir through late fall. The Transition Zone appears to play a critical role in determining subsequent migratory behavior of Clearwater River subyearlings.

The information collected in 2007 and 2009 was obtained by tagging hatchery-origin subyearlings. Because these fish were relatively large (~90-100 mm), they represented the larger portion of the natural population and their behavior may not have been representative of smaller parr. The timing of entry into the Transition Zone of the hatchery fish we tagged may have been influenced in part by their release date because these larger fish travelled rapidly (1-2 d) to the Transition Zone. Their residence time in the Transition Zone may also have been influenced by their stage of development and previous migratory experience. In contrast, smaller parr rearing in riverine habitats upstream of the Transition Zone may have different entry times because they may disperse downstream more slowly as they continue to rear in shoreline habitats. Further, they may spend more time in the Transition Zone as they continue to rear and develop into smolts. Determining when natural-origin fish enter the Transition Zone is important to defining their period of residence there and their predation risk because of smaller sizes.

Given our findings from 2007 and 2009 using larger hatchery-origin fish, we focused our 2010 field efforts to better understand the entry timing into the Transition Zone of smaller natural-origin parr. Our approach was to collect parr in riverine rearing areas of the Clearwater River and tag them with newly available 0.25g radio tags. Through a combination of fixed-site monitoring and mobile tracking, we sought to accomplish the following objectives: (1) determine the entry time into the Transition Zone of natural-origin subyearlings, (2) determine their residence time in the Transition Zone, and (3) determine the relative mortality of tagged subyearlings within the Transition Zone and Confluence area.

Methods

Data Collection

Study area.—The upstream boundary of our study area in 2010 was Cherry Lane on the Clearwater River (approximately 258 river kilometers [rkm] from the Snake River mouth). The downstream boundary of our study area was Silcott Island (rkm 210; Figure 2). The Clearwater River enters the Snake River at Rkm 224. We divided our study area into four reaches. The first reach extended from the Cherry Lane Bridge (rkm 34, as measured from the Clearwater River mouth) to Potlatch (Clearwater rkm 6). We refer to this reach as the River, which was unimpounded. The second reach included the lower 6 km of the Clearwater River from its confluence with the Snake River upstream to Potlatch where the river transitions to impounded habitat. We refer to this as the Transition Zone. We refer to the reach between the confluence and Red Wolf Bridge (rkm 221) on the Snake River as the Confluence. The fourth reach included the area from the Red Wolf Bridge downstream to Silcott Island (rkm 210) which we refer to as the Upper Reservoir (Figure 2).

Fish collection and radio tagging.—Our goal was to collect rearing parr from the riverine section of the Clearwater River. We attempted to collect subyearlings in the Clearwater River using a beach seine in late June, 2010. However, we could not collect fish that were large enough for tagging. Therefore, we collected subyearlings from the Transition Zone using a lampara seine on July 20 and July 27. The lampara seine was 73 m long by 7 m deep at the bunt. The wings were made of 100 mm (stretch) mesh that decreased to 6 mm at the bunt. The net was set in a circle by paying out one wing, followed by the bunt section, and then the other wing. The free wing was then retrieved and both wings we hauled into the boat simultaneously.

Immediately after collection, we surgically tagged subyearlings with radio tags (Lotek Wireless, Inc., Newmarket, Ontario) following the methods of Adams et al. (1998). The tags we used (model NTQ-1) measured 10 mm long, 5 mm wide, weighed 0.25 g in air, had a pulse interval of 10 s, and had a life expectancy of 33 d. Antenna length was 18 cm. For all tagged fish, the ratio of tag weight to fish weight did not exceed 5% (range 1.2 to 4.7%). Immediately after surgery, fish were allowed a 15-min recovery in oxygenated water and then released. Three fish died post-tagging, and their radio tags were reimplanted into new fish. A total of 100 radio-tagged fish were released in the Transition Zone—half on July 20 and half on July 27. Grand mean fork length at release was 96.3 mm (8.2 mm SD; range 80-120 mm) and mean weight was 9.6 g (2.8 g SD; range 5.3-19.4 g).

Given the spatial patterns of subyearling mortality that we observed in 2007 and 2009, we speculated that some of this might have been due to predation. In 2010, we collected smallmouth bass in the Confluence reach and implanted them with radio tags that were not used

in 2008. Fish were collected by angling in the Confluence reach from Red Wolf Bridge to the mouth of the Clearwater River. Collected bass were surgically implanted with coded radio tags (model NTC-3-L; Lotek Wireless, Inc., Newmarket, Ontario) following the methods of Adams et al. (1998) on the day they were collected. The tags measured 15.0 mm long, 4.5 mm in diameter, weighed 0.85 g in air, and had a life expectancy of 42 d. Antenna length was 16 cm. For all tagged fish, the ratio of tag weight to fish weight did not exceed 5%. After tagging, fish were released at their location of capture after a 20-min recovery period. A total of 66 radio-tagged smallmouth bass were released in the Confluence reach—39 on July 23 and 27 fish on July 28. Grand mean fork length at release was 226.8 mm (31.9 mm SD; range 182-358 mm) and mean weight was 185.3 g (93.7 g SD; range 60-670 g).

Fixed-site detection and mobile tracking.—We detected radio-tagged subyearlings with fixed antenna arrays located at the boundaries of our study reaches (Figure 2). Three- or six-element Yagi antennas were used at each site in conjunction with a Lotek SRX 400 receiver (Lotek Wireless, Inc., Newmarket, Ontario), a solar panel, and a 12-V battery. At Potlatch, one receiver was placed on each side of the river. Detection sites were set up where the railroad crosses the Clearwater River (about 1 km upstream from its mouth) with antennas and receivers being located on each side of the river and on a pier in the middle of the river. Six antennas were placed along the top of the Red Wolf Bridge and oriented upstream, and six antennas were placed on the downstream side of the bridge's piers and oriented downstream. One detection array was set up on Silcott Island and another on the north side of the river to monitor fish passing the downstream boundary of the study area. Receivers recorded the tag code, signal strength, and the time and date of each signal emitted by the tag (i.e., every 10 s) while in the vicinity of the receivers. Data from receivers were downloaded twice a week from July through August.

The locations of tagged subyearlings and predators between fixed-detection sites were monitored one to two times a week by mobile tracking from late July through August. Mobile tracking was conducted from boats equipped with two 3-element Yagi antennas oriented toward the front of the boat and at 45º angles from the centerline of the boat, and a receiver. Each reach, except the free-flowing river, was tracked by navigating a boat along each shoreline as well as along transects parallel to the river flow located about 1/3 the channel width offshore along each shore. If time permitted, additional transects were navigated to provide more complete coverage of each reach. Lotek SRX 600 receivers were used to continuously record the tag code, signal strength, time and date of each signal, and GPS location of each signal from radio-tagged subyearlings. Lotek SRX 400 receivers were set to continuously log radio tag detections from smallmouth bass. Trimble GeoXT GPS units were also set to log the location of the boat every 3 s. These data were used to determine smallmouth bass locations by later selecting the GPS point that corresponded to the highest signal power for a detected fish.

Radio tag life.—We measured radio tag life (d) of transmitters used in subyearlings by withholding 13 tags and measuring their life at the USGS's Columbia River Research Laboratory. Activated transmitters were placed in 0.6-m-diameter circular tanks and were maintained at 7ºC. Each day, tags were scanned for their code and power level until each tag had expired. The life of tags used in predators was not measured.

Data analysis.—Radiotelemetry data were processed to remove erroneous data records and produce a final dataset for analyses. Detection records from fixed-detection sites were first arranged in sequential order by time and date. Records that did not fit a logical sequence in space or time, those with low signal strength, or represented by a single observation at a detection site were considered false positives and removed from further consideration. Acceptable detection data were typified by high signal strengths, multiple records at a detection site, and progression of detections as fish moved downstream. No fish were observed making upstream excursions after having passed a detection site.

For each subyearling detected at the downstream boundary of the Transition Zone, we calculated their residence time in this reach as the elapsed time between release and their last detection at the boundary detection array. For the Confluence and Upper Reservoir reaches, residence time was calculated as the elapsed time between the last detection at upstream reach boundary and last detection at the downstream boundary of that reach. Migration rates through each reach were calculated by dividing the reach length by the travel time (time between the last detection at an upstream site and the first detection at the next downstream site) of each fish. Residence times and downstream migration rates were qualitatively compared among reaches to identify spatial trends.

Mobile tracking data from subyearlings was analyzed to determine the location of the highest signal strength for each tagged fish detected on each day of tracking. Detected fish with few (i.e., 1-2) records or low signal strengths (i.e, <40) were discarded as false positives. Remaining location data were imported into a GIS and the pattern of each fish's locations were used to determine its fate. A fish was determined to be alive if it had a diffuse spatial pattern of locations over time, indicative of movement throughout the study area, or if it was subsequently detected at downstream detections sites after being mobile tracked (Figure 3). A fish was determined to be dead if it was repeatedly detected in the same location over numerous weeks with no subsequent detection of the tag elsewhere. Such locations usually showed a tight, clustered pattern (Figure 3). For some fish there were too few detections over time to be certain of their fate, so these fish were assigned a fate of "unknown". The locations of smallmouth bass were overlayed with subyearling locations in GIS to provide a graphical view of habitat overlap and the correspondence between predator locations and dead subyearling locations.

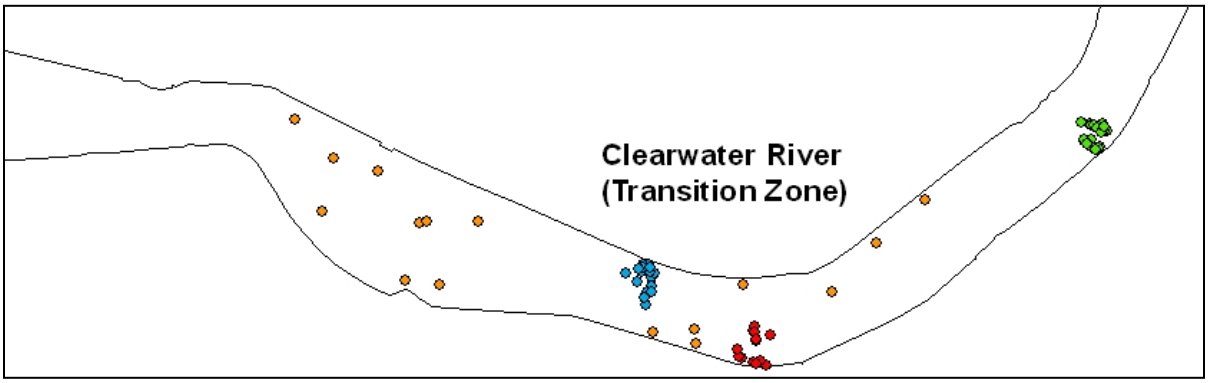

Figure 3.—Examples of the spatial patterns of fish locations used to determine if radio-tagged subyearlings were alive (orange circles) or dead (blue, red, and green circles) in 2010.

Results

As previously mentioned, we were unsuccessful at capturing rearing parr in the unimpounded Clearwater River as originally planned. Therefore, we collected and released 100 subyearlings in the Transition Zone in late July. We detected a total of 56 (56%) radio-tagged subyearlings at fixed-detection sites. A total of 48 fish were detected at the downstream boundary of the Transition Zone, 36 fish were detected passing Red Wolf Bridge at the downstream end on the Confluence reach, and only 10 fish were detected at Silcott Island. Median residence time (calculated from fixed detection data) of subyearlings in the Transition Zone was 8.8 h (N=48, range 0.7-698.8 h), in the Confluence median residence time was 4.5 h (N=28, range 1.3-486.0 h), and in the Upper Reservoir the median residence time was 25.6 h (N=10, range 15.8-438.0 h; Table 1). In contrast, median residence time of fish in the Transition Zone that were not detected at fixed sites but were detected during mobile tracking was 31.5 d (N= 6, range 15-42 d). Median residence times could not be calculated for mobile-tracked fish in the other reaches because too few were detected. Median migration rate (calculated from fixed detection data) of subyearlings in the Transition Zone was 8.6 km/d (N=48, range 0.1-138.5 km/d), in the Confluence median migration rate was 17.2 km/d (N=28, range 3.1-92.1 km/d), and in the Upper Reservoir the median migration rate was 2.9 km/d (N=10, range 0.5-10.7 km/d; Table 1).

Table 1.—Residence time and migration rate of radio-tagged subyearling fall Chinook salmon in three reaches of the Clearwater River and Lower Granite Reservoir in 2010.

		Residence time (h)		Migration rate (km/d)	
Reach	N	Median	Range	Median	Range
Transition Zone	48	8.8	0.7-698.8	8.6	0.1-138.5
Confluence	28	4.5	1.3-486.0	17.2	3.1-92.1
Upper Reservoir	10	25.6	15.8-438.0	2.9	0.5-10.7

A total of 71 radio-tagged subyearlings were detected during mobile tracking in 2010. Thirty-nine fish were detected in the Transition Zone of which 14 were alive, 18 were dead, and the fate of 7 fish was unknown (Table 2). In the Confluence, 24 fish were detected of which 4 were alive (these fish were also detected in the Transition Zone), 14 were dead, and the fate of 6 fish was unknown. In the Upper Reservoir, 12 fish were detected of which 4 were alive, 5 were dead, and the fate of 3 fish was unknown (Table 2). All dead fish were found in shoreline areas whereas most fish that were determined to be alive were found farther from shore (Figure 4). Of the 66 smallmouth bass that we radio tagged, we detected 59 (89%) during mobile tracking. Most fish were detected along the shorelines of the Confluence where they were initially collected for tagging (Figure 5). However nine smallmouth bass were detected below Red Wolf Bridge (the lower boundary of the Confluence) and travelled downstream from 1.9 to 9.4 km through the Upper Reservoir. No bass were detected in the Snake River above the Confluence or in the Clearwater River. Most radio-tagged subyearlings that we determined to be dead were located along shorelines in the same areas occupied by smallmouth bass, particularly in the Confluence where most predators were tagged (Figure 5).

Table 2.—The number and fates of radio-tagged subyearling fall Chinook salmon detected by mobile tracking in three reaches of the Clearwater River and Lower Granite Reservoir in 2010.

Reach	Alive	Dead	Unknown
Transition Zone	14	18	7
Confluence	4*	14	6
Upper Reservoir	4	5	3

* These fish were also detected alive in the Transition Zone.

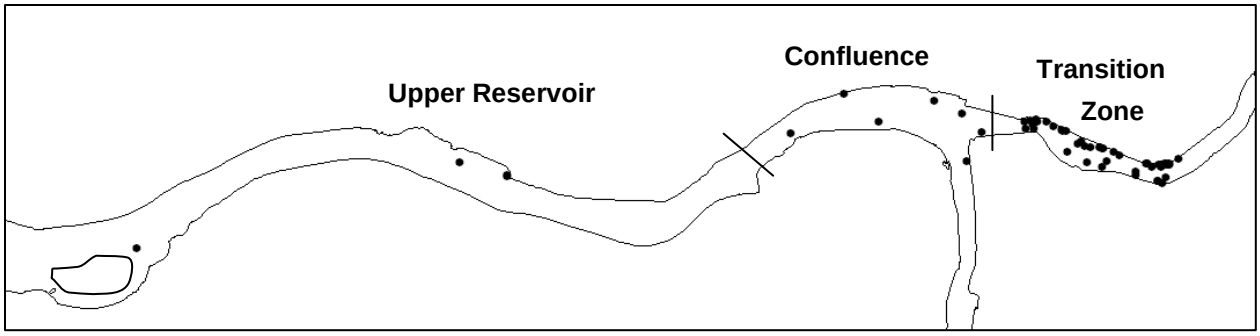

Figure 4.—Locations of live radio-tagged subyearling fall Chinook salmon (black circles) as determined by mobile tracking in 2010. Some fish are represented by multiple locations.

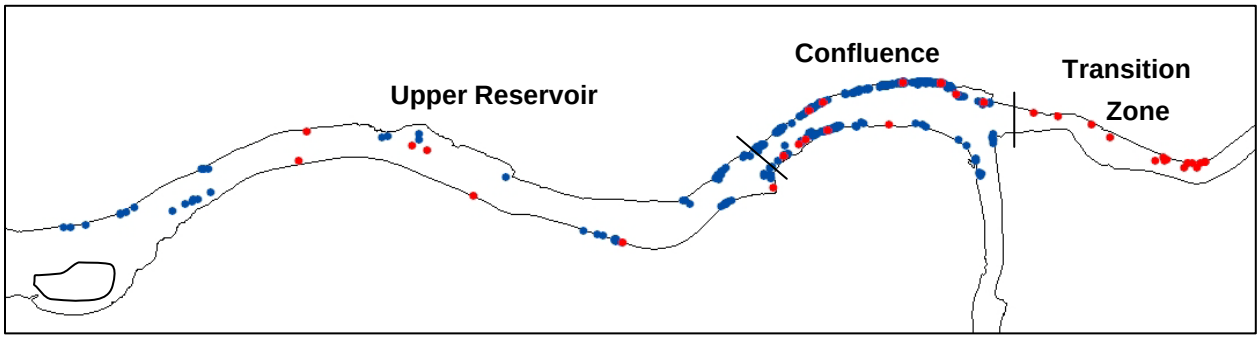

Figure 5.—Locations of radio-tagged smallmouth bass (blue circles) and dead subyearling fall Chinook salmon (red circles) as determined by mobile tracking in 2010. All smallmouth bass were initially tagged and released in the Confluence reach.

The tag life test showed that all tags lasted longer than their expected life of 33 d. Radio tags began expiring on day 56 and all were dead by day 67 (Figure 6).

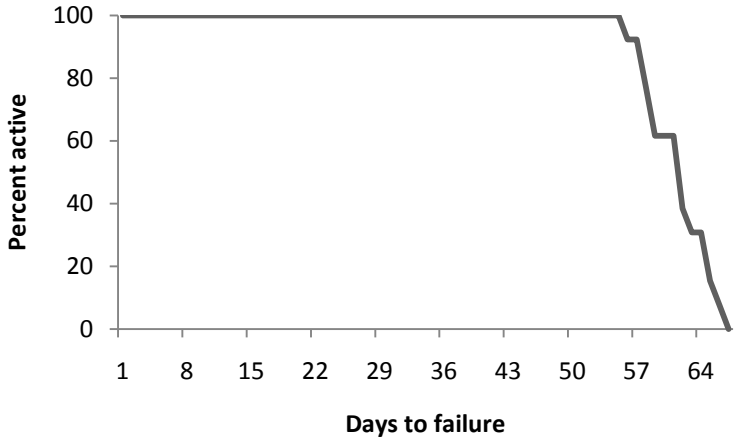

Figure 6.—Observed time to failure for 13 radio tags used in a tag-life test, 2010.

Discussion

The subyearlings we tagged showed a wide range of residence times in all study reaches. Median residence times were shortest in the Confluence and longest in the Upper Reservoir. Though most fish did not reside long in the Transition Zone and Confluence, some fish spent considerable time (e.g., 700 h) before moving downstream. Fish that did move downstream moved at generally slow rates. Tiffan et al. (2009b) found that active migrants from the Snake River moved through the Upper Reservoir at about 20 km/d whereas the fish we studied only moved at about 2.9 km/d. This comports with the migration rate of 6.4 km/d for hatchery subyearlings passing through the same reach in 2009 (Tiffan et al. 2010). These results suggest that the subyearlings we tagged in the Clearwater River were not active migrants. Indeed, only 10 fish (out of 100 released) made it to Silcott Island. Because the fish we tagged probably represented the larger fish in the population residing in the Transition Zone, they may have been more developed physiologically and more likely to move downstream than smaller fish. Therefore, residence times may have been longer and movement rates slower for smaller fish in the population.

One reason for the relatively slow movement rates of subyearlings through our study reaches may relate to low water velocities in impounded habitats. Water velocities in the Transition Zone are only about 0.25 m/s during July and August (Tiffan et al. 2010) and are even lower in Lower Granite Reservoir (Tiffan et al. 2009b). The velocities in the Transition Zone, Confluence, and Upper Reservoir may not be high enough to cue continued downstream movement. This is supported by our observations of both up and downstream movement by tagged fish within the Transition Zone. The migratory behavior of subyearlings from the Clearwater River may also be related to their degree of smoltification, which in turn can affect their downstream movement rate (Zaugg et al. 1985; Zaugg 1989). In contrast to subyearlings in the Snake River that outmigrate under an increasing photoperiod, the later emergence of Clearwater subyearlings results in their outmigration occurring under a decreasing photoperiod. Increasing photoperiod and temperature have been shown to increase smoltification in salmonids (Wedemeyer et al. 1980; Muir et al. 1994). Thorpe (1981) discusses the influence that photoperiod has on specific hormones that may be related to downstream movement. It is possible that the combination of decreasing photoperiod (after June 21) and the large reduction in water temperature that accompanies summer flow augmentation may reduce growth (Arnsberg and Statler 1995), physiological development, and the urge to migrate in subyearlings.

One of the consequences of long residence times and slow movement rates of subyearlings originating in the Clearwater River is increased exposure time to mortality risks such as disease and predation. Tiffan et al. (2010) showed that subyearling survival was low (30-40%) in the Transition Zone and Confluence reach and that mortality increased with increasing time spent in those reaches. We believe that many subyearlings that delay and die are eaten by predators because migratory delay should lead to increased exposure to predators.

Predation is likely a significant source of mortality for subyearlings because of their relatively small size and because their main-stem rearing habitats often overlap or are in close proximity to habitats used by piscine predators such as smallmouth bass (Curet 1993; Tabor et al. 1993). The overlap of dead subyearling locations with that of tagged smallmouth bass locations that we observed provides partial support for this. We qualify this statement because we recognize that we could not detect radio-tagged fish in water deeper than about 10 m, so our conclusion may merely be an artifact of greater detection efficiency in shallower water during mobile tracking. However, we reject this notion because of additional evidence that suggests predation may be a real threat to subyearlings. First, both Zimmerman (1999) and Naughton et al. (2004) showed that fish can comprise a large portion of smallmouth bass diets in Lower Granite Reservoir. Subyearlings probably now make up a larger portion of the forage fish population than they did 15 years ago when these studies were done, because of their increase in abundance following hatchery supplementation. Therefore, it is plausible that subyearlings should make up a larger portion of smallmouth diets. Second, we often found subyearling remains regurgitated when we were radio-tagging smallmouth bass during our study. Third, we have observed smallmouth bass attacking schools of subyearlings along the shorelines of the confluence area of Lower Granite Reservoir while collecting predators for tagging. Fourth, most predatory fish hold in lower velocities near shore when not feeding and thereby have a greater chance of passing tags of depredated fish in those locations regardless of where they were consumed. Finally, mortality due to predation should be high during the summer because predators have higher consumption and metabolic rates at warmer temperatures.

Potential exposure to chronic low levels of total dissolved gas (TDG) concentrations may also represent a mortality risk to subyearlings that reside in the Transition Zone. Tiffan et al. (2010) found that TDG levels in the Transition Zone cycle between 101 and 109% daily. This may pose a threat to fish if they spend time above the compensation depth feeding or become stressed in some way. Fish Collection and tagging stress in 2008 resulted in increased mortality in subyearlings that was attributed in part to elevated TDG levels and consequent GBT in fish held in shallow water. Work is ongoing to more fully understand the role that elevated gas levels play in subyearling mortality risk.

