IDENTIFICATION AND CHARACTERIZATION OF JUVENILE SPRING CHINOOK SALMON OVERWINTER REARING HABITAT IN UPPER GRANDE RONDE VALLEY

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ABSTRACT

This study was designed to document and describe overwinter rearing reaches of Catherine Creek early migrant spring Chinook salmon in the Grande Ronde Valley. Early migrants occupied a reach of Catherine Creek residing between Union, OR and the mouth of Mill Creek for overwinter rearing from October 2009 through March 2010. Median weekly linear range was high during fall migration however, decreased toward zero (i.e., no movement) during winter. A considerable increase in movement occurred during mid-January and coincided with elevated water temperatures. A gradient shift occurs within this reach near the mouth of Pyles Creek, where Catherine Creek transitions from complex habitat comprised of riffles and pools to homogenized deep run habitat. Juvenile spring Chinook salmon preferred deep water and slow currents near cover and the bank throughout their distribution; however, coarse substrates were optimal within the high gradient reach; silt was most suitable in the low gradient reach. Survival of radio-tagged juvenile Chinook appeared relatively high through winter.

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Introduction

Successful recovery strategies for Chinook salmon *Oncorhynchus tshawytscha* listed under the Endangered Species Act (ESA) require knowledge of factors limiting seasonal carrying capacity of their stream habitats (Van Dyke et al. 2009). Given the large geographic extent of their life history, critical habitat for anadromous Chinook salmon varies on a temporal and spatial scale. For Chinook salmon populations exhibiting a 'stream-type' life history, whereby juveniles remain in freshwater for one year prior to seaward migration (Wydoski and Whitney 2003), the quality and quantity of rearing habitat within natal subbasins governs the quantity and size of fish produced (Bjornn and Reiser 1991).

Catherine Creek, a tributary of the Grande Ronde River, supports a depressed population of ESA-listed Snake River spring/summer Chinook salmon. Available habitat varies widely from headwater tributaries in the Wallowa Mountains to the mouth. Most Chinook salmon spawning occurs from Union, OR to the confluence of North Fork Catherine and Middle Fork Catherine creeks (Figure 1). Icing conditions are present within the tributaries and main stem of Catherine Creek from November to April (Van Dyke et al. 2009).

The carrying capacity and survival of anadromous fish have been reduced within the Grande Ronde River Subbasin by land management activities which have contributed to riparian and instream habitat degradation (Nowak et al. 2004). Stream conditions in Catherine Creek, below the city of Union, consist of highly modified meandering and channeled sections of stream flowing through agricultural land. Following construction of the Grande Ronde Ditch for flood-control in the late 1800's, Catherine Creek flowed through the historic Grande Ronde River channel and currently meets the Grande Ronde Ditch near Alicel, OR (Nowak et al. 2004, Figure 1).

Catherine Creek is on the 303(d) Stream List based on concerns of high temperatures, habitat and flow modifications, and low dissolved oxygen (Nowak et al 2004). Riparian vegetation is sparse and provides little shade or instream cover in lower Catherine Creek. The river is heavily silted due to extensive erosion associated with agricultural, forest management practices and mining activities (Yanke et al. 2008). This reach of Catherine Creek is currently listed as an Oregon Water Resources Department (OWRD) flow restoration priority, as irrigation withdrawals in the Grande Ronde Valley generally reduce Catherine Creek flows by 90-95% until November 1 (end of irrigation season).

Winter rearing habitat quantity and quality in Grande Ronde River Valley may be important factors limiting spring Chinook salmon smolt production for Catherine Creek. Anthropogenic alterations to lower Catherine Creek (e.g., isolated oxbows, irrigation diversions, artificial levees) may degrade the ability of spring Chinook salmon to successfully emigrate into the Grande Ronde River. Naturally-produced spring Chinook salmon exhibit two migrational life history strategies corresponding to different river reach selection during freshwater rearing (Jonasson et al. 1997). Early migrants redistribute downstream from upper rearing areas to overwinter in the Grande Ronde Valley between Union and Elgin, OR (Figure 1), whereas late migrants overwinter in upper rearing areas before both groups migrate seaward in the spring. On average, approximately 80% of Catherine Creek Chinook salmon juveniles select the early migrant life history and overwinter in the Grande Ronde Valley downstream of Union, OR (Yanke et al. 2008).

Early migrant survival to Lower Granite Dam (fish overwintering in the Grande Ronde Valley) is typically lower for the Catherine Creek population than other Chinook salmon populations in the Grande Ronde Subbasin. From migration years (MY) 2004-08, early migrant survival to Lower Granite Dam (LGD), for Catherine Creek, averaged 0.13±0.06 (SD), compared to an aggregate mean of 0.24±0.05 for other Grande Ronde River populations (Yanke et al. 2008). Previous research estimated that travel times through the Grande Ronde Valley reach were considerably greater than any other reach, and accounted for 42% of the mortality incurred in freshwater for naturally-produced Chinook salmon (Monzyk et al. 2009).

A recent Biological Opinion by the National Marine Fisheries Service calls for efforts to increase survival for these threatened populations in areas outside the hydrosystem (NMFS 2008). It has been identified that a better understanding of the survival and migration dynamics of smolts on a reach specific scale will provide greater focus for fisheries managers to apply limited resources to improve survival of these populations (Monzyk et al. 2009). The reaches meandering through the Grande Ronde Valley were identified as the highest priority for restoration for Catherine Creek spring Chinook salmon (Nowak et. al 2004); however, little is known regarding the timing, location, and source of mortality for this depressed population. This research was designed to identify and describe spring Chinook salmon overwinter rearing reaches within the Grande Ronde Valley.