Assumptions and Limitations

The run-at-large subyearlings we tagged were larger (mean = 96.3 mm) than many of the natural fish that were in the Transition Zone during July, but were probably representative of natural fish residing in the Transition Zone by the end of August. We recognize that the larger fish we tagged may have displayed different migratory behavior than that of the natural population. Because of their larger size, our estimates of residence times and migration rates for the fish we tagged may be different than that experienced by smaller natural fish and should be viewed in this context. We also recognize that radiotelemetry has limitations that should be

considered when interpreting our results and conclusions. Although we did not examine specific tag effects during this study, we recognize that tagged fish may have had differential behavior and survival compared to untagged fish. In addition, there are limitations on our ability to detect radio tags, namely, we could only detect them in the top 10 m of the water column. This certainly affected our detection of fish at both fixed sites and during mobile tracking, particularly in deeper reservoir habitats. In spite of these limitations, our results provide insight into the extent of migratory behavior and potential mortality in the Transition Zone, Confluence, and Upper Reservoir.

We intended to capture and tag run-at-large subyearlings from the free-flowing Clearwater River for our study in 2010. Our goal was to tag and release natural rearing parr in riverine habitat and then describe their migratory behavior and entry into the Transition Zone. This has not been done to date and represents a large gap in our understanding of behavior of natural subyearlings in the Clearwater River. Our in-river collection efforts in 2010 were unsuccessful for two reasons. First, we were not able to collect enough fish to meet our tagging goal of 100 fish. Second, although we had hoped to tag fish as small as 75 mm with a 0.25-g radio tag, fish of this size were still too small to tag. We were concerned that the effect of the tag on fish behavior would be too great. Furthermore, although the new tag was only 0.25 g, we believed its volume represented a constraint because there is only so much room in the abdominal cavity of a fish that size. Collecting data on natural parr and their subsequent migratory behavior is currently limited by available technology. Both radio and acoustic tags are currently not small enough to implant in rearing parr that would be necessary to understand the early migratory and delay behaviors for these fish. These tags are also limited by their battery life and do not last long enough to obtain data over long time intervals (e.g., months). Detection of radio tags and mobile tracking acoustic tags remain limitations as well. Until a long-lived telemetry tag can be developed that can be used in very small fish with minimal effects on swimming performance and fish behavior, other avenues of research will have to be pursued.

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CHAPTER TWO

Hydroacoustic Assessment of the Density of Overwintering Juvenile Fall Chinook Salmon in Lower Granite and Little Goose Reservoirs, 2010-2011

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Introduction

Fall Chinook salmon *Oncorhynchus tshawytscha* in the Snake River Basin were listed under the Endangered Species Act in 1992 (NMFS 1992). At that time, it was believed that Snake River fall Chinook salmon adhered to an ocean-type life history in which fry emerged in the spring, reared for 2-3 months, and migrated seaward during the summer to enter the ocean as subyearlings (Healey 1991). However, recent work has shown that Snake River fall Chinook salmon also exhibit a reservoir-type life history whereby juveniles delay seaward migration in the summer, spend their first winter in lower Snake River reservoirs or freshwater above the estuary, and then resume their seaward migration in the spring as yearlings (Connor et al. 2005).

Understanding the reservoir-type life history in important because of its implications to management and recovery of the Snake River fall Chinook salmon population. Fish passage measures intended to improve the survival of spring and summer migrants are not implemented during late fall and winter when many reservoir-type fish (hereafter holdovers) pass lower Snake River dams (Kock et al. 2007). Holdovers that pass dams after fish bypass and collection facilities have been shut down, do so through powerhouse turbines—the main route of passage during this time of year. This may increase mortality due to turbine blade strike, pressure changes, or blunt force trauma (Muir et al. 2001). Fish that pass lower Snake River dams during the winter also are not detected because fish collection facilities and PIT-tag detection equipment are not operated. This has the potential to bias smolt-to-adult return (SAR) ratios which are used to measure the success of juvenile fish transportation relative to in-river migration (Buchanan and Skalski 2009). The extent of this bias may depend in part on the abundance of holdovers in lower Snake River reservoirs that are available to pass the dams undetected. Because holdovers have the potential to contribute substantially to adult returns (Connor et al. 2005), knowing the abundance of overwintering fish might put future adult returns in context. Therefore, it has become increasingly important to gain information on the abundance, location, and emigration timing of Snake River fall Chinook salmon that adopt a reservoir-type life history and overwinter in lower Snake River reservoirs.

In this report, we conclude efforts started in 2007 to estimate the number of juvenile fall Chinook salmon that holdover in Lower Granite Reservoir and other lower Snake River reservoirs during winter (see Haskell and Tiffan 2009; Haskell and Tiffan 2010). Our primary objectives were to estimate the population of holdovers using active hydroacoustics and to examine spatial and temporal population changes during winter when fish bypass systems at Lower Granite and Little Goose dams are not operated. In 2010-2011, we also sampled the forebays of Ice Harbor and Lower Monumental reservoirs to further explore holdover residence in those areas. This report summarizes field data collected from October 2010 to March 2011.

Methods

Study area

Lower Granite and Little Goose dams are located 173 km and 113 km upstream of the Snake and Columbia River confluence. They are the first and second dams on the lower Snake River encountered by juvenile salmon emigrating from the Snake and Clearwater rivers. Lower Granite Dam impounds Lower Granite Reservoir (Lower Granite Lake) and is 51 km downstream of the confluence of the Snake and Clearwater rivers. Little Goose Dam impounds Little Goose Reservoir (Lake Bryan) and is 60 km downstream of Lower Granite Dam. We divided each reservoir into three reaches that we refer to as the forebay, middle, and upper reaches. We classified the forebay as the lower 3.2 km (2 miles) of the reservoir and the middle and upper reaches as two longitudinally equal sections of the non-forebay reach of each reservoir. We also sampled in the forebays of Lower Monumental (Lake Herbert G. West) and Ice Harbor (Lake Sacajawea) reservoirs. Lower Monumental Dam, located 68 km above the confluence of the Snake and Columbia River confluence, impounds Lower Monumental Reservoir and Ice Harbor Dam, located 16 km above the confluence of the Snake and Columbia River confluence, impounds Ice Harbor Reservoir (Figure 1).

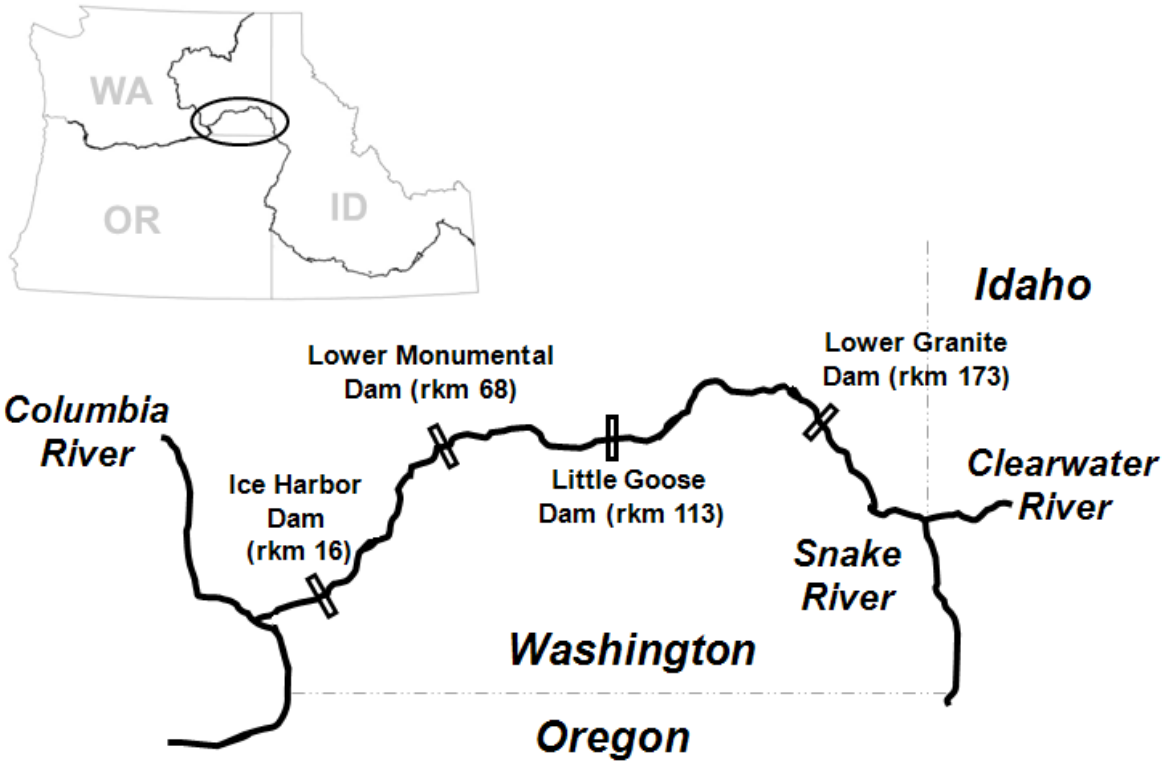

Figure 1.—Map of the lower Snake River with locations of hydroelectric dams in river kilometers (rkm).

Lampara seining

In 2008, we began using a large lampara seine to more efficiently determine the size and relative percent of taxa of fish targets identified by hydroacoustic sampling. Our lampara seine is a 305-m encircling net that is fished using a single boat. The net is deployed by paying out one of the wings while the boat is driven in a large circle. At the halfway point when the middle of the net is reached, the bunt section is deployed followed by the other wing. When the net is fully deployed, the circle is closed and both wings are brought in simultaneously, reducing the net area, and concentrating the fish in the bunt section. The lead line is shorter than the float line and becomes the floor of the net as the wings are hauled in. We used a 7.3-m boat equipped with two large hydraulic drums to pull in the two wings of the lampara seine. The two wings each measured 91.4 m long and were connected by a 22.9-m bunt section. The lead line weighed 189 g per m, was 30.5 m deep at the bunt, and tapered to the float line at the end of each wing section. The net material was 5 inch (127 mm) stretch mesh and the bunt material was ¼ inch (6.35 mm) delta mesh. The net effectively fished to a depth of about 21 m at the bunt based on depth sensor readings. All juvenile salmonids were measured to the nearest 1 mm total length (TL), weighed to the nearest 0.1 g, scanned for the presence of a PIT-tag, and released. Juvenile non-salmonids were measured to the nearest 1 mm TL and released. On three lampara sets, it was not feasible to count the large number of fish captured, therefore we used a large hand net to remove fish from the lampara seine. We identified and counted the single net scoop and then estimated the total number of fish by multiplying by the total number of net scoops in the lampara seine.

We collected fish with the lampara seine monthly from October to March in the forebay, middle, and upper reaches of Lower Granite and Little Goose reservoirs and in the forebays of Lower Monumental and Ice Harbor reservoirs. We made seine hauls concurrently with hydroacoustic sampling to better identify the fish targets from hydroacoustic transects. Following each hydroacoustic transect, we immediately completed a seine haul on the same transect, the location of which was randomly selected as described later.

Lampara sampling in past years resulted in relatively low catches which raised the question as to whether fish were just not abundant or whether the net was not sampling effectively. We tested the efficacy of our lampara seine to collect juvenile salmon by sampling in Lower Granite Reservoir in May 2010 when we knew that many fish (e.g., juvenile spring Chinook and steelhead outmigrants) would be present. We conducted eight lampara sets during the day and eight lampara sets during the night on 20 May to 21 May 2010. Overall, we captured 2,094 juvenile steelhead, 915 juvenile fall Chinook salmon, 225 juvenile coho salmon, 4 juvenile sockeye salmon, and 4 peamouth chub (Table 1). These data convinced us that our lampara seine was effectively sampling the water column for fish whose behavior was similar to

Table 1.—River kilometer (km), mean (± SD) total length, range total length, and estimated number of juvenile steelhead (n = 2,094), subyearling Chinook salmon (n = 915), juvenile coho (n = 225), juvenile sockeye (n = 4), and peamouth chub (n = 4) collected by lampara seine during daytime and nighttime sampling in the forebay of Lower Granite Reservoir, Snake River on 20 May 2010.

River km	Mean total length (mm)	Range total length (mm)	Estimated number captured
		Daytime	
174.3	204.7 ± 58.2	98-331	389
174.5	188.3 ± 46.2	95-293	113
175.6	194.4 ± 34.7	85-286	90
176.4	200.2 ± 48.0	97-310	149
176.7	178.9 ± 50.1	95-315	165
176.9	234.2 ± 49.2	125-331	1,040
177.0	219.5 ± 57.8	103-375	55
178.2	226.9 ± 57.4	97-321	525
Overall	**203.6 ± 52.7**	**85-375**	**2,525**
		Nighttime	
175.1	211.5 ± 58.7	119-299	106
175.4	210.1 ± 62.9	98-315	77
177.0	206.1 ± 65.8	126-342	153
177.2	199.8 ± 63.3	122-343	64
177.7	193.9 ± 58.6	90-325	123
178.3	228.8 ± 63.5	119-351	97
178.8	189.8 ± 69.8	49-302	28
179.0	210.5 ± 69.9	116-337	75
Overall	**206.4 ± 64.0**	**49-343**	**722**

our target species (juvenile fall Chinook salmon). Our higher catch of fish during the day than at night also supported our daytime sampling for hydroacoustic surveys.

Hydroacoustic sampling

We conducted mobile hydroacoustic surveys in Lower Granite and Little Goose reservoirs using an HTI model 244 split-beam echo sounder operated at a frequency of 200 kHz. Using the echo sounder, we multiplexed between a 6º "side-looking" transducer and 15º "down-looking" transducer. The down-looking transducer was oriented 90° down from the water

surface and the side-looking transducer was oriented 4° down from the surface. The transducers were mounted to an adjustable pole that hung over the starboard side of a 7.3-m jet boat. The pole mount was connected by cables fore and aft to eliminate movement. We used a Trimble GeoXT GPS to both navigate the boat along pre-established transects and to stream a continuous string of GPS coordinates into the laptop computer during hydroacoustic data collection. Acoustic returns were received and coupled with GPS coordinates using HTI data collection software (EchoScape version 3.56). We generally operated the boat at a speed of 1.6 m/s. Before data collection every month, the hydroacoustic system was calibrated using a 38.1 mm diameter tungsten sphere with a known target strength of -40.0 dB (Simmonds and MacLennan 2005).

Before sampling started, all possible cross-sectional transects were plotted at 160-m intervals from rkm 6.8 to 20.9 in the Ice Harbor Reservoir forebay, rkm 67.6 to 70.8 in the Lower Monumental Reservoir forebay, rkm 114.3 to 165.8 in Little Goose Reservoir, and from rkm 173.9 to 223.9 in Lower Granite Reservoir. For each day of sampling, 10 cross-sectional transects were randomly selected without replacement within an individual reservoir reach (forebay, middle, or upper) so that 30 cross sections were sampled from an entire reservoir over a 3-d period. Sampling within a reservoir was conducted from downstream to upstream to minimize sampling fish twice in the same month that were moving downstream. For individual hydroacoustic transects, the boat was navigated perpendicularly from the south shore (river right looking upstream) to the north shore at about 4.0 km/h. We sampled each reservoir monthly from October through March. Target verification along each transect was obtained by setting the lampara seine on the transect immediately following hydroacoustic sampling. High winds, exceptionally cold weather, generally rough sampling conditions, and boat repairs occasionally altered our sampling schedule.

Raw file processing

Raw data collection files were processed using acoustic analysis software (HTI EchoScape, version 2.12) to distinguish acoustic echoes from noise and track them as fish targets. We used a combination of an auto tracking algorithm with user defined settings and manual editing to separate fish from noise. The auto tracking algorithm begins by selecting an initial echo which meets specific requirements and then searching in three-dimensional space for the next echo. Groups of echoes are selected as fish targets based on number of pings, echo gap (missing pings), target amplitude, and pulse width at differing decibel levels (power points). We parameterized the auto tracker to select groups of echoes as fish targets that had a minimum of 4 pings, a maximum ping gap of 5, a maximum target velocity of 6.0 cm/s, a 0.3 m maximum change in distance between echoes, a maximum change in range (target to transducer face) of 0.2 m, and a mean target strength between -70 and -10 dB, which correspond to the size range of holdovers we were likely to encounter.

We also manually edited auto-tracked fish files for two reasons. First, because of varying bathymetry and substrate within our study site, the echo sounder, which was set to automatically detect the bottom of the reservoir, occasionally lost the bottom or misclassified the depth. Because depth values along with distance traveled were ultimately used in estimating volume sampled and deriving fish densities, we edited the files using a bottom edit tool in EchoScape. In many instances, the bottom was lost at the beginning or ending of transects and the true bottom was easily distinguishable. Second, we manually edited auto-tracked files to further separate fish from noise. In some instances, the auto tracker appeared to separate a single series of aligned echoes into two distinct fish. For auto-tracked files in which we subjectively thought there was a lot of noise (often resulting from increased wave action during sampling), we filtered the data by generally increasing the target strength threshold from 0.108 to 0.150 V for data from the down-looking transducer, and from 0.150 to 0.200 V for data from the side-looking transducer. This filtering further rejected echoes that were from noise and very small targets. In extreme instances, we used the bottom edit tool to eliminate sections of transects that were deemed too noisy to effectively track. In general, the data from the side-looking transducer became noisier when sampling conditions were rough, though the down-looking transducer data remained relatively free of noise.

The end result of a tracked file corresponding to an individual transect was a single Microsoft Access database file. For each Access file, we imported a bottom table that contained all of the depth and GPS data, and a fish table that contained all tracked fish targets and associated information, into a SAS database. After all the information was combined into a single SAS database, we calculated the mean depth of each transect and used the Great Circle Distance Algorithm to calculate the distance between successive GPS points where:

$$\Delta\sigma = 2\arcsin \sqrt{(\sin^2(\Delta\Phi/2) + \cos \Phi_s \cos \Phi_f \sin^2(\Delta\lambda/2))}$$

Φ_s, λ_s; Φ_f, λ_f are the geographical latitude and longitude of the two GPS points where $\Delta\Phi$ is the difference between Φ_f and Φ_s and $\Delta\lambda$ is the difference between λ_f and λ_s. The distance in radians (arc length) is $d = r\Delta\sigma$ where r = the radius and $\Delta\sigma$ = the angular distance.

Estimation of length of ensonified fish targets

The mean target strengths of individual fish targets ensonified from the dorsal aspect (down-looking transducer) were converted to length using the formula of Love (1971):

$$TS = 19.1 * \log (L) – 0.9 * \log (f) – 62.0$$

where:

TS = Target strength (dB)
L = fish total length (cm)
f = transmitted frequency (kHz)

For our purposes where f = 200 kHz, $L = 10^{(TS + 64.1)/19.1}$

Estimation of reservoir volume

To extrapolate the abundances of holdovers measured using hydroacoustics to estimates of total numbers in Lower Granite and Little Goose reservoirs, we first needed to calculate reservoir volumes during the times when we sampled. We used reservoir storage capacity curves developed by the U.S. Army Corps of Engineers (USACE) in 1994, coupled with pool elevation and total inflow at Lower Granite and Little Goose dams to estimate reservoir volumes for the specific dates when we sampled. When differences occurred over successive days of a sampling period, we took the mean of the calculated reservoir volumes over the days when we sampled. The USACE capacity estimates for Lower Granite Reservoir cover the length of the Snake River from Lower Granite Dam to the town of Asotin (river km 235) and also extend up the Clearwater River 7.4 km from the Snake and Clearwater confluence. Our sampling ended at river km 222.9. Therefore, we calculated mean cross-sectional area from eight acoustic Doppler current profiler (ADCP) transects that were collected in the Snake River from Asotin, Washington downstream to the upper extent of our sampling. The ADCP data were collected in 2003 and summarized in Tiffan et al. (2009). For the Clearwater River, we assumed water volume per river mile was generally half of that we calculated for the Snake River. We then subtracted the calculated volume of the lower 7.4 km of the Clearwater River and the 12.9 km upstream of our hydroacoustic sampling area (rkm 222.9 to 235.0) on the Snake River from the initial reservoir volume to obtain our final volume estimate for a particular sampling period.

Data analysis

The primary goal of hydroacoustic surveys was to develop population estimates of holdover fall Chinook salmon in Lower Granite and Little Goose reservoirs. The overall population abundance (A) of holdovers ensonified using hydroacoustics was estimated from the relation $A = DVP$, where

D = the density of fish of appropriate size
V = volume of reservoir
P = proportion of fish of appropriate size that are holdovers

For each sample period (month), we developed an individual population estimate for Lower Granite and Little Goose reservoirs. This estimate was based on the median transect density multiplied by the entire reservoir volume.

We placed bounds on our estimate by developing 95% confidence limits about the median where:

$$P(X_i \leq M \leq X_j) \geq 1 - \alpha.$$

The upper bound $X_i = C_{\alpha(2),n} + 1$, and the lower bound $X_j = n - C_{\alpha(2),n}$.

where:

P = the probability
M = the population median
C = the critical value of C for the Sign Test
α (2)= the two-tailed probability
n = the number of measurements from which M is calculated

Lampara seine catch data were primarily used to apportion the percentage of fall Chinook salmon to hydroacoustic density estimates. We also used lampara seine catch data to examine temporal trends in relative condition of holdovers in Lower Granite and Little Goose reservoirs. In a few cases, we converted holdover fork lengths (FL) to TL using the relationship: TL = 1.1126*FL -0.3427; n = 261; r^2 = 0.98.

In addition to estimating the population of holdovers, we also examined spatial and temporal trends in density. We compared densities of holdovers estimated using hydroacoustics to that of catch per-unit-effort (CPUE) using the lampara seine between the lower, middle, and upper reach of each reservoir, between reservoirs for each year, and between years with both reservoirs combined. Distributions of seine catch data are often skewed to the right, have many zeroes, have high variance, and typically fit a binomial rather than a normal distribution. In our study, the distribution of lampara seine CPUEs were non-normal and attempts to normalize them using standard $\log_{10}(x+1)$ transformations were unsuccessful. To circumvent these problems, we used the proportion of positive lampara CPUEs (Ep) for statistical comparison (Uphoff 1993; Counihan et al. 1999). We compared the critical value of the q distribution to the calculated value of q where:

$$q = p_i/\mathrm{SE}$$

and,

$$p_i = ½[\arcsin\sqrt{X/(n + 1)} + \arcsin\sqrt{(X + 1)/(n + 1)}]$$

where:

p_i = the ranked transformed proportion
X = the number of lampara hauls where at least one holdover was captured
n = the total number lampara hauls within a reservoir reach, reservoir, or year and the standard error for each comparison in degrees is:

$$SE = \sqrt{[(410.35/(n_A + 0.5)) + (410.35/(n_B + 0.5))]}$$

where:

n_A = the number of lampara hauls from the first proportion
n_B = the number of lampara hauls from the second proportion

Hydroacoustic densities were compared by reaches within Little Goose and Lower Granite reservoirs, between Little Goose and Lower Granite reservoirs after pooling densities within each reservoir, and between the forebays of Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams. For each comparison, only densities collected within the same monthly period were compared. Different statistical tests were used based on whether data had equal numbers of densities and no tied ranks, had unequal numbers of densities and no tied ranks, or had unequal numbers of densities and tied ranks.

For testing the hypotheses that the abundance of holdovers is the same among reservoirs or reservoir reaches, we used a Kruskal-Wallis test because the distributions of densities were not normal. For this procedure, we calculated the Kruskal-Wallis test statistic, H, as:

$$H = 12/N(N + 1)\ \Sigma^{k}_{i=1}\ R_i^2/n_i - 3(N + 1)$$

where:

N = the total number of hydroacoustic densities in all k groups
R= the sum of hydroacoustic density n_i ranks for each k group

If the ranked data for comparisons contained ties, then H was corrected by dividing by C

$$C = 1 - [\Sigma^{m}_{i=1}(t_i^3 - t_1) / (N_3 - 1)]$$

where:

t_i = the number of ties in the *i*th group and *m* is the total number of ties.

H is then compared to the critical value of the Chi-square, χ^2, distribution.

If the Kruskal-Wallis tests indicated rejection of the null hypothesis, then multiple comparisons were made following a procedure that is similar to the Tukey-type comparison (Zar 1999). If the comparison had equal numbers of transect densities for each group and no tied ranks then a Tukey-type multiple comparison was used where rank sums were used to compare nonparametric densities when the null hypothesis was rejected where:

$$SE = \sqrt{[((n(nk)(nk + 1)) / 12]}$$

We compared the critical value of the *q* distribution to the calculated value of *q*:

$$Q = (\text{mean}X_B - \text{mean}X_A / SE)$$

where:

X_B = the rank sum of the hydroacoustic densities from the first reservoir reach or reservoir
X_A = the rank sum of the hydroacoustic densities from the second reservoir reach or reservoir

If the null hypothesis was rejected and unequal numbers of data existed in the groups then the SE was calculated as:

$$SE = \sqrt{[((N(N+1)/12)(1/n_A + 1/n_B)]}$$

where,

N = the total number of hydroacoustic densities,
n_A = the number of hydroacoustic densities from the first reservoir or reservoir reach
n_B = the number of hydroacoustic densities from the second reservoir or reservoir reach

We compare the critical value of the *Q* distribution to the calculated value of *Q*:

$$Q = (\text{mean}R_B - \text{mean}R_A) / SE$$

where:

R_B = the mean rank of hydroacoustic densities from the first reservoir reach or reservoir

R_A = the mean rank of hydroacoustic densities from the second reservoir reach or reservoir

If tied ranks and unequal sample sizes were present than the SE was calculated as:

$$SE = \sqrt{[((N(N + 1)/12) - (\Sigma t/12(N - 1))\ (1/n_A + 1/\ n_B)]}$$

where,

$$\Sigma_t = \Sigma^m{}_{i=1}(t_i^3 - t_i)$$

Results

We conducted monthly lampara seining and mobile hydroacoustic surveys from 4 October 2010 to 7 March 2011. Discharge was above average before our sampling in late summer, was generally near the ten-year average during our sampling from October 2010 to early January 2011, and was higher than average during our sampling in February and March (Figure 2). A large discharge peak occurred in mid January 2011, followed by above average discharge for the duration of our sampling into early March. Lower Granite dam discharge ranged from 392 m^3/s (14 kcfs) on 21 October 2010 to 2,647 m^3/s (95kcfs) on 18 January 2011 and Little Goose dam discharge ranged from 362 m^3/s (13 kcfs) to 2,546 m^3/s (91 kcfs). Discharge trends at Lower Granite and Little Goose dams were similar to each other (Figure 2). Fish bypass systems did not operate at Lower Granite Dam from 1 November 2010 to 25 March 2011 and at Little Goose Dam from 1 November 2010 to 3 April 2011. Water temperatures ranged from a high of 18.5ºC in early October 2010 to a low of 2.2ºC in early February 2011. Seasonal temperature patterns were warmer than average until December after which they generally remained cooler than average for the duration of our sampling (Figure 3).

Lampara seining

The vast majority of the fish we collected were juvenile Chinook salmon with the exception of sampling in the Ice Harbor forebay in October, when we captured large numbers of juvenile American shad (Table 1). We made 48, 41, and 31 lampara seine sets in the forebay, middle, and upper reaches of Lower Granite Reservoir, respectively and 39, 33, and 23 lampara seine sets in the forebay, middle, and upper reaches of Little Goose Reservoir, respectively. We also made 26 sets in the forebay of Lower Monumental Reservoir and 24 sets in the forebay of

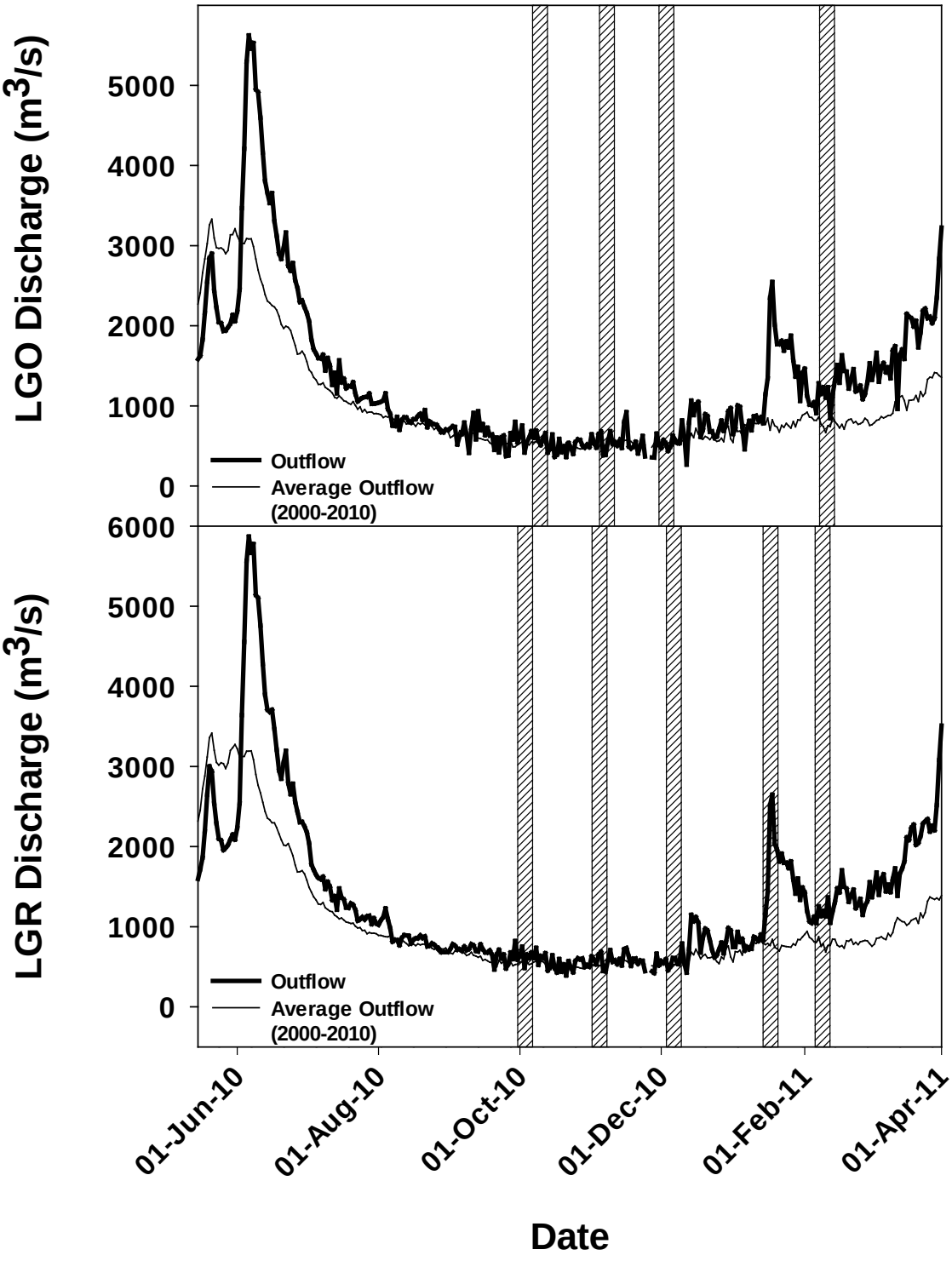

Figure 2.—Total outflow (bolded line) and 10-year mean outflow (thin line) at Little Goose (top panel) and Lower Granite (bottom panel) dams from 15 May 2010 to 1 April 2011. Shaded bands depict sampling dates.

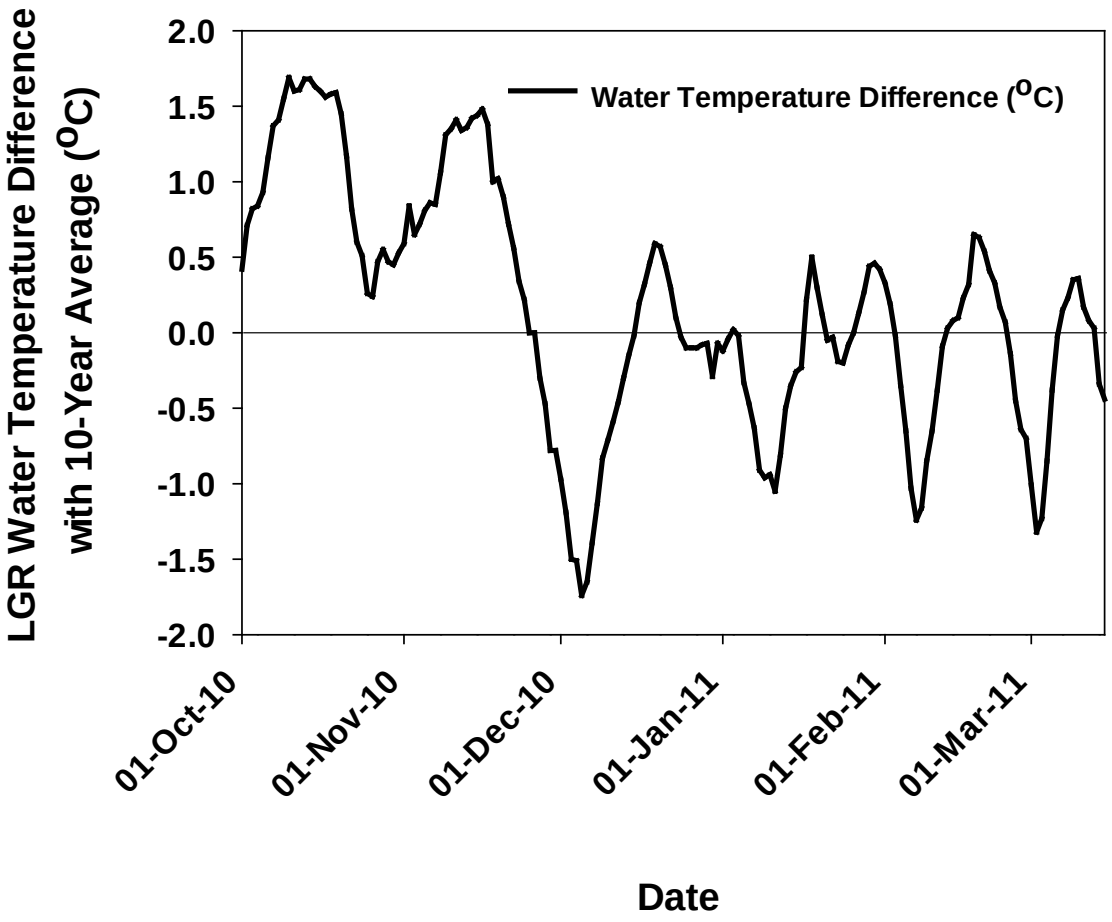

Figure 3.—Seasonal change in the difference between daily water temperatures (bold line) and the ten year average (2000-2010) collected at Lower Granite Dam from 1 October 2010 to 15 March 2011.

Table 1.—Reservoir, reach, number of lampara seine hauls, species, total number collected, percent of total, and range of total lengths (mm) of fish captured using a 305-m lampara seine in the lower Snake River from 4 October 2010 to 7 March 2011.

Reservoir Reach	Hauls	Species	Total[1] number	Percent of total	Range total length (mm)
Lower Granite					
Forebay	48	Chinook juvenile	383	90.3	107-245
		Steelhead adult	20	4.7	570-920
		Peamouth chub	8	1.9	70-280
		Sockeye juvenile	5	1.2	113-238
		Kokanee	2	0.5	104-119
		Chinook adult	1	0.2	760
		Chinook jack	1	0.2	-
		Northern pikeminnow	1	0.2	224
		Steelhead juvenile	1	0.2	250
		American shad juvenile	1	0.2	133
Middle	41	Chinook juvenile	61	81.3	146-222
		Sockeye juvenile	7	9.3	103-158
		Steelhead adult	5	6.7	560-830
		Peamouth chub	1	1.3	300
		Kokanee	1	1.3	190
Upper	31	Steelhead adult	12	25.0	610-900
		Chiselmouth	10	20.8	138-193
		Chinook juvenile	9	18.8	97-248
		Peamouth chub	8	16.7	160-310
		Sockeye juvenile	3	6.3	103-111
		Steelhead juvenile	2	4.2	134-180
		Chinook jack	1	2.1	-
		Carp	1	2.1	-
		Mountain whitefish	1	2.1	-
		Kokanee	1	2.1	186
Little Goose					
Forebay	39	Chinook juvenile	960	98.7	111-260
		Steelhead adult	6	0.6	550-790
		Peamouth chub	5	0.5	90-330
		Steelhead juvenile	1	0.1	240
Middle	33	Chinook juvenile	76	90.5	149-255

Table 1.—Continued.

Reservoir Reach	Hauls	Species	Total[1] number	Percent of total	Range total length (mm)
		Steelhead adult	4	4.8	680-860
		Carp	3	3.6	620-660
		Sockeye juvenile	1	1.2	110
Upper	23	Chinook juvenile	6	66.7	130-213
		Steelhead adult	2	22.2	-
		Steelhead juvenile	1	11.1	304
Lower Monumental Forebay	26	Chinook juvenile	12	80.0	146-229
		Carp	2	13.3	690
		Steelhead adult	1	6.7	-
Ice Harbor Forebay	24	American shad juvenile	8,357	96.2	80-111
		Chinook juvenile	315	3.63	157-253
		Steelhead adult	7	0.08	600-780
		Peamouth chub	5	0.06	70-340
		Carp	2	0.02	620-690

Ice Harbor Reservoir. In Lower Granite Reservoir, we captured 546 fish, of which 456 (83.5%) were juvenile Chinook salmon. We captured 1,065 fish in Little Goose Reservoir, of which 1,042 (97.8%) were juvenile Chinook salmon. In Lower Monumental forebay, we captured 15 fish of which 12 (80.0%) were juvenile Chinook salmon and in Ice Harbor we captured 8,686 fish of which 315 (3.6%) were juvenile Chinook salmon. Overall, we collected 81.1% juvenile American shad *Alosa sapidissima*, 17.7% juvenile Chinook salmon, 0.6% adult steelhead *Oncorhynchus mykiss*, 0.3% peamouth chub *Mylocheilus caurinus*, 0.2% juvenile sockeye salmon, 0.1% chiselmouth *Acrocheilus alutaceus*, and 0.04% adult common carp *Cyprinus carpio*. All of the juvenile shad were captured from two seine hauls in the Ice Harbor forebay during October. Of the major fish taxa that we collected, only peamouth chub were in the size range (68-341 mm TL) similar to that of holdovers (Table 2). Overall, we captured holdovers ranging from 141 to 260 mm TL. Holdovers represented 97.6% (992 of 1016) of the fish catch that was within this size range so we applied this percentage to the ensonified fish which fell within this range based on the TL to target strength relationship developed by Love (1971).

Table 2.—Sample period, mean water temperature (°C), number of juvenile fall Chinook salmon, mean total length (mm± SD), and mean CPUE (Catch Per Unit Effort), and proportion of juvenile fall Chinook salmon in the 141-260 mm size range that were collected by lampara seining in the lower Snake River from 4 October 2010 through 17 February 2011.

Reservoir Sample Period	Hauls	Mean water temp (°C)	Number of juvenile fall Chinook salmon	Mean total length (mm)	Mean CPUE	Proportion of fall Chinook in size range
Ice Harbor						
15 Oct	10	16.8	92	184.7 ± 19.9	5.00	1.00
21 Dec	4	5.4	222	210.7 ± 19.2	55.50	1.00
7 Mar	10	3.8	1	216.0	0.10	1.00
Overall	**24**		**315**	**206.5 ± 21.5**	**13.13**	**1.00**
Lower Monumental						
8 Oct	10	17.6	11	190.0 ± 18.3	1.10	1.00
10 Dec	6	6.4	0	-	0.00	-
18 Feb	10	3.3	1	146.0	0.10	1.00
Overall	**26**		**12**	**204.6 ± 21.7**	**0.46**	
Little Goose						
12 Oct – 14 Oct	30	17.7	563	214.0 ± 15.2	4.13	1.00
17 Nov – 19 Nov	14	10.9	323	217.9 ± 23.2	23.07	1.00
13 Dec – 17 Dec	25	5.8	149	221.5 ± 21.6	5.96	1.00
1 Mar – 4 Mar	26	3.5	7	227.6 ± 17.6	0.27	0.78
Overall	**95**		**1042**	**217.7 ± 21.3**	**10.97**	
Lower Granite						
4 Oct – 7 Oct	32	18.3	232	190.0 ± 18.3	7.25	0.99
1 Nov – 3 Nov	24	12.7	207	190.9 ± 21.5	8.63	0.99
6 Dec – 8 Dec	28	4.3	1	216.0	0.04	1.00
25 Jan – 26 Jan	11	3.3	2	214.0	0.18	0.40
15 Feb – 17 Feb	29	3.5	7	198.3	0.24	0.32
Overall	**124**		**449**	**190.8 ± 20.1**	**3.62**	

Holdover size and abundance

Holdovers that we collected in 2010-2011 were generally similar in size to those we collected in prior years (Figure 4). The mean size of holdovers in 2010-2011 was 204.4 mm, whereas it was 205.0 mm in 2009-2010 and 197.6 mm in 2008-2009. The mean size of holdovers collected in 2007-2008 (242.4 mm; Haskell and Tiffan 2009) was 44.8 mm longer than those collected in 2008-2009 (197.6 mm) and 37.4 mm longer than those collected in 2009-2010 (205.0 mm). Yearly differences in size generally coincided with yearly differences in water temperature where larger fish were captured in warmer years and smaller fish were captured in cooler years. In 2010-2011, we lowered our cut-off value for classification of holdovers to juvenile fall Chinook salmon that were greater than 140 mm TL. Using the size range of 141 to 260 mm based on the lampara catch, 97.6 % (992 of 1,016) of the fish that fell within this size range were holdovers. This distinction is important because we used the target strengths (dB) of ensonified targets to estimate their lengths and then apportioned these targets based on the percentage of seine-captured fish that were classified as holdovers.

Lampara CPUE

The number of holdovers captured with the lampara seine peaked in the Ice Harbor forebay in late December and in Little Goose and Lower Granite reservoirs in November. Overall, we captured 449 holdovers from 124 seine hauls in Lower Granite Reservoir and 1,042 holdovers from 95 seine hauls in Little Goose Reservoir during 2010-2011. In the Ice Harbor forebay reach we collected 315 holdovers from 26 seine hauls and in the Lower Monumental we collected 12 holdovers from 26 seine hauls. Holdover total length generally increased seasonally irrespective of reservoir sampled. The highest CPUE of holdovers was observed in November to late December with diminishing numbers in January through March. Mean monthly CPUE ranged from 0.18 to 8.63 in Lower Granite Reservoir and from 0.27 to 23.07 in Little Goose Reservoir. In the Ice Harbor forebay reach, mean monthly CPUE ranged from 0.10 to 55.50 and in the Lower Monumental forebay reach, it ranged from 0 to 1.10. Compared to the other reservoirs, Lower Granite had the highest CPUE in October, Little Goose had the highest CPUE in November, and Ice Harbor had the highest CPUE in December (Table 2).

The lampara catch distributions of holdovers were highly skewed which precluded the use of parametric statistical methods for spatial and temporal comparisons. Overall, 32.3% (87 of 269) seine hauls contained holdovers (Figure 5). Therefore, we used the percentage of ranked arcsine-transformed proportions of the number of positive tows (E_p) for spatial comparisons between reservoirs and between reaches within each reservoir.

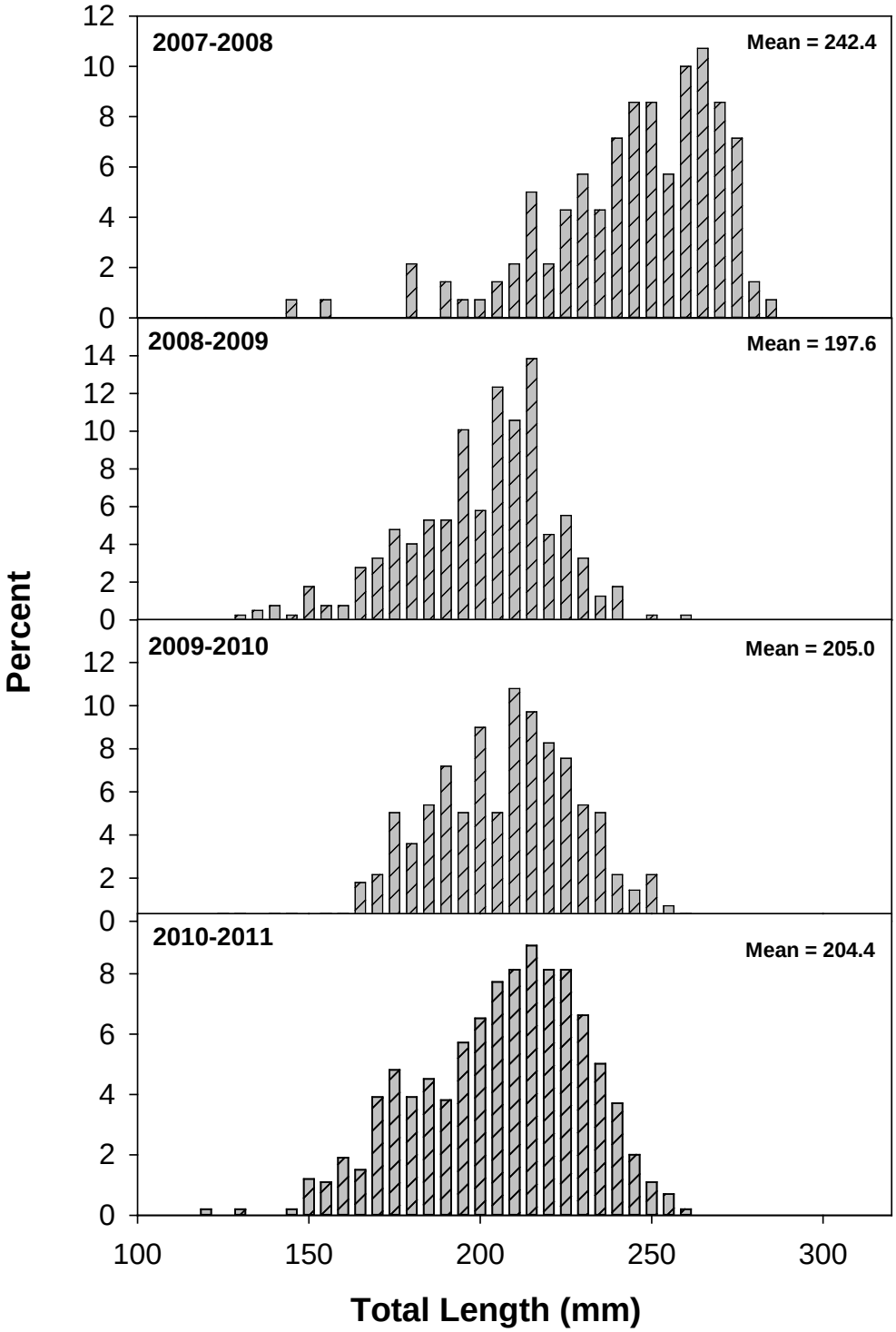

Figure 4.—Comparison of lengths of juvenile fall Chinook salmon collected in 2007-2008, 2008-2009, 2009-2010, and 2010-2011 using a 305-m lampara seine in Lower Granite and Little Goose reservoirs, Snake River.