Methods

Site Description

This study was conducted within Grande Ronde Valley located in upper Grande Ronde Basin of the Blue Mountains Province in northeast Oregon (Figure 1). Catherine Creek, a highly regulated and known spring Chinook salmon spawning tributary of the Grande Ronde River, was chosen for this study due to juvenile spring Chinook salmon emigrants having comparatively low survival rates to the Snake and Columbia river hydrosystem. Catherine Creek is a seventh-order river where it converges with the Grande Ronde River, at the downstream section of the Grande Ronde Ditch, and drains approximately 1,045 km^2. Catherine Creek, which is approximately 109.3 km long, originates in the southern slopes of the Eagle Cap Mountains at a maximum headwater elevation of 2679 m and converges with the Grand Ronde River at an elevation of 816 m. Catherine Creek has a diverse flow and habitat regime being comprised of an upstream high gradient reach and downstream low gradient reach; the gradient transition occurs in close proximity to the mouth of Pyles Creek. The high gradient watershed that encompasses Catherine Creek is composed of mixed-coniferous forest, while lower Catherine Creek is primarily dedicated to agriculture sustained by irrigation. Catherine Creek is partially impounded by three irrigation dams (i.e., upper and lower Davis dams and Elmer Dam) from late-summer to mid-winter.

Radiotelemetry and PIT Tagging

Ninety-eight wild Catherine Creek juvenile spring Chinook salmon early migrants were implanted with Lotek Wireless radio transmitters (Model NTQ-1) with a 12 h/d duty cycle from 20 October 2009 to 1 December 2009 (Table 1). In addition, a 134.2 kHz 12 mm passive integrated transponder (PIT) tag (Destron Fearing; Model TX1411SST) was implanted into the periodontal cavity of 826 wild early migrants from 14 September 2009 to 30 November 2009. Tagged fish were captured using a 5 ft rotary screw trap (Figure 2).

Fish were randomly selected for PIT tagging per 24 h sample. Initially, fish were placed into a 6.0 L container and anesthetized in an aerated solution containing 50 mg/L of tricaine methanesulfonate (MS-222). Random fish were selected and PIT-tags were inserted intraperitoneally, using a modified hypodermic syringe, posterior of the longest ray of the pectoral fin and offset left of the ventral midline (Prentice et al. 1986, 1990; Matthews et al. 1990, 1992). Syringes and PIT-tags were disinfected for 10 min in 70% isopropyl alcohol and allowed to dry prior to use. Length (FL, mm), weight (0.1 g) and unique tag code was recorded for each fish processed. Tagged fish were then transferred to a covered recovery tank containing aerated freshwater until recovered. Recovered fish were immediately released downstream of the screw trap into habitat exhibiting reduced flow.

Fish weighing greater than or equal to 8.5 g were selected for coded radio tag implantation to ensure the transmitter to fish weight ratio remained ≤3.0%; well below the tag burden of 6.7%, which is the level Brown et al. (2010) documented juvenile hatchery Chinook salmon begin to experience negative effects on survival (Figure 2). Radio transmitters utilized had an 18 mm trailing antenna and a mean weight of 0.27 g (SD 0.004); mean tag burden for implanted transmitters was 2.9% (SD 0.002). Implanted radio transmitters operated between 164.0 and 168.0 MHz and transmitted a signal at a varied burst rate of 6 pluses per minute. This radio tag operating configuration yielded a typical battery life of 41 days and a guaranteed battery life of approximately 33 days. All coded radio tags were divided among three frequencies to minimize receiver scan time while reducing the probability for tag collision.

Radio tag implantation occurred at the sampling location following the conclusion of a 24 h sampling period. Following removal from the screw trap live box, fish were placed into an aerated 19 L covered container. Immediately prior to surgery, fish were placed into a 6 L container containing 70 mg tricaine methanesulfonate (MS 222)/L buffered with sodium bicarbonate. Following anesthetized fish exhibiting loss of equilibrium and reduced opercular rate (i.e., stage 4 anesthesia; Summerfelt and Smith 1990) (mean 5.9 minutes, SD 1.4), a fine foam pad coated with synthetic mucus restoring agent (PolyAqua; Kordon LLC, Hayward, CA) was used to stabilize the fish ventral side up. A plastic tube was used to continuously administer diluted anesthetic (MS 222, 35 mg/L) through the mouth and over the gills to initiate partial recovery and prevent contamination of the incision during surgery. Following surgery, implanted fish were transferred to a covered 19 L aerated freshwater container until equilibrium and opercular rate had restored (mean 6.9 minutes, SD 2.8). Upon complete recovery, fish were immediately returned to a portion of Catherine Creek, near the capture location, which exhibited reduced flow (Moore et al. 1990). Measurements collected for all PIT tagged fish were also collect for radio-tagged fish.

Surgical protocol used was similar to that of Adams et al. (1998). A 5 mm incision was made anterior to the pelvic gridle and offset 2 mm left of and parallel to the ventral midline. The incision was initiated with a 16-gauge needle to a depth adequate enough to merely penetrate the peritoneum (Summerfelt and Smith 1990) and finished with suture scissors to prevent internal injury. A trailing antenna outlet was created in the body wall using the shielded-needle technique (Ross and Kleiner 1982; Adams et al. 1998). Following placement of the antenna through the body wall, a sterilized radio tag coated with oxytetracycline (200 mg/mL) was inserted into the body cavity to minimize infection and positioned directly underneath the incision. Following transmitter implantation, sterile, synthetic absorbable, monofilament surgical suture (Maxon 5–0) with a 17 mm 1/2 circle, reverse cutting needle was used to close the incision with three interrupted sutures (Wagner and Cooke 2005). To reduce infection, completed sutures were coated with antibacterial ophthalmic ointment (Vetropolycin). Mean total surgery time for all radio-tagged juvenile Chinook was 5.7 minutes (SD 1.7).

Stationary radio receivers (Lotek SRX-400 W7AS) were positioned throughout the Grande Ronde Valley to assist mobile tracking efforts (Figure 3). Four receivers were installed on lower Catherine Creek, while one receiver was installed on the Grande Ronde River downstream of the mouth of Catherine Creek. Specifically, stationary receivers were installed near lower Davis Dam, Gekeler Lane, Booth Lane, Alicel Lane and Rhinehart Lane. Stationary receivers were powered by a single 12-V battery that was replaced biweekly during site visits to download detection data.