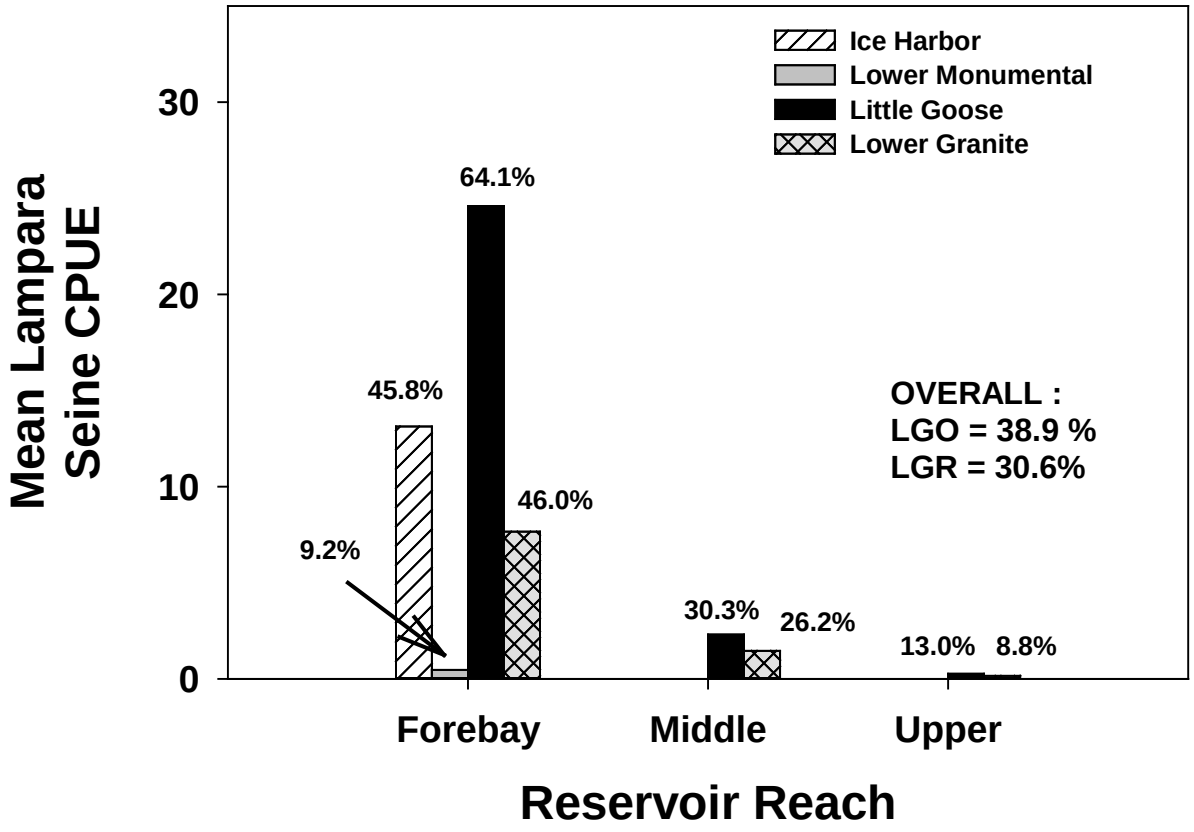

Figure 5.—Mean lampara seine CPUE for each reservoir reach within Little Goose (black bars) and Lower Granite (grey double cross-hatched bars) reservoirs and the forebays of Ice Harbor forebay (white cross-hatched bars) and grey double cross-hatched bars), Snake River from 4 October 2010 to 7 March 2011. Percentages are the number of positive tows (E_p) within each reservoir reach (LGO = Little Goose; LGR = Lower Granite).

Our lampara catch data revealed consistent patterns of higher numbers of holdovers in the forebays than in the upper reaches of both Little Goose and Lower Granite reservoirs with increasing mean CPUE moving from upstream to downstream (Table 3). The percentages of positive tows were significantly higher in the forebay reach relative to the upper reach within Lower Granite Reservoir (q = 5.40, P < 0.05) and within Little Goose Reservoir (q = 3.86, P < 0.05) reaches. In Little Goose Reservoir, no reach comparisons were significant for either year (P > 0.05). Our comparisons of lampara seine catch across forebay reaches indicated significantly greater percentages in the Ice Harbor forebay than in the Lower Monumental forebay (q = 4.65, P < 0.05) and significantly higher percentages in the Lower Granite forebay than the Lower Monumental forebay (q = 3.87, P < 0.05; Table 3).

Table 3.—Tukey multiple comparisons of arcsine-transformed proportions of the number of positive lampara seine catches (E_p) between reservoir reaches, reservoirs with reaches combined, and forebay reaches of reservoirs with the difference between ranked arcsine transformed proportions in degrees, the standard error, the test score (q), the total number of lampara net sets (v), the critical value of the q distribution with a probability of 0.05, and the conclusion on the null hypothesis. Asterisks denote rejection of the null hypothesis (H_o) that the proportions are equal.

Comparison	Difference	*SE* (degrees)	q	v	$q_{0.05}$	Conclusion
Little Goose Reach Comparisons						
Forebay vs. Middle	16.340	5.274	3.098	58	3.399	Accept
Forebay vs. Upper*	21.645	5.601	3.864	52	3.442	Reject
Upper vs. Middle	5.305	5.601	0.947	52	3.442	Accept
Lower Granite Reach Comparisons						
Forebay vs. Middle	2.040	4.447	3.177	82	3.399	Accept
Forebay vs. Upper*	24.345	4.787	5.398	72	3.399	Reject
Upper vs. Middle	22.305	4.787	2.446	72	3.399	Accept
Reservoir Comparison						
Little Goose vs. Lower Granite	5.410	3.280	1.649	153	2.772	Accept
Forebay Comparisons						
IHR vs. LMO*	33.900	7.292	4.649	30	3.845	Reject
IHR vs. LGO	8.705	6.951	1.252	34	3.845	Accept
IHR vs. LGR	8.470	6.822	1.242	36	3.845	Accept
LMO vs. LGO	25.195	6.700	3.761	31	3.845	Accept
LMO vs. LGR*	24.430	6.566	3.873	33	3.845	Reject
LGO vs. LGR	0.235	6.185	0.038	42	3.791	Accept

Hydroacoustic surveys

Our hydroacoustic surveys allowed us to ensonify 0.43% to 0.76% of the Lower Granite Reservoir volume and 0.40% to 0.72% of the Little Goose Reservoir volume during our monthly hydroacoustic surveys. We then extrapolated ensonified volumes to the entire reservoir volume to estimate the population of holdovers. Overall, the monthly number of estimated holdovers we ensonified ranged from 66.13 to 231.81 fish in Lower Granite Reservoir and from 46.92 to 266.67 fish in Little Goose Reservoir (Table 4). This translated to similar overall densities between Lower Granite and Little Goose reservoirs in October and November, but substantially higher densities in Little Goose Reservoir for the remainder of the winter. The highest overall densities were observed in March in the Ice Harbor forebay (Table 4).

Table 4.—Reservoir, sample period, number of transects, volume sampled, total number of holdovers ensonified, median down-looker density (#/100,000 m^3), median side-looker density (#/100,000 m^3), and overall median transect density (#/100,000 m^3) of holdovers (CHK) estimated from hydroacoustic surveys in Ice Harbor, Lower Monumental, Little Goose, and Lower Granite reservoirs from 5 October 2010 to 7 March 2011.

Reservoir Sample period	Transects	Volume sampled (m^3)	Total estimated CHK ensonified	Median down- looker CHK density (#/100,000 m^3)	Median side-looker CHK density (#/100,000 m^3)	Overall Median CHK density (#/100,000 m^3)
Ice Harbor						
15 Oct	10	1,695,553	83.39	0.4148	0.2810	0.3848
21 Dec	10	1,671,896	136.99	0.0000	0.8192	0.7377
7 Mar	10	1,643,290	514.79	10.4646	0.1857	2.8808
Lower Monumental						
8 Oct	10	2,213,253	24.65	0.0000	0.1430	0.1043
10 Dec	6	1,230,393	21.09	0.0000	0.1924	0.1623
18 Feb	10	2,430,965	35.64	0.0000	0.1310	0.1024
Little Goose						
12 Oct – 14 Oct	30	4,950,448	83.19	0.0000	0.1722	0.1655
17 Nov – 19 Nov	13	2,648,101	46.92	0.1224	0.1527	0.1908
13 Dec – 17 Dec	26	3,698,577	146.50	0.0000	0.5234	0.3554
1 Mar – 4 Mar	30	4,246,155	266.67	1.2400	0.1671	0.5619
Lower Granite						
5 Oct – 7 Oct	30	3,946,876	231.81	0.4418	0.3276	0.1655
1 Nov – 3 Nov	30	4,249,621	169.96	0.1865	0.3915	0.1398
6 Dec – 8 Dec	30	4,201,917	124.23	0.0000	0.3147	0.0373
25 Jan – 26 Jan	12	2,341,558	66.13	0.9510	0.3924	0.1559
15 Feb – 17 Feb	30	3,853,217	73.17	1.8828	0.1765	0.0202

Population estimates

The population of holdovers decreased seasonally in Lower Granite and Little Goose reservoirs based on monthly estimates. In Lower Granite Reservoir, the seasonal peak was in October and in Little Goose Reservoir the seasonal peak was in March. In Lower Granite Reservoir, monthly population estimates ranged from 27,290 in October 2010 to 13,114 in March 2011. In Little Goose Reservoir, monthly population estimates ranged from 11,907 in October 2010 to 30,045 in March 2011 (Table 5). There was little difference in reservoir volume from one sample period to the next within each reservoir, and population trends within a reservoir reflected differences in median transect abundances for a particular sample period. The ranges in confidence limits around the population estimates were the result of the sample size (generally 30) and the variability of transect abundances.

Table 5.—Reservoir, sample period, reservoir volume, median transect density (number/100,000 m^3), *C* statistic, total population estimate, and 95% CI of holdovers estimated from hydroacoustic surveys in Ice Harbor, Lower Monumental, Little Goose and Lower Granite reservoirs from 5 October 2010 to 4 March 2011.

Reservoir Sample period	Reservoir volume (m^3)	Number of transects	Median transect density (#/100,000 m^3)	*C* statistic	Population estimate	95% CI
Little Goose						
12 Oct – 14 Oct	684,031,465	30	0.1655	9	11,907	4,335-17,540
17 Nov – 19 Nov	669,957,437	13	0.1908	2	12,892	6,342-15,301
13 Dec – 17 Dec	672,274,738	26	0.3554	7	24,473	9,379-45,128
1 Mar – 4 Mar	681,807,086	30	0.5619	9	30,045	17,355-52,619
Lower Granite						
5 Oct – 7 Oct	559,854,252	30	0.1655	9	27,290	18,884-37,729
1 Nov – 3 Nov	560,211,961	30	0.1398	9	19,509	16,809-25,784
6 Dec – 8 Dec	558,460,417	30	0.0373	9	18,179	9,980-23,955
25 Jan – 26 Jan	541,964,653	12	0.1559	2	13,680	8,450-19,425
15 Feb – 17 Feb	548,107,393	30	0.0202	9	13,114	6,130-16,823

Hydroacoustic seasonal and longitudinal density comparisons

In Lower Granite Reservoir, the density of holdovers was generally similar between sample periods, with the highest densities in October and November. Peak seasonal density in Lower Granite Reservoir was in October and in Little Goose Reservoir peak seasonal density was highest in December and March. Most fish were detected with our side-looking transducer compared to our down-looking transducer, indicating that most holdovers were in the upper 7 to 8 m of the water column. The overall median transect density in Lower Granite Reservoir ranged from 0.17 holdovers/100,000 m^3 in October 2010 to 0.02 holdovers/100,000 m^3 in February 2011. The median transect density in Little Goose Reservoir ranged from 0.17 holdovers/100,000 m^3 in October 2010 to 0.56 holdovers/100,000 m^3 in March 2011 (Table 5).

The highest density of holdovers in Little Goose Reservoir was in December in the upper and middle reservoir reaches but highest in March in the forebay reach. Of the 99 transects sampled in Little Goose Reservoir, 4 transects had a density of zero; whereas in Lower Granite Reservoir, only 1 of 132 transects had a density of zero. The grand median density of all individual hydroacoustic transects in Lower Granite Reservoir was 3.30 (range: 0 to 6.29 fish/100,000 m^3) whereas in Little Goose Reservoir it was 2.51 (range: 0 to 18.76 fish/100,000 m^3).

Longitudinal comparisons of hydroacoustic densities showed that densities were generally similar between reaches in Lower Granite Reservoir with the highest densities in the forebay reach being observed in October and the highest densities in the middle and upper reaches being observed in November (Figure 6). In Little Goose Reservoir, the highest densities in the forebay reach were observed in March but the highest densities in the middle and upper reaches were in observed in December (Figure 6). None of the holdover densities were significantly different between reaches in either reservoir ($P > 0.05$; Table 6). Our hydroacoustic data also showed that transect densities were higher overall in Lower Granite Reservoir than in Little Goose Reservoir ($Q = 2.97$, $P < 0.05$).

Our forebay comparisons revealed that many holdovers were overwintering in the Ice Harbor forebay relative to the other lower Snake River dam forebays. The Ice Harbor forebay had the highest densities of holdovers in December and March and the second highest density behind Lower Granite forebay in October (Figure 7). Overall, the density of holdovers in Ice Harbor was significantly greater than that in Lower Monumental forebay ($Q = 4.27$, $P < 0.05$) and Little Goose forebay ($Q = 5.26$, $P < 0.05$), but not the Lower Granite forebay. Overall, the Lower Granite forebay also had a significantly higher density of holdovers than the Little Goose forebay ($Q = 2.86$, $P < 0.05$).

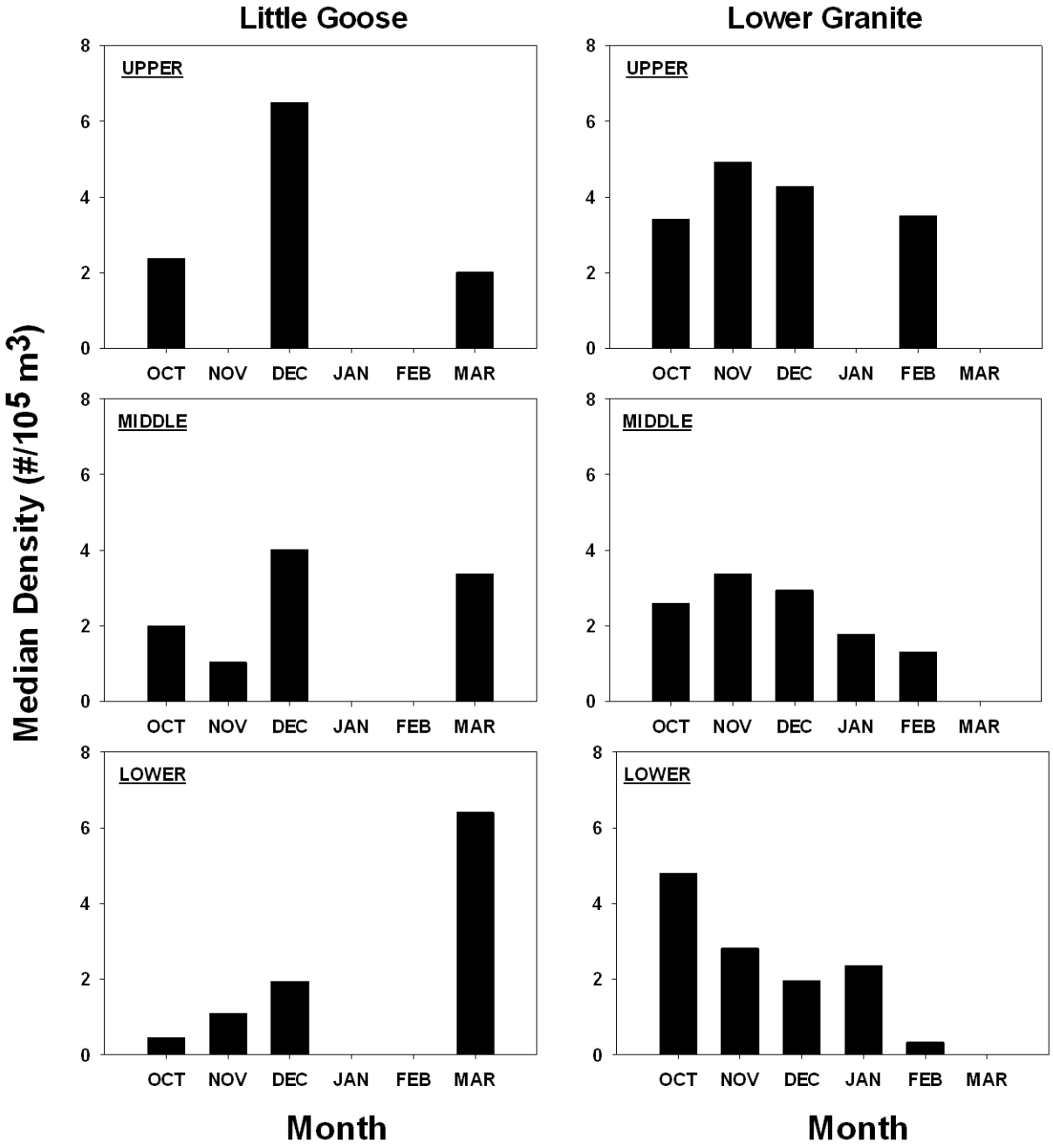

Figure 6.—Median juvenile fall Chinook salmon (>140 mm TL) density (#/100,000 m^3) estimated from hydroacoustic surveys from the lower (top panels), middle (middle panels), and upper (bottom panels) reservoir reaches of Little Goose (left panels) and Lower Granite (right panels) reservoirs from 5 October 2010 to 4 March 2011.

Table 6.—Kruskal-Wallis nonparametric multiple comparisons with tied ranks of hydroacoustic densities between reservoir reaches within years, reservoirs with years combined, and sampling years with reservoirs combined with the difference in mean ranked densities, the standard error (*SE*), the test score (*q* or *Q*), the critical value with a probability of 0.05, and the conclusion on the null hypothesis. Asterisks denote rejection of the null hypothesis (H_o) that the densities are equal.

Reservoir Comparison	Difference (ranks)	*SE*	*q* or *Q*	$Q_{0.05}$	Assess null hypothesis
Little Goose Reach Comparisons					
Forebay vs. Middle	4.50	6.45	0.70	2.394	Accept
Forebay vs. Upper	2.47	6.69	0.37	2.394	Accept
Upper vs. Middle	2.03	6.69	0.30	2.394	Accept
Lower Granite Reach Comparisons					
Forebay vs. Middle	541.00	1,140.00	0.47	2.394	Accept
Forebay vs. Upper	704.00	1,140.00	0.62	2.394	Accept
Upper vs. Middle	163.00	1,140.00	0.14	2.394	Accept
Reservoir Comparison					
Goose vs. Granite*	18.56	6.25	2.97	1.960	Reject
Forebay Comparisons					
IHR vs. LMO*	31.67	7.41	4.27	2.639	Reject
IHR vs. LGO*	36.73	6.98	5.26	2.639	Reject
IHR vs. LGR	16.76	6.98	2.40	2.639	Accept
LMO vs. LGO	5.06	7.41	0.68	2.639	Accept
LMO vs. LGR	14.91	7.41	2.01	2.639	Accept
LGO vs. LGR*	19.97	6.98	2.86	2.639	Reject

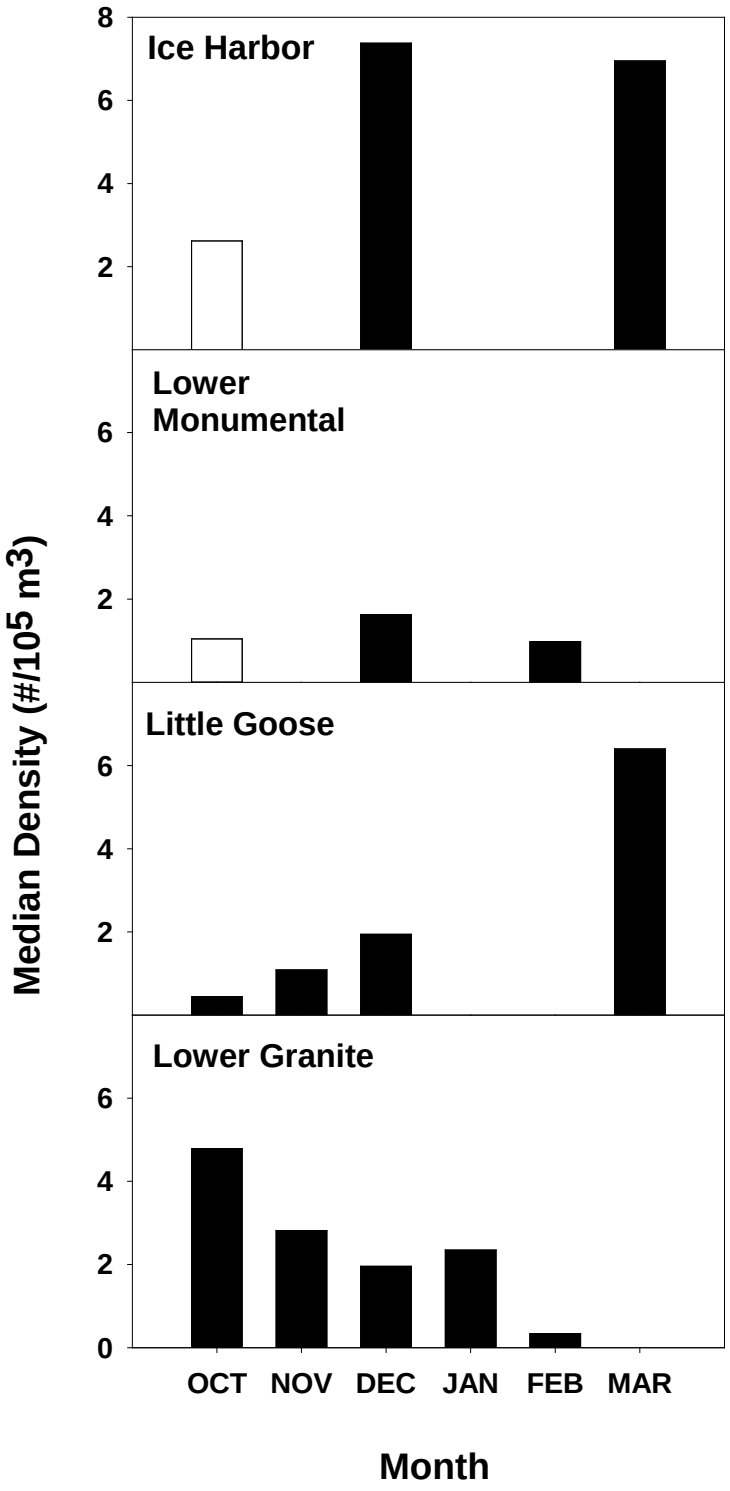

Figure 7.—Median juvenile fall Chinook salmon (>140 mm TL) density (#/100,000 m^3) estimated from hydroacoustic surveys from the forebay reservoir reaches of Ice Harbor (top panel), Lower Monumental (second from top panel) Little Goose (second from bottom panel) and Lower Granite (bottom panel) reservoirs from 5 October 2010 to 4 March 2011.