Effort was made to obtain a weekly relocation, from 21 October 2009 to 22 March 2010, for each radio-tagged fish following a 5-day recovery period (Martinelli et al. 1998). Typically, the portion of Catherine Creek between the screw trap and Gekeler Lane was tracked weekly; however, tracking extended to the mouth of Catherine Creek at least once monthly to ensure that possible radio-tagged emigrants occupying these areas were relocated. In addition, on 22 December 2009, aerial tracking was conducted of Catherine Creek tributaries Mill and Little Creek and the Grande Ronde River from Elgin, OR to the upstream margin of the Grande Ronde Ditch in an effort to relocate stray emigrants. Lower reaches of Pyles Creek and Little Creek were tracked weekly. Periodically, the lower reaches of Ladd Creek and Mill Creek were radio-tracked in attempt to relocate missing fish.

Mobile tracking was typically accomplished by foot or boat using a Lotek SRX-400 W5XG receiver and a three-element Yagi antenna (Lotek). Upon receiving a signal from a radio-tagged fish, geographic coordinates were obtained using a hand-held global positioning system unit (Garmin GPS II Plus) for all relocations. During free flowing periods (i.e., minimal surface ice), 30 codes were randomly selected weekly and identified as fish to determine an exact location for using triangulation techniques. For all triangulated fish, microhabitat use data was collected; however, considerable surface ice (~ 0.5 m thick) during mid to late-December hindered weekly tracking efforts and prohibited the collection of microhabitat use data. Microhabitat variables measured included water temperature (C°), dissolved oxygen (mg/L), depth (m), bottom velocity (m/s), mean column velocity (m/s), dominant substrate, subdominant substrate, cover type, distance to cover (m) and distance to bank (m).

Significant effort (1,130 person hours, 14 hours/day) was required to accomplish the necessary field work needed to address our research objectives. A total of 81 tracking sessions were completed resulting in 1,053 relocations and 854.8 river km were tracked. An average of 0.81 river km was tracked to obtain a single radio-tagged fish relocation.

Microhabitat Use and Availability

Microhabitat use data were collected at each exact location occupied by a relocated radio-tagged juvenile Chinook salmon (Table 2). Microhabitat availability data were collected using line-transect survey techniques. Both the high and low gradient reaches of Catherine Creek used by radio-tagged early migrants were divided into lower, middle and upper sections (Table 2; Figure 4).

Microhabitat availability data was obtained, within these sections, from reaches occupied by tagged fish during flow conditions synonymous to those associated with microhabitat use (Figure 4). Microhabitat variables measured at each transect point included depth (m), bottom velocity (m/s), mean column velocity (m/s), dominant substrate, subdominant substrate, cover type, distance to cover (m) and distance to bank (m). Morphological stream characteristics obtained during habitat availability surveys included bank angle (°), undercut bank distance (m), and 30-m riparian land use (%). Microhabitat availability data and morphological stream characteristics for Catherine Creek were collected during late-January and early-February 2010 (Table 3). Evenly spaced transects positioned two mean stream widths (2MSWs) apart were divided into evenly-spaced points from which microhabitat variables were measured (Simonson et al. 1994). A total of 57 transects were surveyed yielding 698 survey points, resulting in approximately 12 points per transect. A total of 1.3 km of the 29.9 km (~ 4.3%) regularly radio-tracked was included in these microhabitat availability surveys (Table 4).

For microhabitat use and availability, a top-set wading rod was used to measure depth to the nearest centimeter. A Marsh-McBirney flow meter (Model 2000) was used to measure bottom and mean current velocity (m/s). Mean current velocity was measured in the water column at a depth 60% from the surface in water depths of 0.75 m or less. For depths greater than 0.75 m, current velocity was measured at depths 20% and 80% from the surface, which were averaged to produce mean column velocity (McMahon et al. 1996). Dominant and subdominant substrates were visually determined using a modified Wentworth particle size classification (Bovee 1986; Table 5). Nearest dominant cover type was visually determined by establishing the presence or absence of cover and then determining the distance to the fish location. Cover types used were no cover, coarse woody debris, fine woody debris, root wad, emersed aquatic vegetation, submersed aquatic vegetation, terrestrial vegetation, undercut bank, and boulder (Table 6). Cover types were considered associated with fish occurrence when the cover was 2 m or less from the fish location.

In addition to collecting an instantaneous temperature measurement at each fish location, continuous hourly water temperature data were collected using HOBO Pendant Temperature Loggers (Onset Computer Corporation) from mid-July 2009 to early-May 2010 at strategic locations along Catherine Creek (Figure 5). Flow in cubic feet per second (cfs), for Catherine Creek, was acquired from the Oregon Department of Water Resources gauging station 13320000 (available online at http://apps2.wrd.state.or.us/apps/sw/hydro_near_real_time/display_hydro_graph.aspx?station_nbr=13320000) and converted to m^3/s.

Night-time Snorkeling

Larger juvenile Chinook salmon have been documented to use significantly different habitats compared to smaller individuals of the same cohort (Everest and Chapman 1972; Holecek et al. 2009). Since we were restricted by tag burden to only radio-tagging the upper echelon of sampled early migrants, we conducted post-surgery night-time snorkeling to recapture radio-tagged and PIT tagged individuals to conduct size and growth comparisons. A three-man crew would initially relocate a radio-tagged fish and determine specific location using triangulation techniques. Subsequent sampling of that location would be conducted by one snorkeler, outfitted with a dive light, slowly moving downstream and attempting to guide all observed juvenile Chinook salmon into a downstream seine operated by a two-person crew. All recaptured tagged fish and a subsample of co-occupants were measured to obtain FL (mm) and weight (g). This technique was conducted at upper, middle and lower reaches of the identified overwintering area to avoid introducing spatial bias; however, excessive depth and limited visibility prohibited effective snorkeling of the lower reach. Night-time snorkeling was conducted on 9 November, 20 November, 12 January and 26 January. Extensive icing conditions precluded night-time snorkeling during December and prohibitive high water events were present during February and March.

Statistical Analysis

Growth.—Growth of recaptured radio-tagged and PIT tagged fish were compared using the Mann-Whitney rank sum test to ascertain if growth of radio-tagged fish significantly differed from that of PIT tagged fish, which are reported to sustain positive growth following PIT tagging (Prentice et al. 1990). To ascertain if overwintering reaches occupied by radio-tagged fish represented that of the entire early emigrant size distribution, size at tagging for recaptured seined PIT tagged fish occupying the same habitat as relocated radio-tagged fish was compared to size at tagging for all temporally similar PIT tagged fish. The Mann-Whitney rank sum test was employed to compare size of emigrants during redistribution to that of recaptured co-occupants during overwinter rearing.

Spatial Analysis.—Median linear range was calculated for all radio-tagged early migrant spring Chinook salmon. Linear ranges were estimated using similar techniques as those described by (Vokoun 2003). Relocation coordinates were imported into ArcView 9.3. A National Hydrology Dataset flow line data layer, obtained from the United States Geological Survey (available online at http://nhdgeo.usgs. gov/viewer.htm), was then used to delineate the Catherine Creek thalweg. Shareware arcscripts Add Points Evenly Along a Line (Lead 2002) and Nearest Neighbor 3.1 (Weigel 2002) were subsequently used to manipulate data layers and estimate overwinter weekly linear range. Fall and winter relocations were compared using the Kolmogorov-Smirnov two-sample test (K-S test). To determine if size of radio-tagged fish influenced migration distance or reach occupancy, simple linear regression was used to compare weight to total linear range for all radio-tagged fish.

Microhabitat.—Microhabitat use and availability data were spatially (i.e., high and low gradient) and temporally (i.e., fall and winter) stratified. High and low gradient microhabitat use data were compared to analogous microhabitat availability data. In addition, high gradient microhabitat use data were compared to low gradient use data. A spatial (i.e., seasonal) difference in microhabitat use was examined by comparing (K-S test) high and low gradient microhabitat use. A K-S test was used to compare microhabitat use to available microhabitat to assess for non-random microhabitat use for all continuous variables (i.e., depth, bottom velocity, mean column velocity, dominant substrate, distance to cover and distance to bank). Substrate was included as a continuous variable due to the continuity of substrate particle size spectrum. An analogous likelihood-ratio chi-square test was performed on the categorical variable cover to test for nonrandom microhabitat use.

Microhabitat suitability was estimated by comparing microhabitat use and availability data. Suitability was calculated by dividing microhabitat use (%) by microhabitat available (%) for each variable. Microhabitat suitability ranges from 0 to 1, with 0 indicating least suitable microhabitat and 1 representing preferred or optimal microhabitat (Waters 1976; Bovee 1986). In an attempt to increase transferability of suitability indexes, influence of uncommon available microhabitat data were eliminated from suitability analyses by omitting rare available microhabitat producing Category III criteria (Bovee 1986). The purpose of this data manipulation was to enhance suitability index transferability to overwinter rearing reaches that may differ from those of Catherine Creek.

Principal component analysis (PCA) was conducted on all continuous microhabitat variables (depth, bottom velocity, mean column velocity, dominant substrate, distance to cover, and distance to bank) to determine selected fall and winter macrohabitat. PCA allows the collective interaction among multiple microhabitat variables to be investigated and ranked by importance by creating sequential uncorrelated linear combinations (i.e., principle components) that maximize variation explanation. Components with eigenvalues greater than 1.0 were retained as recommended by Kaiser (1960), Stevens (1996), and Kwak and Peterson (2007). Habitat availability scoring coefficients were subsequently used to calculate microhabitat use principle component scores. A K-S test was conducted on retained principal component scores to investigate for statistically significantly differences between microhabitat use and availability for both fall and winter.

Results and Discussion

PIT-tags were inserted into 826 Catherine Creek juvenile spring Chinook salmon early migrants between 14 September and 30 November 2009. Water temperatures during tagging ranged from 0.5 °C on 29 November to 15 °C on 26 September. PIT tagged fish had a mean length of 78.4 mm (SD, min–max; 7.9, 56–100) and mean weight of 5.5 g (SD, min–max; 1.6, 2.0–11.0). Radio tags were implanted into 98 juvenile spring Chinook salmon early migrants between 20 October and 1 December 2009. Water temperatures during tagging ranged from 8.0 °C on 22 October to 0.5 °C on 29 November 2009. Radio-tagged fish had a mean length (FL) of 94.6 mm (SD, min–max; 2.8, 89–105) and mean weight of 9.4 g (SD, min–max; 0.9, 8.1–13.3). An essential assumption associated with the integrity of tagging studies is that the employed technique results in unaltered or has a negligible affect on growth, mortality and behavior (Guy et al. 1996). Prentice et al. (1990) reported that 55–120 mm (FL) PIT tagged juvenile Chinook salmon experience negative growth during a 20 d period post-tagging; however, compensatory growth is present following this recovery period. As a general rule of thumb, Winter (1996) recommends that radio transmitters should not weigh more than 2% of body mass out of water; however, this is often difficult to achieve for small fish (e.g., juvenile life stage). Recent research advocates development and implementation of a more scientific based index to assist researchers in selecting the appropriate tag to address established objectives (Brown et al. 1999). Brown et al. (2010) found that acoustic transmitters negatively affected juvenile Chinook salmon (FL, 90–110 mm) when tag burdens exceeded 6.7%. Research by Adams et al. (1998) found that surgically implanted radio transmitters (2.2–5.6% tag burden) did not cause significant long-term decreased swimming performance for juvenile Chinook salmon >120 mm (FL); however, those <120 mm (FL), exposed to a tag burden ≥4.6%, exhibited significantly inhibited swimming performance. Considerable effort was made to conform to the 2% recommendation by Winter (1996), while attempting to tag as representative a size proportion of the early migrant population as possible. During our study, radio tag implanted juvenile Chinook salmon experienced an average tag burden of 2.9% (SD, min–max; 0.002, 2.0–3.3%).