Discussion

Over the course of our 4-year study, we used two basic survey methods. We used a systematic zigzag sampling approach in 2007-2008 and 2008-2009 to estimate the holdover population with smaller confidence intervals but were unable to examine spatial and temporal differences in abundance within or between reservoirs. There is much debate about the use of randomized or systematic sampling and it appears that although systematic approaches increase precision, as was the case with our data, they also increase the likelihood of spatial correlation issues. Further, randomized designs are desirable from an analysis standpoint because they simplify calculations (Simmonds and MacLennan 2005). Future efforts with similar objectives might benefit from the exploring adaptive or weighted type sampling where effort is concentrated in areas of higher abundance. In effect, we used a weighted type of sampling in 2010-2011 because we expended equal effort in the lower 2 miles (forebay reach) where we believed fish were concentrated as we did in the longer middle and upper reaches of each reservoir.

Our data indicate that diel considerations are likely not as important as spatial ones when studying juvenile salmon behavior. In 2007-2008, we sampled at night, under a new moon. We did so following the general rule that fish aggregations disperse, move away from the surface, and off the bottom at night. In other years, we collected all data during daytime due to the logistical difficulty of setting the lampara seine in darkness and to be consistent in when we sampled with the lampara seine and the hydroacoustics gear. Despite this perceived compromise, it is important to note that during our seine effectiveness sampling in May 2010, we captured more juvenile salmonids during daytime sampling (2,525 fish) than during nighttime sampling (722 fish) with an identical level of effort. Future efforts to both estimate population size and examine spatial abundance differences would benefit from employing a similar methodology with stratified random sampling with orthogonal transects. Sacrificing nighttime sampling did not appear to negatively influence the catch rate of the lampara seine.

In our 2009-2010 and 2010-2011 sampling, we altered our methods so that each hydroacoustics transect sampled was immediately followed by a lampara seine haul on the same transect. We believed this concurrent sampling would reduce discrepancies between fish numbers sampled with hydroacoustics and the lampara seine. However, we generally did not have agreement between individual transect densities and lampara CPUE. One reason for this is that the lampara seine was only effective in the pelagic zone to a depth of 21 m whereas the hydroacoustic gear sampled the entire cross section of the reservoir. Another possibility is that the hydroacoustic boat may have altered the distribution of the fish that we tried to subsequently sample with the lampara seine. Nonetheless, concurrent sampling to verify hydroacoustic targets is still the best approach to minimize spatial and temporal variation between the two gear types. Future efforts to estimate the abundance of juvenile salmonids, especially those such as

holdovers that are pelagic, would benefit by limiting hydroacoustic sampling to the pelagic zone of the reservoir where the target fish are distributed. Our data confirmed that the lampara seine can effectively collect fish when they are present and that there is overall agreement between lampara and hydroacoustics trends. We believe that the lampara seine is an important gear type for sampling migratory forms of juvenile salmonids that are typically offshore and pelagically oriented. Further, we believe the lampara seine is a vast improvement over the traditional method of mid-water trawling that we used in 2007-2008 because it samples a much larger portion of the water column with a single net haul, effectively samples fish that are oriented near the surface, captures larger fish that avoid trawls, and is gentler (e.g., less descaling) on the fish. Although purse seines have been used for collection of juvenile salmonids in the Columbia basin, they require a second boat resulting in increased effort.

Catch composition of the lampara seine in 2010-2011 was similar to prior years with holdovers comprising the vast majority of our catch. The exception to this was when we captured an estimated 8,357 juvenile American shad from two seine hauls in the Ice Harbor forebay during October. The non-normal distribution of our lampara catch of holdovers (and shad) illustrates the patchy nature of fish that school and underscores the need for a randomized sampling approach to correctly characterize the population. Our approach of using lampara seine catch data coupled with randomized hydroacoustic transects was necessary to more fully understand the distribution of the fish we sampled but was limited by the amount of effort we could expend. As such, although we sampled randomly, the 30 transects per reservoir should be considered a minimum given the patchy distribution of holdovers and their relatively low abundance during the winter. An alternative approach would have been to use a systematic track design followed by intensive surveys after schools have been located. However, this would require the fish schools or patches to consistently remain in localized areas over time (Jolly and Hampton 1990), which is usually not true for migratory juvenile salmonids. Future efforts should identify the requisite number of target fish that must be captured for species verification which in turn will determine seining effort.

One of the benefits of capturing more fish in 2010-2011 was that we were able to further apportion fish composition from the seine catch to the hydroacoustic densities within individual sampling periods. However, we could not further apportion the seine catch by individual reservoir reach because we often caught few, if any, fish in the middle and upper reservoir reaches. Therefore in our conservative approach to apportioning our seine catch to the whole reservoir, we sacrificed some spatial variability; thus our hydroacoustic density estimates for the upper reservoir reaches may be higher than we report. When apportioning fish to the whole reservoir, one must assume fish are randomly distributed throughout the reservoir, and that the species compositions from positive catches are representative of transects where no fish are caught. As discussed above, the only means of better apportioning the seine catch to other reaches and with more certainty is to increase seining effort.

The differences we observed in population or density estimates between reservoirs are probably the result of longer residence times of fish in Little Goose relative to Lower Granite Reservoir. Our data indicated that residence time of holdovers increases as fish move downstream. We observed the largest densities of holdovers in the Ice Harbor forebay in late December suggesting that this is an important overwintering area. Our data also indicated that holdovers were more abundant in the lower reaches of the reservoirs that we sampled. Longitudinal comparisons of lampara seine CPUE showed higher CPUE in the lower third of Lower Granite and Little Goose reservoirs relative to the middle and upper third of each reservoir, respectively. This suggests that fish moving downstream encounter lower Snake River dams and reside longer in the forebays than upstream reaches. This is consistent with the findings of Kock et al. (2007) who found that radio-tagged holdovers can spend from weeks to months in the forebays of lower Snake River reservoirs during winter, and some fish do not resume seaward migration until spring. The congregation of fish in forebays is likely due to the lower water velocities and lack of migrational cues found there (Venditti et al. 2000). This forebay behavior may be magnified for holdovers because they are moving downstream when flows are declining to their lowest levels of the year.

Our hydroacoustic data showed that most fish were located in the upper portion of the water column rather than deeper, but this changed seasonally. Both our lampara seine catch data and side-looking hydroacoustic densities suggested that holdovers were more likely to be distributed in the upper portion of the water column during most of the fall and winter. This is consistent with the findings of Adams et al. (1997) and Kofoot et al. (1997) who showed that juvenile salmonids are typically located in the upper 18-20 m of the water column. In contrast, the high hydroacoustic densities of fish we observed in March in Ice Harbor and Little Goose reservoirs were derived primarily from fish ensonified by the down-looking transducer suggesting that fish may have been deeper at this time of year. We observed few fish with the side-looking transducer and our low lampara seine catches in March confirmed this. Therefore it appears that the smaller side-looking densities from hydroacoustic surveys in March indicate that fewer holdovers were present during this sample period and most fish had probably left the lower Snake River.

Warmer temperatures likely influence how many juvenile fall Chinook salmon eventually become holdovers that in turn dictates their fall and winter abundance in lower Snake River reservoirs. Our population estimates of holdovers were significantly higher in 2010-2011 relative to the other years that we sampled Little Goose and Lower Granite reservoirs. We also captured more fish with our lampara seine in 2010-2011 compared to other years. The combination of greater hydroacoustic population estimates and lampara catches indicate that more holdovers were present in the lower Snake River in the winter of 2010-201 than in the other three years we conducted surveys. The differences in holdover abundance may be related

to temperature differences between years. Years with warmer water temperatures coincided with higher ranges of population estimates, though the warmest year did not have the greatest population estimate (Table 7). Warmer temperatures also afforded greater growth opportunity for holdovers in the lower Snake River that resulted in greater mean size (Figure 4). Holdovers in the lower Snake River in 2010-2011 were similar in size to those collected in 2008-2009 and 2009-2010 when temperatures were cool or average, but smaller than those collected in 2007-2008 when temperatures were warmer and afforded better growth opportunity.

Table 7.—Sampling year, mean difference between daily water temperature and the ten-year average, and the monthly population ranges of holdover fall Chinook salmon in Little Goose and Lower Granite reservoirs, lower Snake River during 2007-2008, 2008-2009, 2009-2010, and 2010-2011. Water temperatures were collected from the Lower Granite tailrace.

Sampling year	Mean LGR temperature difference with the 10-year average	Little Goose Reservoir	Lower Granite Reservoir
2007-2008	+0.26	-	6,010-9,332
2008-2009	-0.92	1,820-9,645	1,598-6,929
2009-2010	-0.22	1,669-10,419	3,299-7,218
2010-2011	-0.13	11,907-30,045	13,114-27,290

The relationship between seasonal water temperatures and the expression of the juvenile reservoir life history type cannot be explained by fluctuations in mean annual water temperatures alone. The seasonal timing of these water temperatures is also of critical importance. Connor et al. (2002) states that the expression of the reservoir-type life history type by juvenile fall Chinook salmon is inversely proportional to spring water temperatures and subsequent growth opportunity where higher spring water temperatures result in enhanced growth early in the season and propensity to migrate seaward at an earlier age. However, cooler springtime water temperatures followed by warmer summertime water temperatures are likely to increase the propensity to holdover as fish seek cooler water temperatures in the lower Clearwater River, where temperatures on average are 8°C cooler than those in the Snake River upstream of the confluence with the Clearwater River (Tiffan et al. 2003), or in the lower main-stem Snake River where water temperature is moderated to about 20°C by releases of water from Dworshak Dam on the North Fork of the Clearwater during July to mid-September. Apart from annual differences in seasonal water temperatures and flow augmentation, juvenile fall Chinook salmon from the Clearwater River have a much higher propensity to hold over than those originating

from the Snake River (Conner et al. 2002) because of the cooler water temperatures they experience coupled with their late migration timing out of the Clearwater River. Future studies of juvenile fall Chinook salmon in the Snake River basin should include genetic testing or other means to delineate the differing effects of mitigation measures to stocks originating in the Snake River from those originating in the Clearwater River within the context of seasonal water temperature patterns.

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CHAPTER THREE

Covariate Analysis for Survival Parameters and Travel Time
Addendum to 2009 Annual Report

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Introduction

This report presents the analysis of effects of various biological, environmental, and timing factors on survival parameters and travel time estimated from radio-tagged and acoustic-tagged subyearling fall Chinook salmon released in the Clearwater River in 2009. This effects analysis consisted of regression of the joint probability of migration and survival, and the joint probability of migration delay and survival, against covariates describing environmental conditions measured throughout the study period. Travel time was related to both biological and environmental covariates. Analysis focused on the reach from Potlatch on the Clearwater River to Red Wolf Bridge on the Snake River. For detailed information on the study design, tagging and estimation methods, and results of the fate determination analysis, see Tiffan et al. (2010).

Methods

Estimates of both the joint probability of migration and survival (ϕ) and the joint probability of migration delay and survival (ψ) were available for the reach consisting of the transition zone between the free-flowing Clearwater River and the confluence with the Snake River ("Transition Zone"), and the confluence itself ("Confluence"). This reach extended from Potlatch on the Clearwater River to Red Wolf Bridge on the Snake River. For radio-tagged smolts, estimates of ϕ were available from mid-August through mid-October 2009, and estimates of ψ were available from mid-August through early October 2009 (Figure 1). For acoustic-tagged smolts, estimates of ψ were available starting in mid-August, and estimates of ϕ were available starting in late September (Figure 1). Earlier estimates of ϕ were unavailable for acoustic-tagged fish because of delay either within the Transition Zone-Confluence reach or downstream of that reach. A missing estimate of ϕ should not be interpreted as 0.

Travel time was measured for all fish that were detected at both the upstream and downstream boundaries of the Transition Zone-Confluence reach (Potlatch and Red Wolf Bridge, respectively). Because of differences in the locations of acoustic hydrophones and radio antennae, travel times were converted to migration rate (km/d) for combined analysis of data from both types of tag.

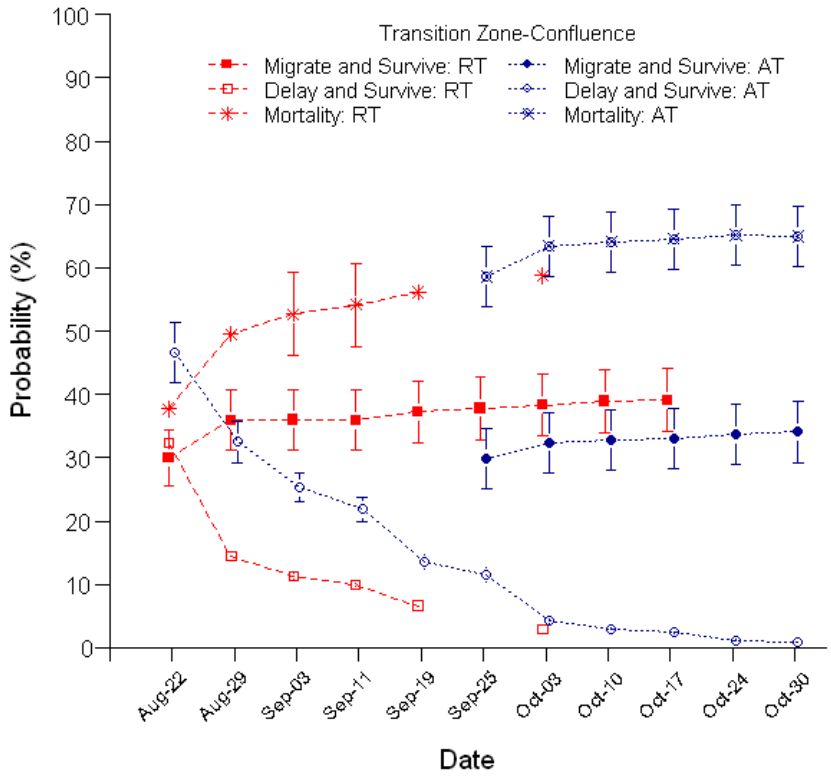

Figure 1.—Estimates of the joint probability of migrating and surviving (ϕ), the joint probability of delaying and surviving (ψ), and the probability of mortality (μ) in the combined reaches of the Transition Zone and Confluence, from Potlatch to Red Wolf Bridge on the Snake River, based on radio-tag data and acoustic-tag data.

Covariates

Covariates were classified as either environmental, biological, or timing metrics (Table 1). Environmental covariates included measures of the difference in river conditions between the free-flowing Clearwater River and the Confluence region, and measures of water temperature at sites just upstream and downstream of the Confluence. The difference in both cross-sectional velocity ("Delta Velocity") and river discharge ("Delta Flow") were measured between rkm 12.6 on the Clearwater River (from the Confluence) and a site on the Clearwater River immediately upstream of the Confluence ("LGR-1"). Water temperature was represented by the percentage of the cross-sectional area of the river channel that was colder than 20° C, measured both at LGR-1 on the Clearwater River ("Percent Cold LGR-1"), and at a site on the Snake River several km downstream of the Confluence ("LGR-3", located at rkm 220 on the Snake River, measured from the confluence of the Snake and Columbia rivers; "Percent Cold LGR-3"). An additional measure of river conditions was river regime ("Regime"), a categorical variable representing

water temperature, water velocity in the Confluence, and the amount of intrusion of the Snake River into the Clearwater River. Although Regime reflected environmental conditions, it was defined temporally as follows:

- Regime 1 = 13 August – 13 September 2009: cool Clearwater River, warm Snake River, high velocity through Confluence;
- Regime 2 = 14 September – 28 September 2009: warm Snake River intrusion into Clearwater River, low velocity through Confluence;
- Regime 3 = 29 September – end of study (30 October 2009): no intrusion, low velocity in Confluence.

In the event that multiple regression found Regime to have a significant effect (α=0.05), additional multiple regression models were explored that omitted Regime in order to assess the relative importance of the factors that are represented by Regime (i.e., water temperature and velocity). For more information on the environmental covariates, see Tiffan et al. (2010).

Biological covariates were restricted to fish length and fish weight at the time of tagging. Length and weight were highly correlated (r=0.90), so only the effect of fish length was explored in the regression analyses (Table 1). Timing covariates included detection period, used for group-based analyses (see below), and day of year, used for individual-based analyses (Table 1). Day of year was measured as the number of days after the start of the study, 13 August 2009. Both detection period and day of year may reflect changes in migration through time, but neither provides insight into which environmental or biological factors may influence migration. Thus, these timing covariates are included in the single-variate models, but omitted from the multiple regression models. Tag type (acoustic or radio) was included as a factor in all analyses.

Premature failure of both radio and acoustic tags meant that survival effects of covariates could be measured only on a release group basis rather than on an individual fish basis. A group-based analysis accounts for tag failure, unlike an individual-based analysis, but also has lower statistical power to detect significant effects than an individual-based analysis. The survival effects analyses were restricted to covariates that varied within a release group, namely the environmental and timing covariates, as well as tag type. Fish length was omitted from the survival effects analyses because, with only one release group per tag type, the average fish length per release group was completely confounded with tag type.

Detection periods for this study all began at the time of release (13 August 2009), with successive detection periods ending two weeks apart (Table 2). Thus, estimated values of ϕ, the joint probability of migration and survival, represented the joint probability of migrating through a reach and surviving to exit the reach at any time from the beginning of the study through the end of the detection period. Factors influencing migration and survival may have acted at any time during that time period, thus, it made sense to explore covariates measured on the scale of the entire detection period (Table 1). Estimates of ψ, on the other hand, represented the joint

probability of delaying migration in the reach and surviving within the reach through the end of the detection period. While migration delay may be influenced by factors that occurred throughout the detection period, survival was necessarily influenced by factors occurring at the end of the detection period. Thus, it made sense to compare estimates of ψ to covariates measured on a short time scale at the end of the time period. For this reason, each of Delta Velocity, Delta Flow, Percent Cold LGR-1, and Percent Cold LGR-3 were measured as averages over both a "short" and a "long" time period for each detection period, as defined in Table 1. For each detection period, the "long" period consisted of the entire detection period, notably starting at the beginning of the study (13 August 2009). The "short" period consisted of the final two weeks of the detection period. For the first detection period, the "long" and "short" measures were identical. The measures Percent Cold LGR-1 and Percent Cold LGR-3 were also measured at the start of each "short" time period. Both "long" and "short" measures of environmental covariates were used to model ϕ (probability of migration and survival), while only "short" measures were used to model ψ (probability of delay and survival).

The analysis of covariate effects on travel time (migration rate) was performed on an individual fish basis, because travel time was measured for individual fish. Environmental, biological, and timing covariates and tag type were all analyzed for travel time effects, on the migration rate scale. Delta Velocity and Delta Flow were averaged over the hour of arrival at the upstream boundary of the Transition Zone. Percent Cold LGR-1 and Percent Cold LGR-3 were measured as the average over the 24-hour period of arrival at the Transition Zone.

Table 1.—Covariates used in the effects analyses, and how they are represented in the survival and travel time analyses. Site LGR-1 was located on the Clearwater River immediately upstream of the Confluence. Site LGR-3 was located downstream of the Confluence, at rkm 220 on the Snake River (measured from the confluence of the Snake and Columbia rivers). "Long" period = entire detection period (see Table 1). "Short" period = final two weeks of detection period.

Covariate	Description	Survival Analyses	Travel Time Analysis
Delta Velocity	The difference in cross-sectional velocity between rkm 12.6 on the Clearwater River and site LGR-1.	• Average over long period • Average over short period	Measured at time of arrival at upstream boundary of the Transition Zone
Delta Flow	The difference in discharge (cfs) between rkm 12.6 on the Clearwater River and site LGR-1.	• Average over long period • Average over short period	Measured at time of arrival at upstream boundary of the Transition Zone
Percent Cold LGR-1	The percentage of the river channel that is colder than 20° C, measured at site LGR-1. This covariate is a measure of temperature stratification.	• Average over long period • Average over short period • Start of short period	Measured at time of arrival at upstream boundary of the Transition Zone
Percent Cold LGR-3	The percentage of the river channel that is colder than 20° C, measured at site LGR-3. This covariate is a measure of temperature stratification.	• Average over long period • Average over short period • Start of short period	Measured at time of arrival at upstream boundary of the Transition Zone
River Regime	A categorical variable that combines water temperature and velocity, and the amount of intrusion of the Snake River into the Clearwater River. This environmental covariate defined temporally as follows: • Regime 1 = 13 August – 13 September 2009: cool Clearwater River, warm Snake River, high velocity through Confluence. • Regime 2 = 14 September – 28 September 2009: warm Snake River intrusion into Clearwater, low velocity through Confluence. • Regime 3 = 29 September – end of study: No intrusion of Snake River into Clearwater, low velocity in Confluence.	Measured at start of short period.	Measured at time of arrival at upstream boundary of the Transition Zone
Fish Length	Fish length at time of tagging; an individual-based covariate	NA	Measured at time of tagging
Day of year	Measured from start of study (13 August 2009)	NA	Measured from start of study
Detection period	The number of the detection period (see Table 2)	Used primarily in single-variate regressions	NA
Tag Type	Categorical variable with levels: 0 =Acoustic Tag, 1=Radio Tag.	Used in both single-variate and multiple regressions	Used in both single-variate and multiple regressions.

Table 2.—Detection periods and their ending dates for radio-tag and acoustic-tag release groups. Each detection period began on the first day of release, 13 August 2009. All dates are in 2009.

Detection Period	Radio-Tag Group	Acoustic-Tag Group
1	22 August	22 August
2	29 August	29 August
3	3 September	3 September
4	11 September	11 September
5	19 September	19 September
6	25 September	25 September
7	3 October	3 October
8	10 October	10 October
9	15 October	17 October
10		24 October
11		30 October

Effects Analysis for Survival Parameters

Estimates of both the joint probability of migration and survival through the Transition Zone-Confluence reach (ϕ) and the joint probability of delay and survival in this reach (ψ) were regressed separately on environmental and timing factors using weighted linear regression with a proportional hazards log-log transformation. Estimates over successive detection periods of ϕ, the joint probability of migration and survival, were treated as independent, even though they represented migration and survival over portions of the same detection periods. This assumption was deemed to be justified because successive estimates of ϕ depended both on the number of fish entering the reach in the new detection period and on the number of fish exiting the reach. Thus, as long as there was new movement into and/or out of the reach in the new detection period, the estimate of ϕ from one detection should have been independent of the estimates of ϕ from the previous detection periods. Furthermore, a time series analysis of the sequence of ϕ estimates found no significant autoregression. Estimates of ψ (joint probability of delay and survival) from successive detection periods were also treated as independent, under the assumption that the factors affecting ψ were more likely to occur on a short time scale at the end of successive detection periods.