Twelve (12 %) radio-tagged fish were confirmed mortalities or cases of tag expulsion owing to recovered radio tags; four of the recovered tags were reinserted. One recovered tag was triangulated to and recovered from within avian scat, while two tags were recovered from mink dens. Several other recovered tags were triangulated to and recovered from the bank however, could not be associated with a specific source of mortality. Two mortalities were triangulated to an irrigation ditch located immediately upstream of the Swackhammer Fish Ladder. Three (3%) radio-tagged fish were never relocated. Data collected for confirmed mortalities or shed tags were excluded from all analyses.

Of the remaining 83 fish regularly relocated, all fish remained within the Catherine Creek drainage throughout the study. Six (7 %) fish were relocated within tributaries of Catherine Creek; 3 were relocated within Pyles Creek and 3 were relocated within Little Creek. Fish relocated to Pyles Creek were restricted to occupying only the lower 75 m due to a migration barrier (i.e., culvert).

During fall (22 September–20 December), 5 (6 %) fish were relocated below lower Davis Dam, while the majority (92 %) remained upstream of lower Davis Dam (Figure 6). One (1 %) consistently relocated fish was tagged after 20 December and thus did not contribute to the fall sample. During winter (21 December–19 March), 6 (7%) of the remaining 83 fish were not relocated likely due to radio tags exceeding their typical battery life capacity. Of the remaining 77 fish, 50 (65 %) fish limited their occupancy to reaches upstream of lower Davis Dam. A considerably larger proportion (i.e., 35 % or 27 fish) occupied reaches downstream of lower Davis Dam during winter compared to fall.

During early-spring (i.e., March), the majority (i.e., 88 % or 73 tags) of the remaining radio tags implanted had exceeded their warranty life, while 10 (12 %) continued to transmit a signal. Distribution of these fish was considerable, ranging from Union, OR to lower Catherine Creek. On 10 March 2010, one fish was relocated approximately 11.6 rkm upstream from the mouth of Catherine Creek, likely conducting spring emigration.

Stationary receivers detected 8 radio-tagged juvenile Chinook salmon from 31 October 2009 to 8 March 2010 (Table 7). Detections occurred at lower Davis Dam, Gekeler Lane and Booth Lane; no fish were detected at receivers positioned at Alicel Lane and Rhinehart Lane. The majority (63%) of the detections occurred during mid-January and coincided with an increase in water temperature. All detections occurred during early morning or late evening periods (i.e., before 0800 and after 1700), except for one detection that occurred during mid-March, indicating obligatory nocturnal movement.

Size and Growth

Significantly different microhabitat use and reach occupancy has been reported for juvenile Chinook salmon (Everest and Chapman 1972; Hillman et al. 1987; Holecek et al. 2009). In addition to significantly different summer microhabitat use, Holecek et al. (2009) reported a size associated spatial difference in reach occupancy; where by, smaller juvenile Chinook salmon occupied upper Big Creek, and larger fish occupied lower Big Creek in central Idaho. During our study, fish (n = 290) collected during night-time snorkeling had a mean length and weight of 82.9 mm (SD, min–max; 7.0, 63–100) and 6.3 g (SD, min–max; 1.6, 2.6–10.8), respectively. No statistically significant size difference was found between PIT tagged early migrants and those recaptured PIT tagged fish (n = 14) co-occurring with radio-tagged fish (length, $P = 0.3280$; weight, $P = 0.4950$; Figures 7–8), indicating that occupied stream reaches and microhabitat use of radio-tagged early migrants are representative of that of the entire size distribution of the early migrant population sampled at the screw trap. In addition, simple linear regression revealed that total linear range was not statistically significantly related to size ($P = 0.6954$; Figure 9). Holecek et al. (2009) suggested that spatial differences in water temperature, life history (i.e., summer-run vs. spring-run), fish density and microhabitat availability could possibly explain size associated variation in microhabitat and reach occupancy.

Recaptured PIT tagged early migrants (n = 13) had a mean absolute growth of 0.021 g/d (SE, min–max; 0.017, -0.040–0.200), while recaptured radio-tagged fish (n = 5) had a mean absolute growth of -0.010 g/d (SE, min–max, 0.006, -0.030–0.003; Table 8). No statistically significant growth difference was found between radio-tagged early migrants and PIT tagged fish ($T = 34$, $P = 0.20$). However, these results should be interpreted skeptically due low sample size.

Linear Range and Reach Occupancy

Monthly median linear range was considerably greater during fall than winter (Table 9). Higher monthly median ranges during fall were associated with early migrants redistributing from spawning reaches to downstream winter rearing reaches. Depressed monthly median linear ranges during winter coincided with early migrants demonstrating sedentary behavior while occupying overwintering reaches. During January, monthly median linear range increased significantly despite remaining low compared to fall (Table 9). Elevated January movement was attributed to numerous fish briefly reinitiating emigration. The majority of these mobile fish abandoned high gradient reaches upstream from the mouth of Pyles Creek and occupied low gradient reaches between the mouth of Pyles Creek and Mill Creek. Movement during this study was predominantly directed downstream, however during December one radio-tagged fish returned 1.34 km upstream and remained in this reach the remainder of the winter occasionally demonstrating wandering behavior.

Water temperatures throughout the study area, during the study period, were relatively homogeneous (Figure 10). Water temperature appeared to be a proximate migration stimulus associated with movement during fall migration and overwinter rearing. Weekly median linear range decreased and was associated with decreasing water temperatures during late-October and early-November when sedentary behavior became prevalent (Figure 11). Sedentary behavior persisted and coincided with water temperatures near 0 °C until mid-January when a peak in weekly median linear range occurred and was associated with increasing water temperatures (4–5 °C). Discharge did not appear to have any noticeable affect on movement from mid-October to late-March (Figure 11).

Distribution of radio-tagged early migrant relocations during fall and winter were statistically significantly different ($P < 0.0001$; Figure 12), indicating that a seasonal spatiotemporal shift occurs resulting in considerably different habitat occupancy (i.e., low/high gradient). During fall, the majority of relocations (n = 448, 89 %) occurred in high gradient reaches upstream of the mouth of Pyles Creek, while only 54 relocations occurred in low gradient reaches downstream of the mouth of Pyles Creek. During winter, nearly half (n = 236, 43 %) of the relocations occurred in low gradient reaches downstream of the mouth of Pyles Creek; 315 (57 %) of the relocations occurred in high gradient reaches upstream of the mouth of Pyles Creek (Figure 12).

Microhabitat

Microhabitat Use Comparisons.—Microhabitat use variables depth, dominant substrate and cover type were statistically significantly different ($P < 0.0001$) between low and high gradient reaches; microhabitat use variables bottom velocity, mean column velocity, distance to bank and distance to cover were not statistically significantly different ($P > 0.05$) between low and high gradient reaches (Table 10; Figure 13). Early migrants occupied deeper water in low gradient reaches compared to high gradient reaches. Bottom and mean column velocity currents used were similar between low and high gradient reaches; however, on average, mean column velocity currents used were swifter. Cobble was the modal dominant substrate used in the high gradient reach, while silt was the modal dominant substrate used in the low gradient reach. Mean distance to bank for fish detections were between 2–3 m for both the low and high gradient reach. Boulders were most frequently used as cover within the high gradient reach, while fine woody debris was the modal cover type used in the low gradient reach. Most fish relocations occurred in close proximity to cover for both low and high gradient reaches, with mean distance to cover for both reaches being less than or equal to 0.50 m (Figure 13).

Microhabitat Use and Availability Comparisons.—Microhabitat use and availability univariate frequency distributions were statistically significantly different for all variables (depth, bottom velocity, mean column velocity, dominant substrate, cover, distance to cover and distance to bank) for both the high and low gradient reach ($P < 0.05$; Figures 14–15). Such significant divergence between microhabitat use and availability indicates that early migrant juvenile Chinook salmon nonrandomly select specific microhabitats during fall migration and overwinter rearing irrespective of stream reach occupied.

Catherine Creek juvenile spring Chinook salmon early migrant microhabitat use was uniformly different than that available (Figures 14–15). Average depth used was considerably greater than that available for both the high and low gradient reach, indicating that early migrants select depths greater than those available during fall migration and overwinter rearing. Bottom velocity mean use, corresponding to the high gradient reach, was greater than that of the low gradient reach, indicating that subsequent early migrants select swifter bottom velocities than those available; to a lesser extent, a similar trend was present for the low gradient reach. The same divergent relationship of greater velocities being used than available was documented of mean column velocity for both the low and high gradient reach. High gradient modal available dominant substrate was gravel, while utilized modal dominant substrate was cobble, indicating that coarser substrates are selected than those available; silt was most commonly available and used by early migrants in the low gradient reach. Distance to bank mean use was shorter than the corresponding availability mean for the high gradient reach, indicating that subsequent early migrants tended to select habitat near the bank; low gradient distance to bank mean use was nearly equal to the corresponding availability mean. Early migrants occupying the high gradient reach most frequently used boulders as cover; fine woody debris was most commonly used in the low gradient reach as cover, despite cover not being readily available in either reach (Figures 14–15). Clusters of tumbleweed *Sisymbrium altissimum* and American waterweed *Elodea canadensis* were commonly available and heavily used in the low gradient reach, while not available in the high gradient reach. For both the high and low gradient reach, use and availability distance to cover means demonstrate minimal variation; however, high gradient reach mean use distance to cover was slightly less than the corresponding availability mean, indicating that subsequent early migrants generally select habitat that is in close proximity to cover.

Suitable and Optimal Microhabitat.—Univariate microhabitat suitability indices revealed most suitable or optimal microhabitat during the fall migration and overwintering periods for Catherine Creek early migrant juvenile spring Chinook salmon (Figures 16–17). Deep depths were optimal or preferred for both high and low gradient reaches. Slow bottom and mean column velocity currents were optimal for all reaches occupied. Silt, cobble and boulder substrates were most suitable within the high gradient reach, while silt and sand were optimal substrates within the low gradient reach. Root wad was the preferred cover type for the high gradient reach, while coarse woody debris was most suitable for the low gradient reach (Figures 16–17). Moderate to small distances to cover (i.e., 0.0 – 2.0 m) were optimal for both the high and low gradient reaches. A variety of distances from bank (i.e., 0 – 6.0 m) were highly suitable for the low gradient reach, while distances from bank ≥6.0 m were optimal within the high gradient reach (Figures 16–17).

Catherine Creek juvenile spring Chinook salmon univariate microhabitat suitability indices generally agree with those previously reported. During summer juvenile Chinook salmon occupy shallow to moderate depths sustaining slow to moderate velocities flowing over fine to medium substrates near cover positioned close to the bank (Hillman et al. 1987; Holecek et al. 2009). Juvenile Chinook microhabitat use tends to shift toward deeper depths and slower current velocities, with an elevated use of fine (e.g., silt) and coarse (e.g., boulder) substrates near large cover types (e.g., boulder, coarse woody debris) near the bank (Hillman et al. 1987; Allen et al. 2000). However, previously reported microhabitat use data and subsequent univariate suitability indices were derived based on data obtained from snorkel survey techniques, which have been reported to introduce fright bias (i.e., reactive displacement) and possibly yield erroneous results when only "undisturbed" fish are included in analyses that likely do not represent the entire population (Brignon 2009). Advances in radiotelemetry (i.e., NanoTag transmitters; Lotek Wireless, Inc.) have permitted application of this technology to small fishes; historically tag size was prohibitive. Pertaining to microhabitat use identification, radiotelemetry techniques minimize fright, temporal, spatial, ice cover, turbidity, and depth biases compared to snorkeling techniques (Larimore and Garrels 1985; Winter 1996). Excessive depths and turbidity levels present in the low gradient reach of Catherine Creek (i.e., downstream of Pyles Creek) would have certainly prohibited the application of snorkeling techniques consequentially producing reach occupancy, temporal and spatial biases.