Scatter plots were used first to identify potentially important covariates in explaining variation in either migration and survival or delay and survival. Weighted linear regression models were then used with a proportional hazards transformation and with weights equal to the inverse squared CV of the ϕ_t or ψ_t estimates, based on the observed relationships between point estimates and standard errors. Simple linear regressions were used to identify important single factors, followed by multiple linear regressions to identify important sets of factors. The small number of detection periods with estimates from both acoustic-tagged fish and radio-tagged fish prevented informative assessment of interaction effects with tag type. Significance testing was

based on analysis of variance (ANOVA) using F-tests, and model selection used forward selection. Estimates of ϕ and ψ were transformed using the proportional hazards log-log transformation to generate normally distributed errors:

$$\log\left(-\log\left(\theta_t\right)\right) = \beta_0 + \beta_1 x_t + \varepsilon_t ,$$

where $\theta_t = \phi_t$ or ψ_t; t = detection period; x_t = observed value of covariate x for detection period t, and β_1 = regression coefficient for covariate x.

Effects Analysis for Travel Time

Travel time through the Transition Zone-Confluence reach was calculated for all tagged smolts detected at both the upstream and downstream boundaries of this reach. Differences in the locations of the acoustic hydrophones and the radio antennae marking the upstream and downstream boundaries of this reach meant that for acoustic-tagged fish, the reach was 8.3 km long, while for radio-tagged fish, the reach was 9.9 km long. Thus, travel time was converted to migration rate (km/day) for each fish. Migration rate through the Transition Zone-Confluence reach was regressed on individual-based covariates, including environmental, biological, and timing covariates, as well as tag type (Table 1).

Simple linear regression was used to identify important single factors, followed by multiple linear regression to identify important sets of factors. Model selection was performed using ANOVA and forward selection. Migration rates were transformed using the log transformation to generate normally distributed errors:

$$\ln\left(V_i\right) = \beta_0 + \beta_{1i} x + \varepsilon_i$$

where V_i is migration rate through the Transition Zone-Confluence reach for individual i, and β_{1i} is the effect of covariate x on travel time of individual i.

Results

The difference in cross-sectional velocity between the free-flowing Clearwater River at rkm 12.6 and site LGR-1 ranged from 2.08 ft/s to 3.83 ft/s during the study period, with a mean of 2.71 ft/s. The difference in discharge between rkm 12.6 on the Clearwater and site LGR-1 ranged from -1134.57 cfs to 1148.50 cfs, with a mean of -2.22 cfs. More information on observed cross-sectional velocity and discharge at these two sites is provided in Tiffan et al. (2010, Appendix B). The percentage of the cross-sectional area of the river channel that was cold (<20°C) at site LGR-1 ranged from 21.5% to 100%, with a mean of 93.8%, while the percentage of the river channel that was <20°C at site LGR-3 ranged from 0% to 100%, with a mean of 80.2% (Figure 2). There was little temporal variation in the percentage of the river channel that was cold at LGR-1 (Figure 2). Fish length at tagging ranged from 90 mm to 125 mm, with a mean of 102.8 mm.

All environmental covariates were used in the survival effects analyses except for the percentage cold at LGR-1 at the start of the short detection period, which was consistently observed at a single value (100%) for all detection periods. Other measures were explored in relation to ϕ (joint probability of migration and survival), ψ (joint probability of delay and survival), and travel time. Graphical comparisons of the estimates of ϕ, ψ, and travel time to the covariates are shown first, followed by the regression analysis results.

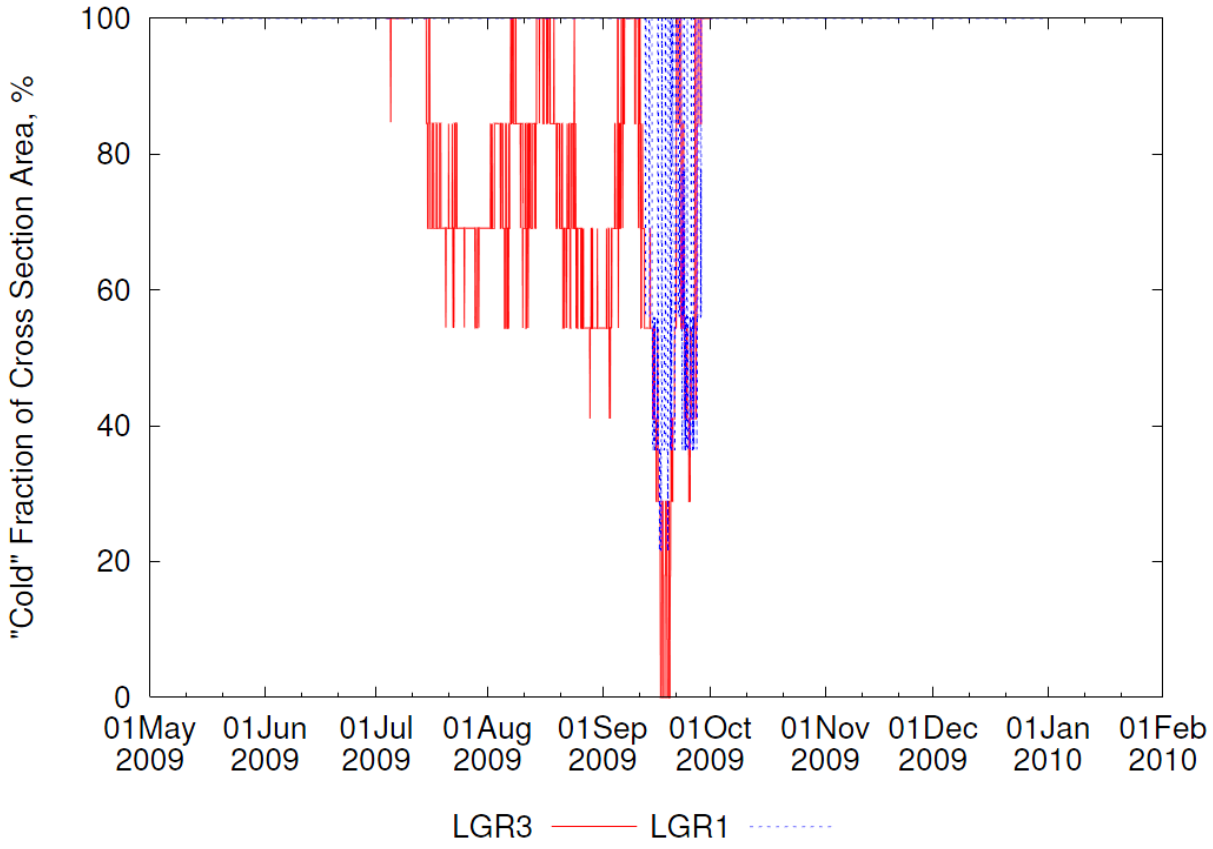

Figure 2.—The percentage of the cross-section of the river channel that was colder than 20°C at sites LGR-1 on the Clearwater River and LGR-3 on the Snake River. Figure courtesy of William Perkins, PNNL.

Migration and Survival Analysis (ϕ)

Estimates of ϕ (joint probability of migration and survival) varied little across the different detection periods, each of which began at the start of the study (13 August 2009) (Figure 1). Estimates of ϕ from radio tags were consistently higher than estimates for acoustic tags, whether considering individual periods (Figure 1) or pooling across periods (Figure 3). A relationship with river regime (i.e., water temperature and velocity) is less obvious, although it appears that Regime 3 may be associated with lower estimates of ϕ than Regime 1 and Regime 2 (Figure 4). However, it is not possible to separate an effect of river regime from an effect of time. Additionally, river regime varied only for radio-tagged fish, so a relationship with river regime is partly confounded by a relationship with tag type.

There was little evidence of a strong relationship between the joint probability of migration and survival through the Transition Zone-Confluence and the short-term average difference in cross-sectional velocity between the free-flowing Clearwater River at rkm 12.6 and site LGR-1 (Figure 5(a)), although there appeared to be a negative relationship between the probability of migration and survival and the long-term difference in velocity (Figure 5(b)). There was no strong suggestion of a relationship between the joint probability of migration and survival without the Transition Zone-Confluence and the average difference in discharge between the free-flowing Clearwater River and site LGR-1, whether measured over the short-term (Figure 6(a)) or over the long-term (Figure 6(b)). The percentage of the river channel at LGR-1 that was colder than 20°C averaged over the final two weeks of the detection period appeared unrelated to the joint probability of migrating and surviving through the Transition Zone-Confluence (Figure 7(a)), but there appeared to be a possible positive relationship between the long-term temperature at LGR-1 and the probability of migration and survival (Figure 7(b)). A similar but more scattered relationship was observed between the joint probability of migration and survival through the Transition Zone-Confluence and proportion of the river channel at LGR-3 that was colder than 20°C (Figure 8).

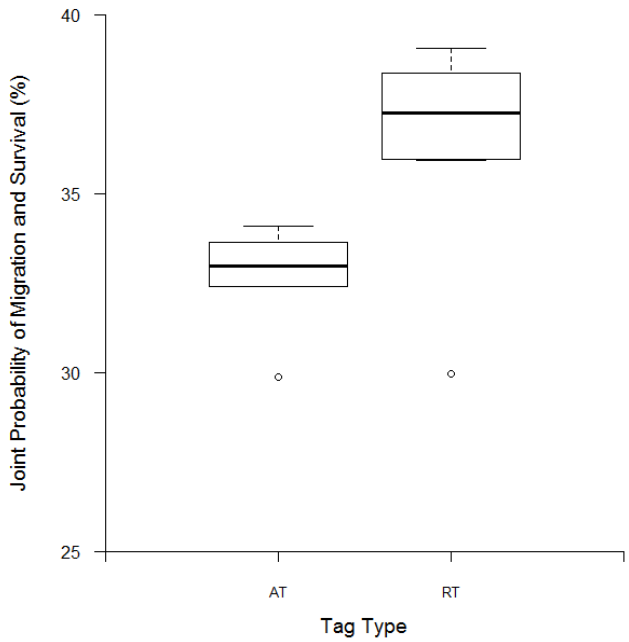

Figure 3.—Estimated joint probability of migration and survival (ϕ) through the Transition Zone-Confluence reach by tag type (AT = Acoustic Tag; RT = Radio Tag). Thick bar = median, box = interquartile range, upper whisker = maximum, open circles = minimum (outliers).

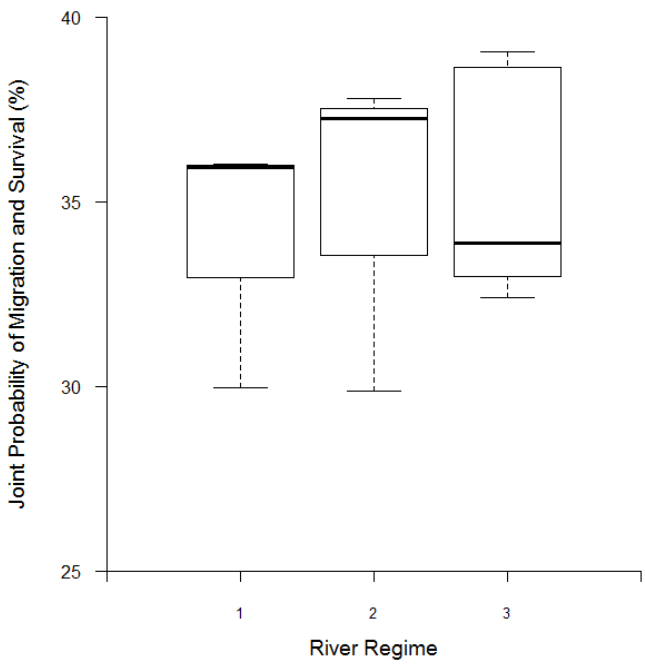

Figure 4.—Estimated joint probability of migration and survival (ϕ) through the Transition Zone-Confluence reach by River Regime: 1 = 13 August – 13 September 2009, 2 = 14 September – 28 September 2009, 3 = 29 September – end of study. Thick bar = median, box = interquartile range, whiskers = range.

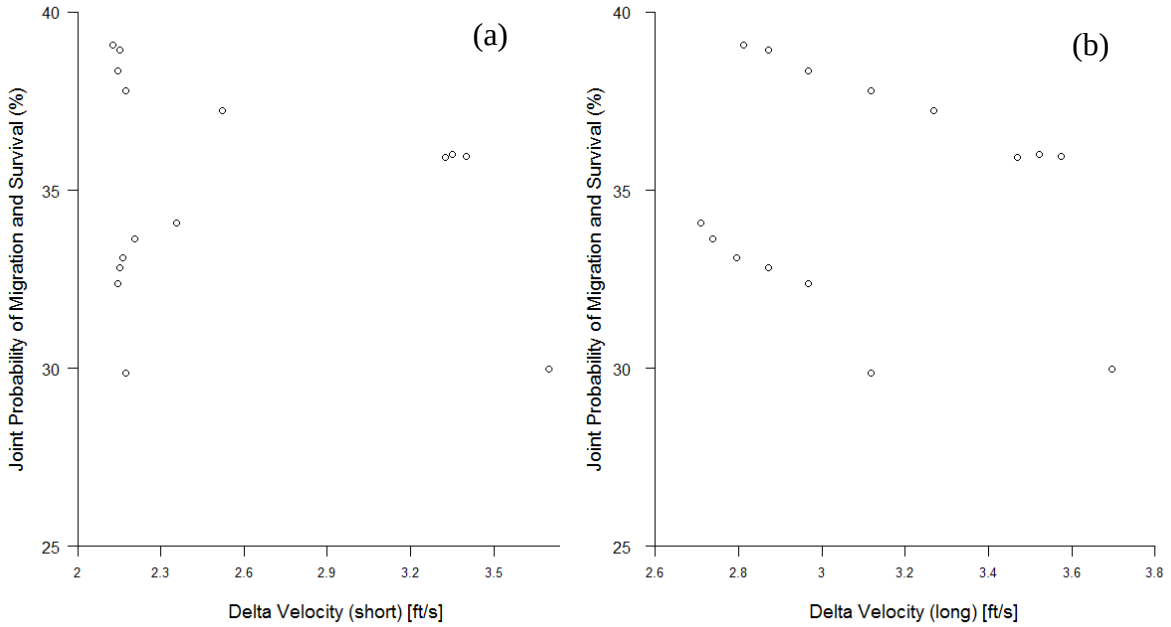

Figure 5.—Estimated joint probability of migration and survival (ϕ) through the Transition Zone-Confluence reach versus the difference in cross-sectional velocity between the free-flowing Clearwater River at rkm 12.6 and site LGR-1, averaged (a) over the final two weeks of each detection period and (b) over the entire detection period.

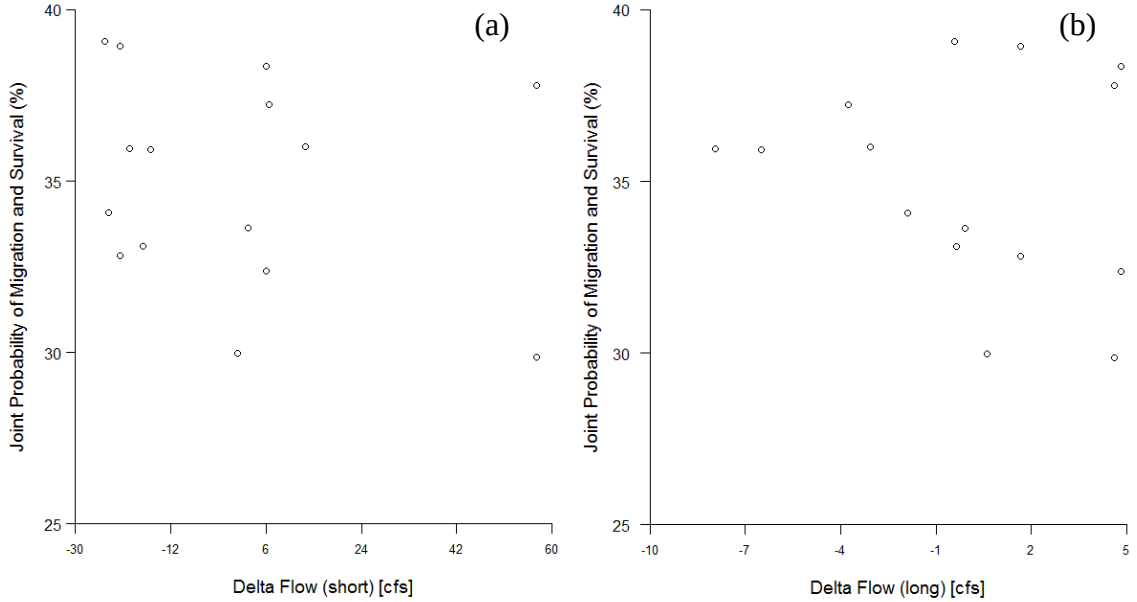

Figure 6.—Estimated joint probability of migration and survival (ϕ) through the Transition Zone-Confluence reach versus the difference in flow (discharge) between the free-flowing Clearwater River at rkm 12.6 and site LGR-1, averaged (a) over the final two weeks of each detection period and (b) over the entire detection period.

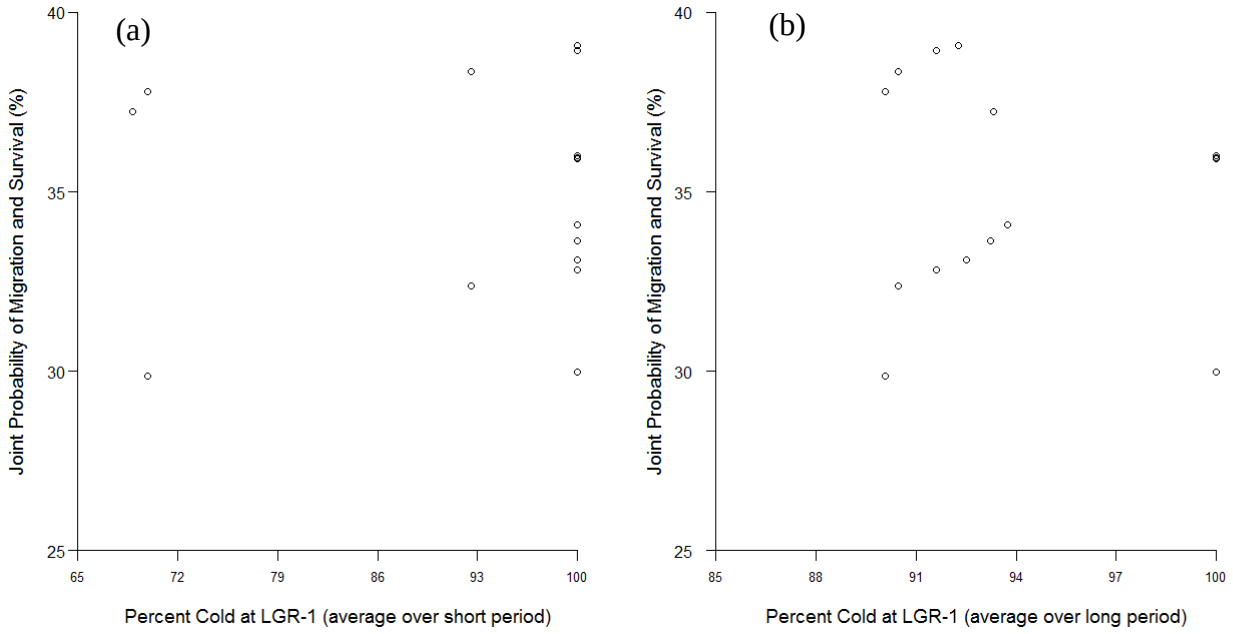

Figure 7.—Estimated joint probability of migration and survival (ϕ) through the Transition Zone-Confluence reach versus the percent of the river channel that was colder than 20°C at site LGR-1, averaged (a) over the final two weeks of each detection period and (b) over the entire detection period.

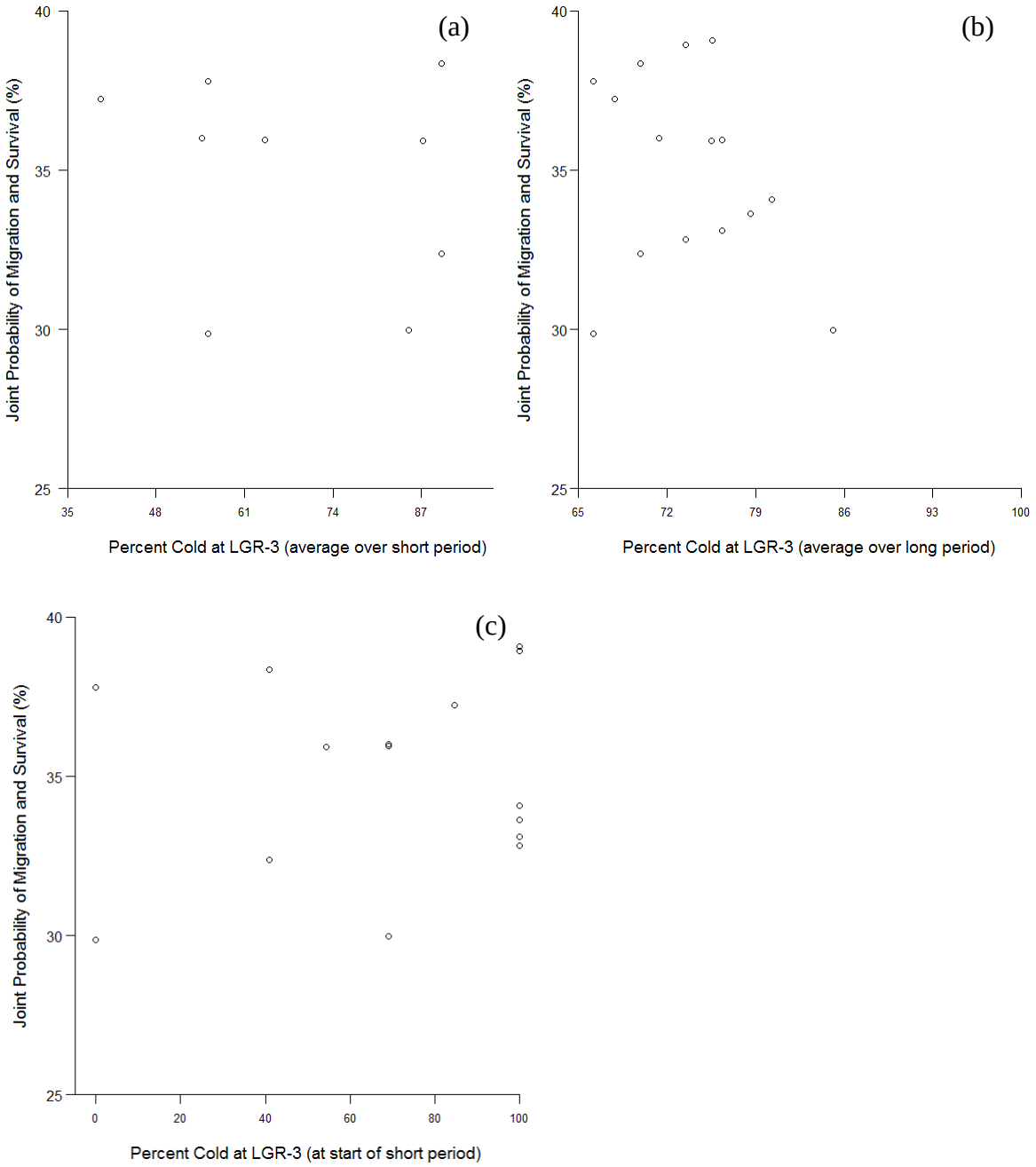

Figure 8.—Estimated joint probability of migration and survival (ϕ) through the Transition Zone-Confluence reach versus the percent of the river channel that was colder than 20°C at site LGR-3, averaged (a) over the final two weeks of each detection period and (b) over the entire detection period, and observed at the start (c) of the final two weeks of each detection period.

Results from the single-variate effects analyses relating the probability of migration and survival (ϕ) through the Transition Zone-Confluence showed a significant effect only of tag type (P=0.0055; Table 3). No environmental variable accounted for a significant (α=0.05) amount of the variation in estimates of the probability of migration and survival (Table 3). Multiple regression accounting for tag type found significant effects of detection period (P<0.0001), the difference in cross-sectional velocity between the free-flowing Clearwater River and the Confluence region (averaged over long period: P=0.0001, and averaged over short period: P=0.0018), and river regime (P=0.0092) when these covariates were considered alone with tag type. Because detection period was a timing covariate that essentially represented temporal changes in a suite of environmental and biological factors without indicating the relative importance of those factors, it was excluded from the final model. With both tag type and Delta Velocity accounted for, no further effect was significant (P≥0.06). The final model included both tag type and Delta Velocity averaged over the long detection period, with R^2=0.8509 (Table 4). There was a positive effect of having a radio tag rather than an acoustic tag (P<0.0001), and the probability of migration and survival decreased as the difference in cross-sectional velocity increased (P=0.0001) (Table 4, Figure 9).

Table 3.—Results of single-variable effects analyses for the joint probability of migration and survival (ϕ) through the Transition Zone-Confluence reach. The response variable was $y = \ln\left(-\ln\left(\hat{\phi}\right)\right)$, based on a proportional hazards model. Group-based covariates were used. Covariates are ordered by P-value. "Short period" = final two weeks of detection period. "Long period" = entire detection period.

Covariate	P-value	R^2
Tag Type	0.0055	0.4594
Percent Cold at LGR-3, averaged over long period	0.2498	0.1004
Delta Velocity, averaged over short period	0.5027	0.0353
Delta Flow, averaged over short period	0.5683	0.0257
Percent Cold at LGR-1, averaged over long period	0.6438	0.0169
Delta Velocity, averaged over long period	0.6540	0.0159
Delta Flow, averaged over long period	0.6681	0.0146
Detection period	0.6789	0.0136
Percent Cold at LGR-3, at start of short period	0.7086	0.0111
Percent Cold at LGR-3, averaged over short period	0.8242	0.0039
Percent Cold at LGR-1, averaged over short period	0.8735	0.0020
River Regime	0.8888	0.0195

Table 4.—Estimates of coefficients from the final linear model for the joint probability of migration and survival (ϕ) in the Transition Zone-Confluence reach, with standard error, observed *t*-statistic, and P-value. The response variable was $y = \ln\left(-\ln\left(\hat{\phi}\right)\right)$, based on a proportional hazards model. Multiple R^2=0.8509.

Coefficient	Estimate	S.E.	*t*	P-value
Intercept	-0.4276	0.0970	-4.410	0.0009
Tag Type = Radio	-0.1817	0.0222	-8.197	<0.0001
Delta Velocity, averaged over long period	0.1882	0.0335	5.613	0.0001

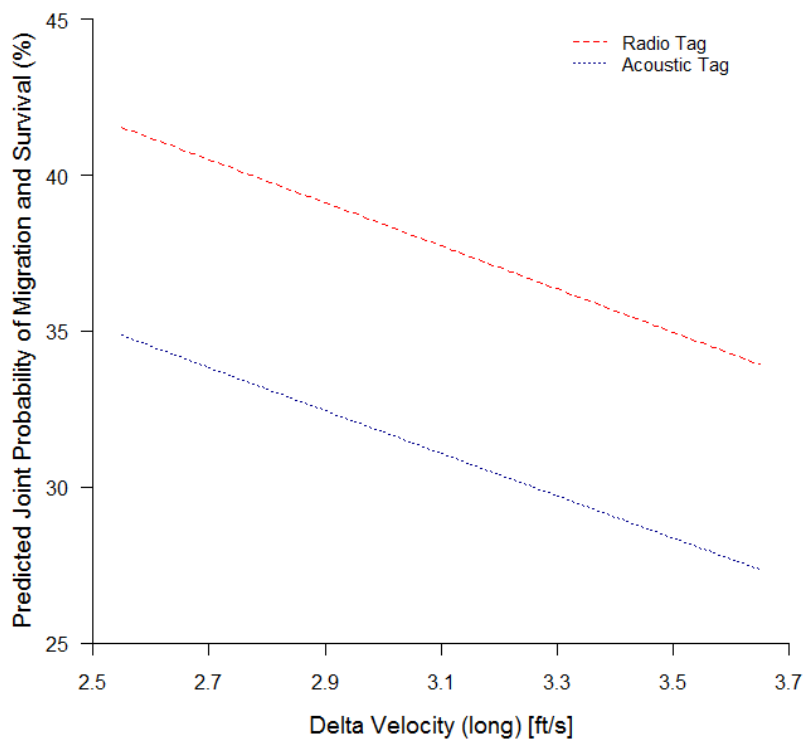

Figure 9.—Fitted joint probability of migration and survival through the Transition Zone-Confluence reach versus the difference in cross-section velocity between the free-flowing Clearwater River at rkm 12.6 and site LGR-1, averaged over the entire detection period, for radio- and acoustic-tagged fish. R^2=0.8509.

Delay and Survival Analysis (ψ)

There was more variation in estimates of ψ (joint probability of delay and survival) within the Transition Zone-Confluence reach for acoustic-tagged smolts than for radio-tagged smolts (Figure 10), and estimates of ψ were considerably lower for the third river regime than for earlier regimes (Figure 11). However, because river regime is strongly correlated with time, it is not clear if temperature, velocity, or day of year is more important in explaining the variation in the probability of delay and survival. There appeared to be a positive relationship between the probability of delay and survival in the Transition Zone-Confluence and the difference in cross-sectional velocity between the free-flowing Clearwater River at rkm 12.6 and site LGR-1 (Figure 12(a)), but there was no obvious relationship between the ψ and the difference in discharge between rkm 12.6 and site LGR-1 (Figure 12(b)). There was a wide range of estimates of the delay and survival probability when the majority of the river channel was cold at LGR-1 (Figure 13). There was more variation in the percentage of the river channel that was cold at site LGR-3, with a possible positive relationship between percentage cold and the probability of delay and survival (Figure 14).

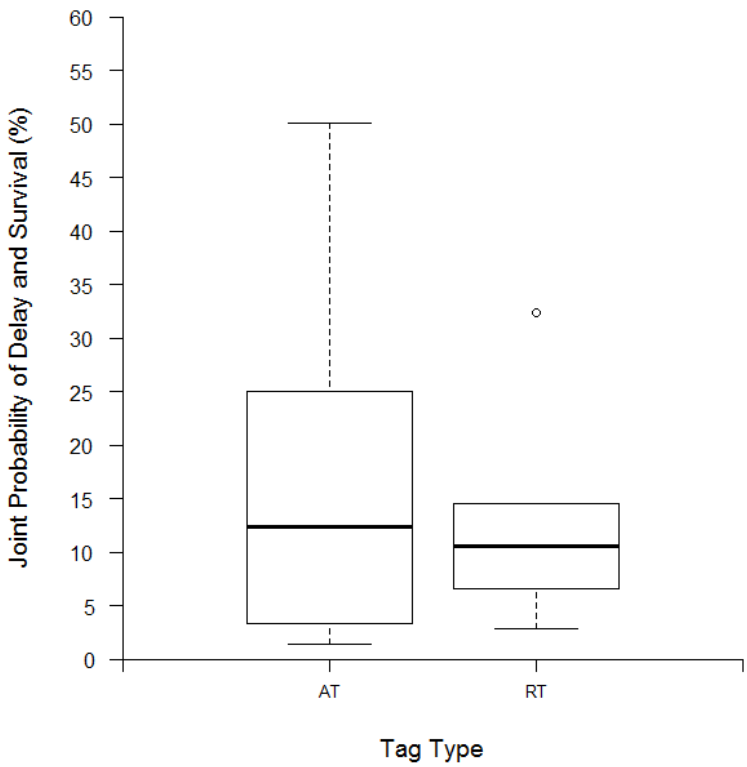

Figure 10.—Estimated joint probability of delay and survival (ψ) within the Transition Zone-Confluence reach by tag type (AT = Acoustic Tag; RT = Radio Tag). Thick bar = median, box = interquartile range, whiskers = range, open circle = outlier.

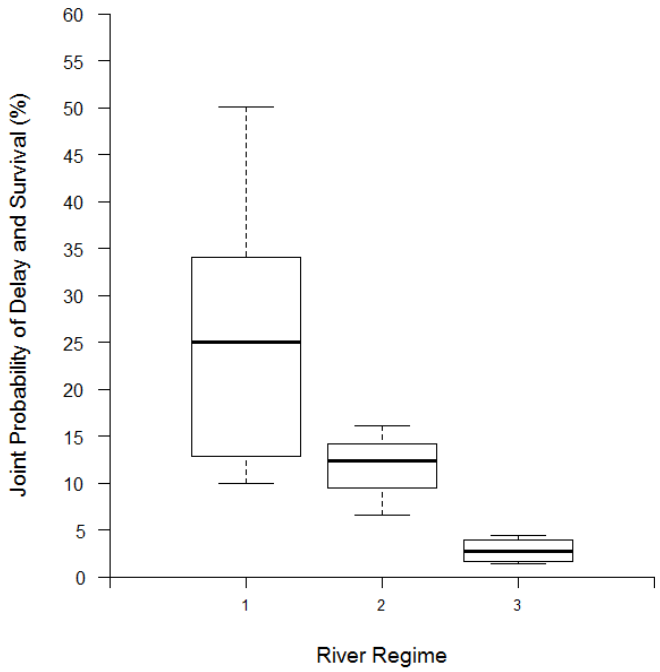

Figure 11.—Estimated joint probability of delay and survival (ψ) through the Transition Zone-Confluence reach by River Regime: 1 = 13 August – 13 September 2009, 2 = 14 September – 28 September 2009, 3 = 29 September – end of study. Thick bar = median, box = interquartile range, whiskers = range.

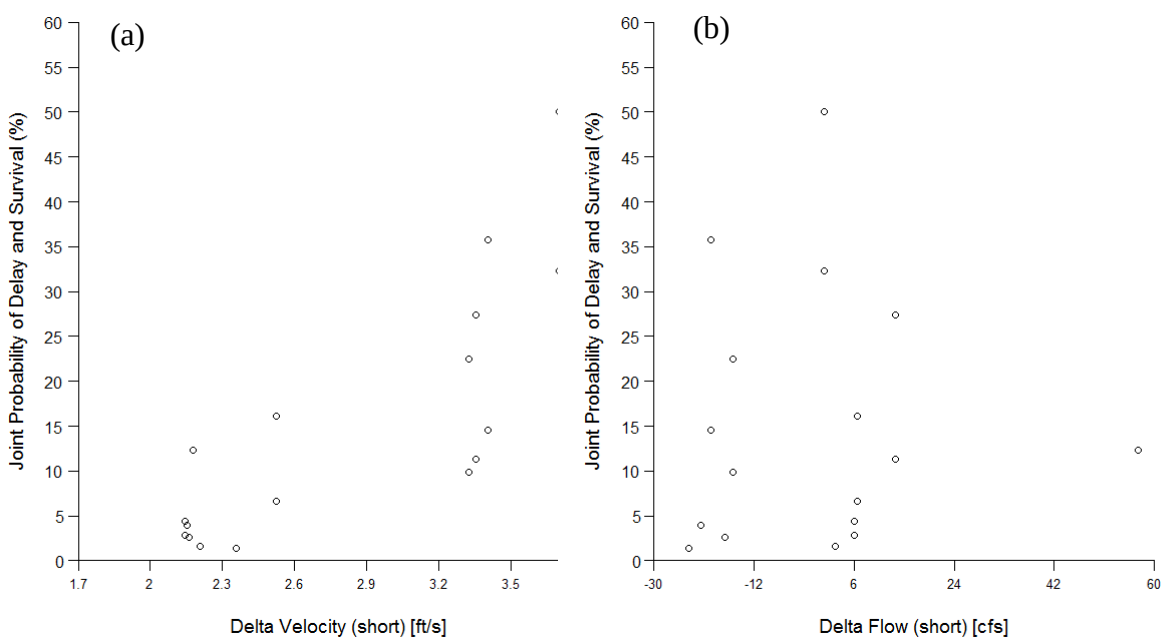

Figure 12.—Estimated joint probability of delay and survival (ψ) through the Transition Zone-Confluence reach versus (a) the difference in cross-sectional velocity and (b) the difference in flow (discharge) between the free-flowing Clearwater River at rkm 12.6 and site LGR-1, averaged over the final two weeks of each detection period.

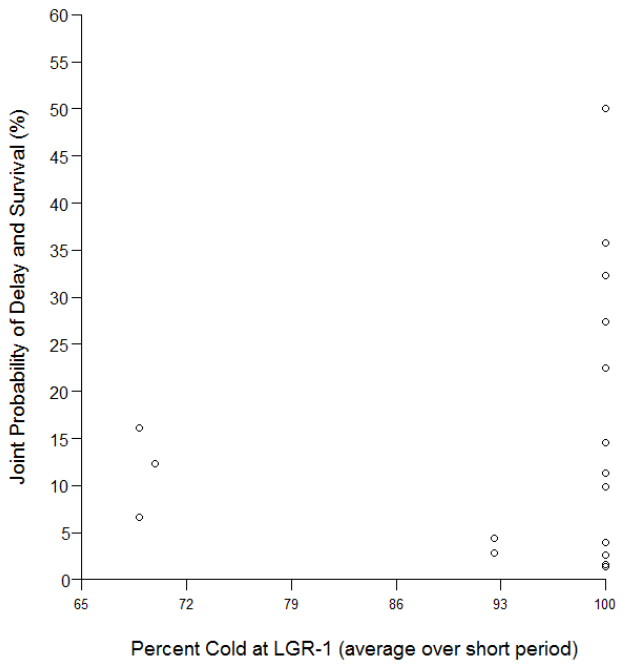

Figure 13.—Estimated joint probability of delay and survival (ψ) through the Transition Zone-Confluence reach versus the percent of the river channel that was colder than 20°C at site LGR-1, averaged over the final two weeks of each detection period.

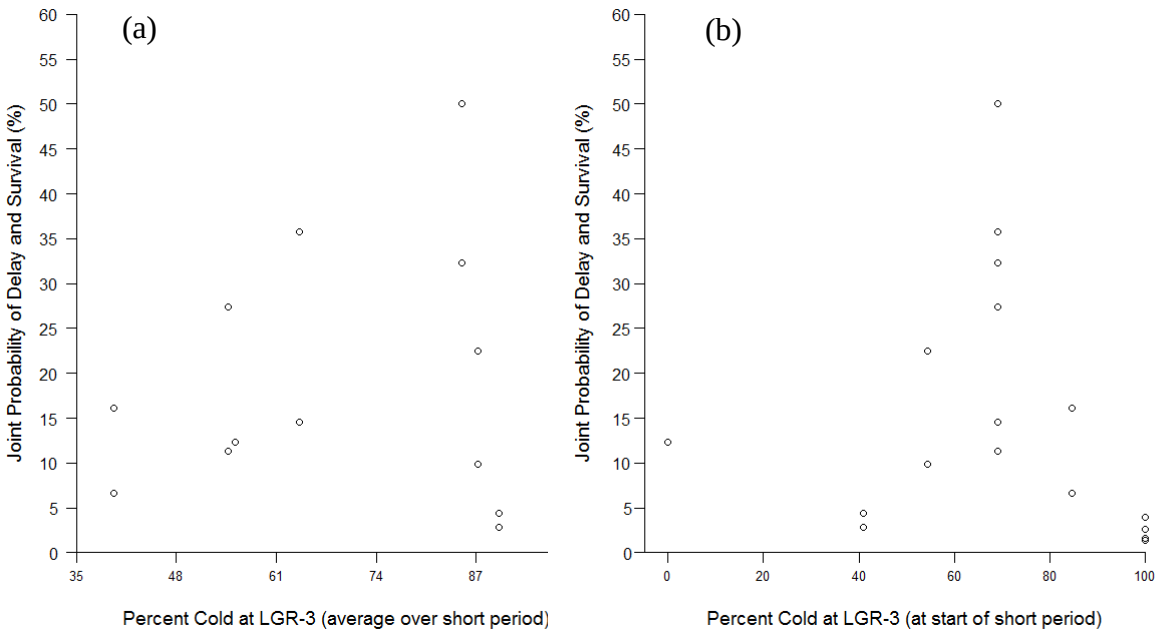

Figure 14.—Estimated joint probability of delay and survival (ψ) through the Transition Zone-Confluence reach versus the percent of the river channel that was colder than 20°C at site LGR-3, (a) averaged over the final two weeks of each detection period and (b) observed at the start of the final two weeks of each detection period.

Results from the single-variate effects analyses relating the probability of delay and survival (ψ) through the Transition Zone-Confluence showed significant (α=0.05) effects of detection period (P=0.0001), river regime (P=0.0026), difference in cross-sectional velocity (P=0.0039) between the free-flowing Clearwater River at rkm 12.6 and site LGR-1, and the percentage of the river channel that was colder than 20°C at LGR-3 during the final two weeks of the detection period (P=0.0228; Table 5). Because detection period does not aid in understanding how environmental factors influence migration delay, it was omitted from the multiple regression analyses.

With detection period omitted, the single covariate that explained the most variation in estimates of the delay and survival probability was river regime (P=0.0026, Table 5). River regime combines information on both water temperature and velocity, so two multiple regression models were explored, one that included river regime and one that excluded it in favor of direct measures of temperature and velocity.

With river regime accounted for, the only other covariate with a significant effect was tag type (P<0.0001). This model predicts consistently higher probabilities of delay and survival for acoustic-tagged fish than for radio-tagged fish for each level of river regime (Figure 15). The probability of delay and survival was predicted to be highest when the Clearwater River was cool, the Snake River was warm, and velocity was high through the confluence (Regime = 1; Figure 15). The probability of delay and survival was predicted to be lowest when water velocity in the confluence was low and the Snake River did not intrude into the Clearwater (Regime =3; Figure 15).

When river regime was omitted from the model, the final multiple regression model included effects of the difference in velocity between rkm 12.6 on the Clearwater and site LGR-1, tag type, and the percentage of the river channel that was colder than 20°C at LGR-1 (Table 7). This model also predicted that acoustic-tagged fish were more likely than radio-tagged fish to delay and survive within the Transition Zone-Confluence, but the difference between the two tag types was lower for smaller differences in velocity between rkm 12.6 on the Clearwater and LGR-1 (Figure 16) and when more of the river channel at LGR-1 was colder than 20°C (Figure 17). The probability of delay was predicted to increase as the difference in cross-sectional velocity between rkm 12.6 on the Clearwater and LGR-1 increased (Figure 16). However, as more of the river channel at LGR-1 grew warmer, the probability of delay in the Transition Zone-Confluence was predicted to decline (Figure 17).

Table 5.—Results of single-variate effects analysis for the joint probability of delay and survival (ψ) through the Transition Zone-Confluence reach. The response variable was $y = \ln\left(-\ln\left(\hat{\psi}\right)\right)$, based on a proportional hazards model. Group-based covariates were used. Covariates are ordered by P-value. "Short period" = final two weeks of detection period. "Long period" = entire detection period.

Covariate	P-value	R^2
Detection Period	<0.0001	0.7045
River Regime	0.0026	0.5721
Delta Velocity, averaged over short period	0.0039	0.4365
Percent Cold at LGR-3, averaged over short period	0.0228	0.3001
Percent Cold at LGR-3, at start of short period	0.1204	0.1531
Delta Flow, averaged over short period	0.4039	0.0469
Percent Cold at LGR-1, averaged over short period	0.5969	0.0191
Tag Type	0.6596	0.0133

Table 6.—Etimates of coefficients from the final linear model (including river regime) for the joint probability of delay and survival (ψ) in the Transition Zone-Confluence reach, with standard error, observed *t*-statistic, and P-value. The response variable was $y = \ln\left(-\ln\left(\hat{\psi}\right)\right)$, based on a proportional hazards model. Multiple R^2=0.8893.

Coefficient	Estimate	S.E.	*t*	P-value
Intercept	0.1205	0.1011	1.191	0.25485
River Regime = 2	0.5534	0.1469	3.767	0.0024
River Regime =3	1.1817	0.1199	9.856	<0.0001
Tag Type = Radio	0.6927	0.1135	6.104	<0.0001

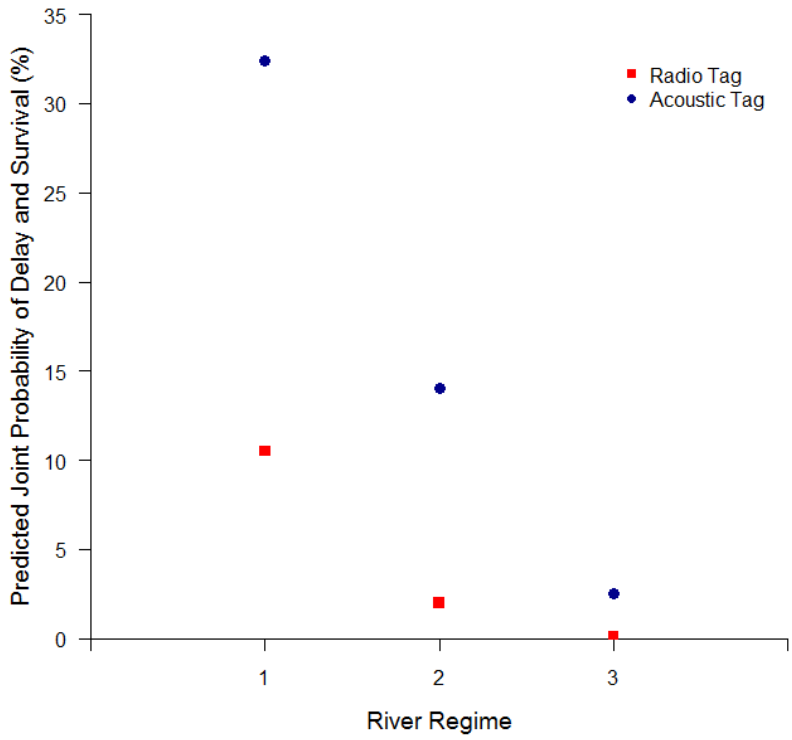

Figure 15.—Fitted joint probability of delay and survival through the Transition Zone-Confluence reach versus river regime. River Regime: 1 = 13 August – 13 September 2009, 2 = 14 September – 28 September 2009, 3 = 29 September – end of study. R^2=0.8839.