High and Low Gradient Reach Comparisons.—Microhabitats occupied by early migrant juvenile spring Chinook salmon revealed similarities and differences between high and low gradient reaches during the fall migration and overwintering periods (Table 11). Microhabitat variables depth, dominant substrate and cover occupied were statistically significantly different ($P < 0.0001$) between high and low gradient reaches, while variables bottom velocity, mean column velocity, distance to cover and distance to bank were not ($P > 0.05$; Table 11). Shallower depths were used within the high gradient reach, while deeper depths were more frequently used in the low gradient reach. Bottom and mean column velocities ranging 0.0–0.1 were most frequently used within both high and low gradient reaches. Coarse substrates (i.e., cobble) were occupied within the high gradient reach compared to fine substrates (i.e., silt) within the low gradient reach. Fine and coarse woody debris, in addition to boulders, were predominately used as cover within the high gradient reach, while fine woody debris and terrestrial vegetation were used heavily within the low gradient reach. Distances to cover ranging 0.0 – 0.5 m were prevalent for both high and low gradient reaches. Distances to bank ranging 0.0 – 4.0 m were most frequent for both high and low gradient reaches.

Multivariate Analyses.—Within the high gradient reach, Catherine Creek early migrant juvenile spring Chinook salmon occupied macrohabitat nonrandomly for components 1, 2 and 3 ($P < 0.0001$; Table 12). Similarly, in the low gradient reach, early migrants selected macrohabitat nonrandomly for components 1 and 2 ($P < 0.05$; Table 12). Principal component analysis (PCA) indicated that combinations of all continuous variables measured (depth, bottom velocity, mean column velocity, dominant substrate, distance to cover, distance to bank) were important in determining macrohabitat selection. Retained components 1, 2 and 3 explained a cumulative variance of 81% for the high gradient reach (Table 13); components 1 and 2 explained a cumulative variance of 64% for the low gradient reach (Table 14). For both reaches, bottom and mean column velocity loadings were large enough to indicate a significant influence on PC1. Dominant substrate was never large enough to contribute to PC1, however contributed to PC2 for both reaches. Loadings for depth were not large enough to contribute to PC1 or PC2 for the high gradient reach, however were large enough to contribute to both PC1 and PC2 for the low gradient reach. Loading for distance to cover and distance to bank were large enough to indicate influence on PC1 and PC2 for the high gradient reach, however were less consistently influential for the low gradient reach. Loadings for depth, bottom velocity and dominant substrate were significantly large enough to indicate considerable influence on PC3.

During the fall migration and overwintering period, within the high gradient reach, early migrants were typically occupying marginal habitat with slow currents near cover, and were rarely located near the thalweg when no cover and fast velocities were prevalent (low PC1 scores; Figure 18). Fish were encountered near the thalweg when coarse substrates (e.g., cobble and boulder) and cover were co-occurring (high PC2 scores); fish were rarely encountered near the bank when cover was absent and substrates were predominately fines (i.e.., clay and silt) (low PC2 scores). Relocations were associated with moderate bottom velocities when coarse substrates (i.e., cobble and boulder) and deep water were present (low PC3 scores), while were less associated with slow bottom velocities co-occurring with fine substrates and shallow depths (high PC3 scores; Figure 19). Within the low gradient reach, early migrants generally selected moderate depths when slow currents and cover were present (low PC1 scores), and tended to avoid deep water when fast currents were present with the absence of cover (high PC1 scores; Figure 20). In addition, low gradient relocations were near the bank when moderate depths and silt were present (moderate PC2 scores; Figure 20).

Microhabitat Availability.—Microhabitat availability surveys of Catherine Creek revealed that the high gradient reach, upstream of the mouth of Pyles Creek, is considerably different from the low gradient reach designated as downstream from the mouth of Pyles Creek (Table 2). The high gradient reach exhibited shallower depths with considerably swifter currents flowing over coarser substrates compared to the low gradient reach. Substrates available in the high gradient reach ranged from clay to boulder, while available substrates ranged from clay to sand in the low gradient reach (Table 2). The dominant cover type for both reaches was “no cover”; cover was absent from 32% and 43% of the high gradient and low gradient reaches, respectively. More than half of all microhabitat availability survey points were within 2.0 m of cover (57%, high gradient; 68%, low gradient; Table 2).

Stream and riparian morphology characteristics, obtained from microhabitat availability surveys, indicate that the high and low gradient reaches are primarily similar (Table 3). The low gradient reach was considerably wider than the high gradient reach; however, both reaches exhibited generally small bank angles. Undercut bank distance was minimal for both reaches suggesting that base flow conditions produces negligible erosion or spring freshets obscure such erosion. Land use conditions, within a 50 m buffer of surveyed reaches, were similar between high and low gradient reaches. The majority of land use was dedicated to agriculture with forested and developed categories constituted ≤25% each (Table 3).

Management Implications and Recommendations

Catherine Creek is a highly altered and degraded system (e.g., berms, channelization, irrigation diversions, dams). Efforts directed toward increasing survival of early migrants during fall migration and overwintering periods would likely be most efficiently directed toward portions bounded by Union, OR and the mouth of Mill Creek. Moreover, the high gradient reach located between Union, OR and the mouth of Pyles Creek was most intensely utilized; holistic rehabilitation efforts would likely be most productive if concentrated within this reach.