Table 7.—Estimates of coefficients from the final linear model (omitting river regime) for the joint probability of delay and survival in the Transition Zone-Confluence reach, with standard error, observed *t*-statistic, and P-value. The response variable was $y = \ln(-\ln(\hat{\psi}))$, based on a proportional hazards model. Multiple R^2=0.9004.

Coefficient	Estimate	S.E.	*t*	P-value
Intercept	1.6968	0.3837	4.422	0.0007
Delta Velocity, averaged over short period	-0.9697	0.0921	-10.525	<0.0001
Tag Type = Radio	0.5776	0.0999	5.780	<0.0001
Percent Cold at LGR-1, averaged over short period	0.0177	0.0039	4.577	0.0005

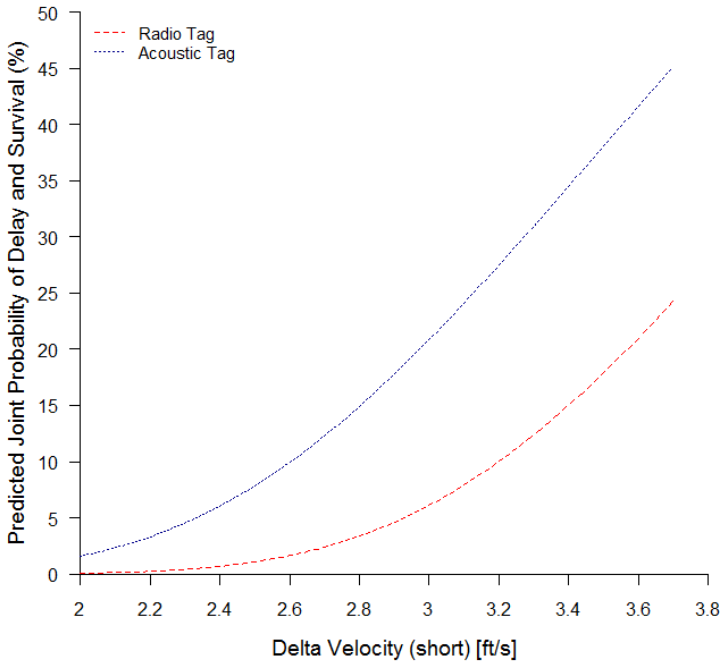

Figure 16.—Fitted joint probability of delay and survival through the Transition Zone-Confluence reach versus the difference in cross-sectional velocity at rkm 12.6 on the Clearwater and LGR-1 (averaged over the final two weeks of each detection period), computed at the average percentage of the river channel at LGR-1 that was colder than 20°C (93.7%). R^2=0.9004.

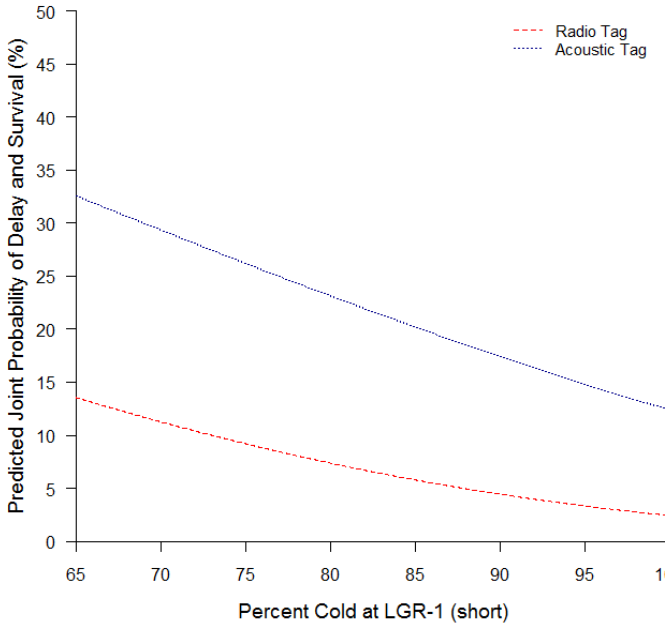

Figure 17.—Fitted joint probability of delay and survival through the Transition Zone-Confluence reach versus the percentage of the river channel at LGR-1 that was colder than 20°C (averaged over the final two weeks of each detection period), computed at the average difference in cross-sectional velocity between rkm 12.6 on the Clearwater and LGR-1 (2.8 ft/s). R^2=0.9004.

Travel Time Effects Analysis

Travel time through the Transition Zone-Confluence reach varied from 2 hours to 54 days for radio-tagged fish, and from 6 hours to 74 days for acoustic-tagged fish (Figure 18). Although there was considerable overlap in the travel time distributions for acoustic-tagged fish and radio-tagged fish, radio-tagged fish tended to spend less time in this reach than acoustic-tagged fish (Figure 18). This is despite the fact that, because of differences in the locations of the acoustic hydrophones and radio antennae, the Transition Zone-Confluence reach was shorter (8.3 km) for acoustic-tagged fish than for radio-tagged fish (9.9 km). Radio-tagged fish appeared to have a higher migration rate in this rate than acoustic-tagged fish (Figure 19(a)).

Fish that arrived at the upper boundary of the Transition Zone during river regime 3 (29 September – 30 October 2009) tended to move through the reach faster than those that arrived during river regime 2 (14-28 September 2009), suggesting that the intrusion of warm Snake River water into the cooler Clearwater River may slow fish migration through the Transition Zone-Confluence (Figure 19(b)). There was little apparent variation in migration rate with arrival day (Figure 20), fish length or weight at tagging (Figure 21), the difference in either cross-sectional velocity (Figure 22(a)) or discharge (Figure 22(b)) between rkm 12.6 on the Clearwater and LGR-1 at the time of arrival at the upper boundary of the Transition Zone, or the proportion of the river channel that was colder than 20°C at either site LGR-1 on the Clearwater River (Figure 23(a)) or site LGR-3 on the Snake River (Figure 23(b)).

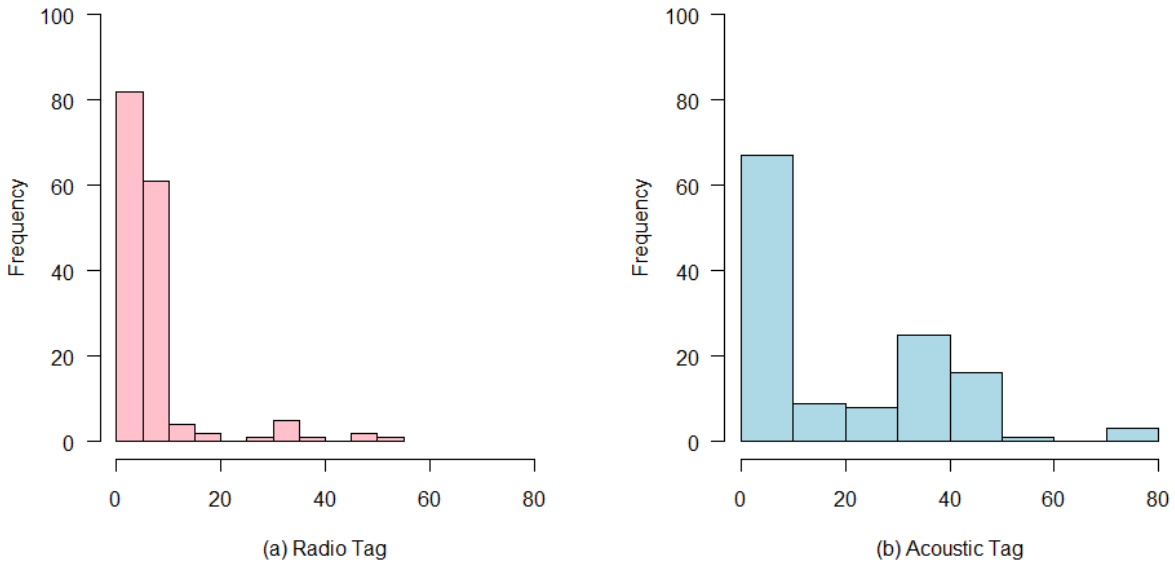

Figure 18.—Observed travel time through the Transition Zone-Confluence reach for (a) radio-tagged fish and (b) acoustic-tagged fish.

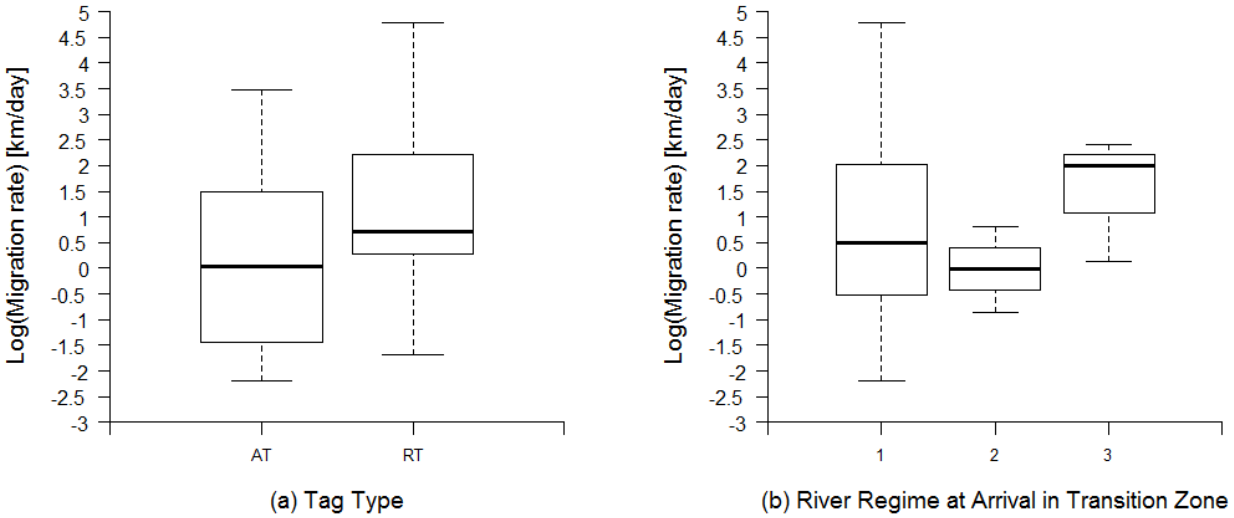

Figure 19.—Observed migration rate through the Transition Zone-Confluence reach (on the log scale) versus (a) tag type and (b) river regime at the time of arrival at the upstream boundary of the Transition Zone. Tag type: "AT" = acoustic tag, "RT" = radio tag. River regime: 1 = 13 August – 13 September 2009, 2 = 14 September – 28 September 2009, 3 = 29 September – end of study. Thick bar = median, box = interquartile range, whiskers = range.

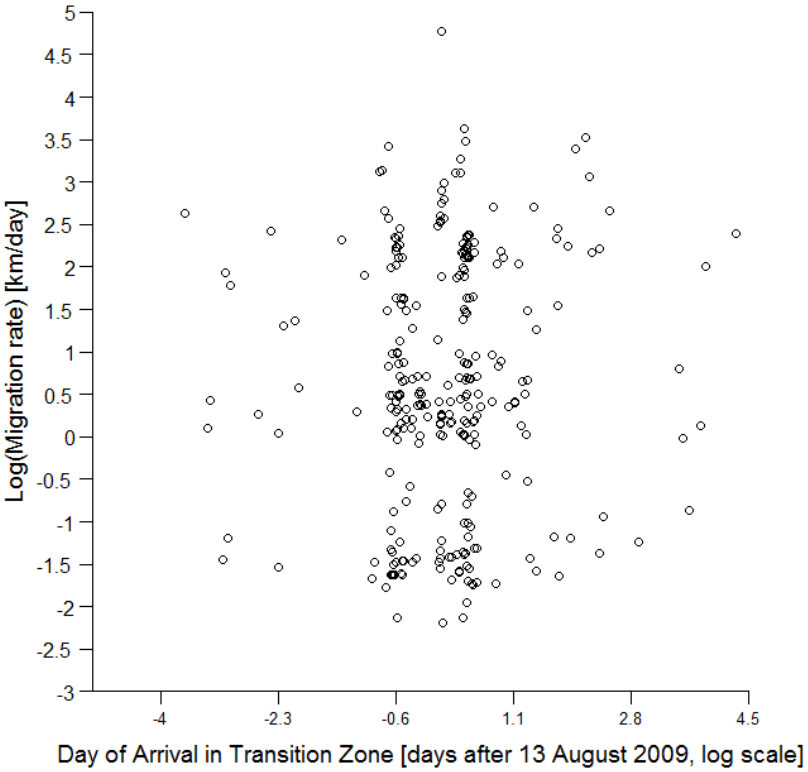

Figure 20.—Observed migration rate through the Transition Zone-Confluence reach (on the log scale) versus the number of days after 13 August 2009 before arrival at the upper boundary of the Transition Zone (on the log scale).

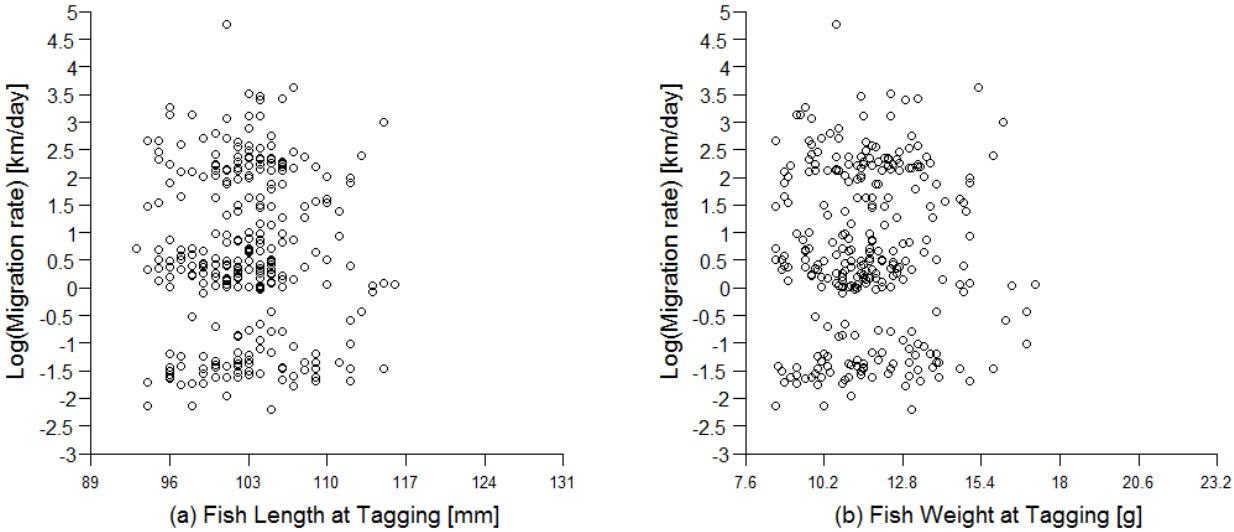

Figure 21.—Observed migration rate through the Transition Zone-Confluence reach (on the log scale) versus (a) fish length at tagging, and (b) fish weight at tagging.

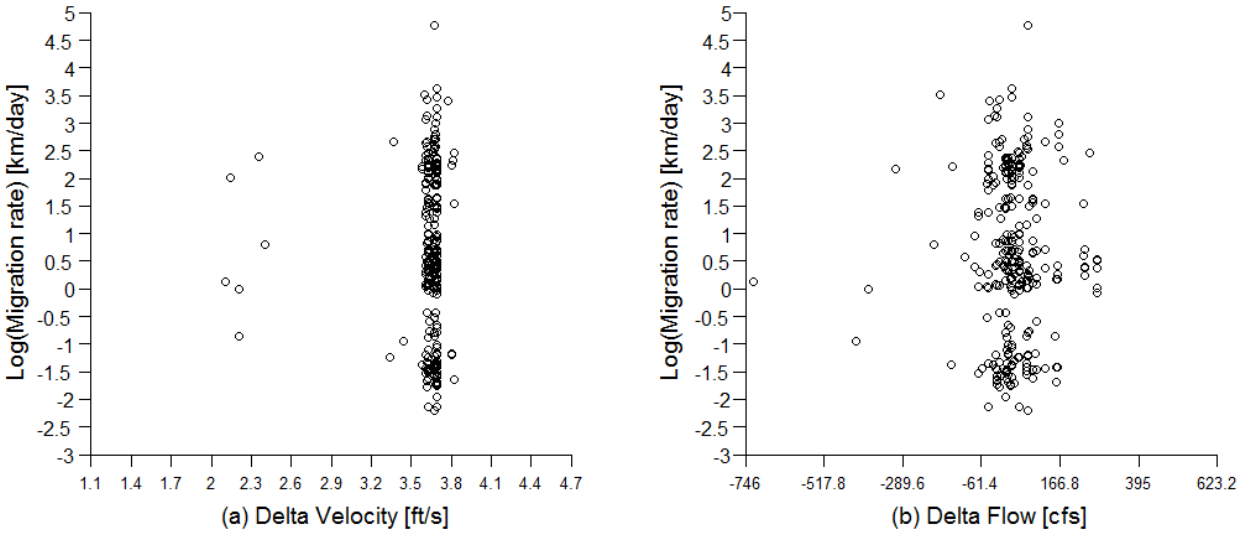

Figure 22.—Observed migration rate through the Transition Zone-Confluence reach (on the log scale) versus (a) the difference in cross-sectional velocity, and (b) the difference in flow (discharge), between the free-flowing Clearwater River at rkm 12.6 and LGR-1 at the time of arrival at the upper boundary of the Transition Zone.

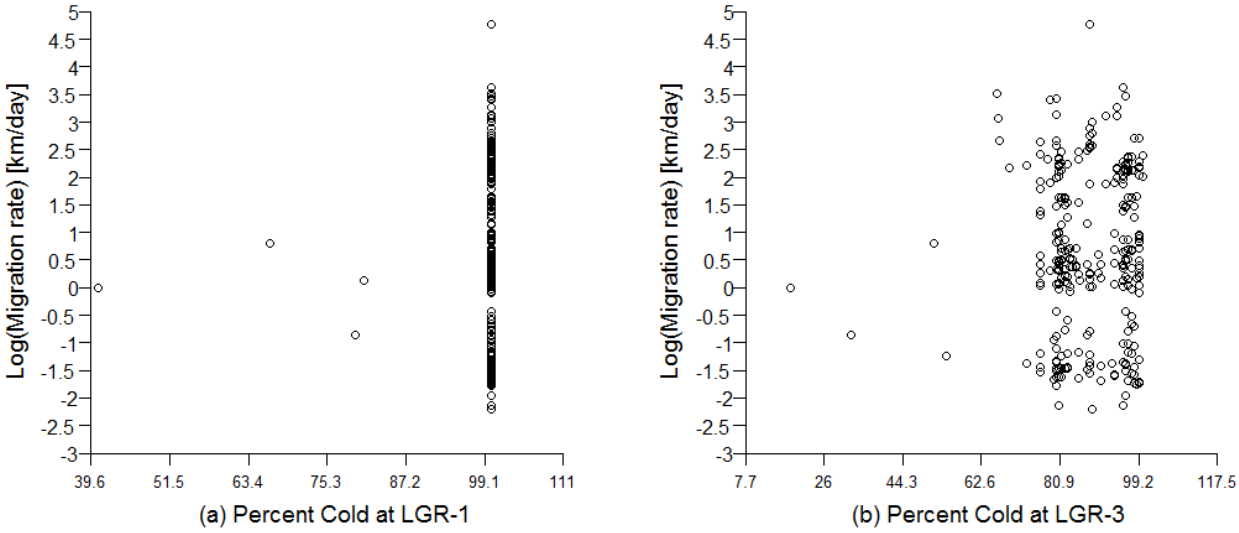

Figure 23.—Observed migration rate through the Transition Zone-Confluence reach (on the log scale) versus the proportion of the river channel that was colder than 20°C at (a) LGR-1 and (b) LGR-3 at the time of arrival at the upper boundary of the Transition Zone.

Single-variate regressions were performed relating migration rate through the Transition Zone-Confluence to tag type, river regime, arrival day, fish length at tagging, the difference in both cross-sectional velocity and discharge between rkm 12.6 on the Clearwater and LGR-1 at the time of arrival at the Transition Zone, and the percentage of the river channel that was colder than 20°C at LGR-3 at the time of arrival at the Transition Zone. Fish weight was omitted because fish length and fish weight were highly correlated (r=0.90). The percentage of the river channel that was colder than 20°C at LGR-1 at the time of arrival at the Transition Zone was also omitted because it varied very little among the individual fish (Figure 23(a)).

Results from the single-variate effects analyses for migration rate through the Transition Zone-Confluence reach found a significant effect (α=0.05) only of tag type ($P<0.0001$) (Table 8). No other covariate had a significant effect ($P\geq0.3989$; Table 8). With the effect of tag type accounted for, no covariate had a significant effect on migration rate (α=0.05). Thus, the final model included only the effect of tag type, with R^2=0.1162 (Table 9), and reflected the observation that radio-tagged fish had a higher migration rate (lower travel time) than acoustic-tagged fish through this reach.

Table 8.—Results of single-variate effects analysis for migration rate (*V*) through the Transition Zone-Confluence reach. The response variable was $y = \ln(V)$. Individual-based covariates were used. Covariates are ordered by P-value.

Covariate	P-value	R^2
Tag Type	<0.0001	0.1162
Arrival Day	0.3989	0.0025
River Regime	0.4380	0.0058
Percent Cold at LGR-3 at arrival in Transition Zone	0.6660	0.0007
Delta Flow at arrival in Transition Zone	0.8004	0.0640
Fish Length	0.8857	0.0207
Delta Velocity at arrival in Transition Zone	0.9730	<0.0001

Table 9.—Estimates of coefficients from the final linear model for migration rate (*V*) through the Transition Zone-Confluence reach, with standard error, observed *t*-statistic, and P-value. The response variable was $y = \ln(V)$. Multiple R^2=0.1162.

Coefficient	Estimate	S.E.	*t*	P-value
Intercept	0.0699	0.1225	0.571	0.569
Tag Type = Radio	1.0107	0.1648	6.132	<0.0001

Conclusions

The joint probability of migrating and surviving through the Transition Zone-Confluence tended to decrease as the difference in cross-sectional velocity between the free-flowing Clearwater River and the Confluence area increased. In contrast, the probability of delaying in the Transition Zone-Confluence tended to increase as the difference in cross-sectional velocity increased, suggesting that subyearling fall Chinook salmon smolts may delay migration when they encounter large changes in water velocity. Smolts were also seen to be more likely to delay migration within the Transition Zone-Confluence when the water was cold near the Confluence of the Clearwater and Snake rivers. Radio-tagged fish were observed to be more likely to migrate and less likely to delay within the Transition Zone-Confluence than acoustic-tagged fish. Among those smolts that moved through the Transition Zone-Confluence reach, radio-tagged smolts tended to move faster than acoustic-tagged smolts.

References

Tiffan, K.F., Connor, W.P., Bellgraph, B.J., and Buchanan, R.A. 2010. Snake River Fall Chinook Salmon Life History Investigations. 2009 Annual Report to the Bonneville Power Administration, Project #200203200, Portland, Oregon.