Several reaches within the high gradient overwintering reach were not occupied consistently by the early migrant population, indicating that these reaches do not contain habitat conditions conducive to successful overwintering. Specifically, the reach extending approximately 1.7 km upstream of Swackhammer Fish Ladder appeared to only be utilized as a migration corridor, suggesting that this high gradient channelized reach exhibiting homogenized riffle habitat is being avoided as overwintering habitat. In addition, several smaller reaches positioned between Union, OR and the mouth of Pyles Creek appeared channelized and lacked habitat complexity (e.g., pools and cover). Employing habitat restoration techniques, within these degraded reaches, that facilitate habitat complexity and increase occupancy potential will likely increase overwintering carrying capacity. In addition to rehabilitation of existing stream reaches, stream restoration that reclaims historic stream channels within the high gradient reach would considerably increase habitat availability by increasing stream length. Increasing habitat availability, habitat complexity, stream length and subsequently overwinter carrying capacity of the high gradient reach could potentially decrease linear range (i.e., movement) and the associated elevated mortality risk associate with migration.

The majority of radio-tagged early migrant relocations were associated with cover (e.g., log, root wad, terrestrial vegetation). The riparian zone of both the high and low gradient reaches used by early migrants was primarily devoted to agriculture, indicating that riparian vegetation which ultimately is the source of numerous types of cover may be a limiting factor. In addition, reaches associated with agriculture and minimal riparian vegetation exhibited extensive stream entrenchment, bank erosion and reduced habitat complexity. Establishment and protection of riparian vegetation would likely elevate the contribution of terrestrial vegetation into the stream, thereby elevating habitat complexity and cover availability. In addition, riparian vegetation is associated with bank stability and reduced erosion. Holistic management practices that enhance the riparian corridor vegetation of Catherine Creek could improve overwinter carrying capacity of early migrants by increasing habitat complexity (i.e., cover) and bank stability.

References

Adams, N. S., D. W. Rondorf, S. D. Evans, J. E. Kelly, and R. W. Perry. 1998. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 55:781-787.

Allen, M. A. 2000. Seasonal microhabitat use by juvenile spring Chinook salmon in the Yakima River Basin, Washington. Rivers 7:317-332.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 *in* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.

Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Instream Flow Information Paper 21. U.S. Fish and Wildlife Service Biological Report 86(7).

Brignon, W. R. 2009. Habitat selection of hatchery and wild juvenile salmonids in Eagle Creek Basin, Oregon. Master's thesis. Oregon State University, Corvallis, Oregon.

Brown, R. S., S. J. Cooke, W. G. Anderson, and R. S. McKinley. 1999. Evidence to challenge the "2% Rule" for biotelemetry. North American Journal of Fisheries Management 19:867-871.

Brown, R. S., R. A. Harnish, K. M. Carter, J. W. Boyd, K. A. Deters, and M. B. Eppard. 2010. An evaluation of the maximum tag burden for implantation of acoustic transmitters in juvenile Chinook salmon. North American Journal of Fisheries Management 30:499-505.

Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile Chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29:91-100.

Guy, C. S., H. L. Blankenship, and L. A. Nielsen. 1996. Tagging and marking. Pages 353-383 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile Chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116:185-195.

Holecek, D. E., K. J. Cromwell, and B. P. Kennedy. 2009. Juvenile Chinook salmon summer microhabitat availability, use, and selection in a central Idaho wilderness stream. Transactions of the American Fisheries Society 138:633-644.

Jonasson, B. C., J. V. Tranquilli, M. Keefe, and R. W. Carmichael. 1997. Investigations into the early life history of naturally produced spring Chinook salmon in the Grande Ronde River basin. Annual Progress Report 1997. Bonneville Power Administration, Portland, OR.

Kaiser, H. F. 1960. The application of electronic computers to factor analysis. Educational and Psychological Measurements 20:141-151.

Kwak, T. J., and J. T. Peterson. 2007. Community indices, parameters, and comparisons. Pages 677-763 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Larimore, R. W., and D. D. Garrels. 1985. Assessing habitats used by warmwater stream fishes. Fisheries 10(2):10-16.

Lead, S. 2002. Add points evenly along a line. ArcView GIS arcscript. Available: www.esri.com. (July 2010).

Martinelli, T. L., H. C. Hansel, and R. S. Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling Chinook salmon (*Oncorhynchus tshawytscha*). Hydrobiologia 371/372:79-87.

Matthews, G. M., J. R. Harmon, S. Achord, O. W. Johnson, and L. A. Kubin. 1990. Evaluation of transportation of juvenile salmonids and related research on the Columbia and Snake rivers, 1989. Report of the U.S. Army Corps of Engineers, Contract DACW68-84-H0034. National Marine Fisheries Service, Seattle.

Matthews, G. M., S. Achord, J. R. Harmon, O. W. Johnson, D. M. Marsh, B. P. Sandford, N. N. Paasch, K. W. McIntyre, and K. L. Thomas. 1992. Evaluation of transportation of juvenile salmonids and related research on the Columbia and Snake Rivers, 1990. Report of the National Marine Fisheries Service to the U.S.Army Corps of Engineers, Walla Walla, Washington.

McMahon, T. E., A. V. Zale, and D. J. Orth. 1996. Aquatic habitat measurements. Pages 83-120 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland.

Monzyk, F. R., B. C. Jonasson, T. L. Hoffnagle, P. J. Keniry, R. W. Carmichael, and P. J. Cleary. 2009. Migration characteristics of hatchery and natural spring Chinook salmon smolts from the Grande Ronde River Basin, Oregon, to Lower Granite Dam on the Snake River. Transactions of the American Fisheries Society 138:1093-1108.

Moore, A., I. C. Russell, and E. C. E. Potter. 1990. The effects of intraperitoneally implanted dummy acoustic transmitters on the behavior and physiology of juvenile Atlantic salmon, Salmo salar L. Journal of Fish Biology 37:713-721.

NMFS (National Marine Fisheries Service). 2008. 2008 Federal Columbia River Power System Biological Opinion (URL: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm)

Nowak, M. C., lead writer. 2004. Grande Ronde Subbasin Plan. Northwest Power and Conservation Council, Portland. Available: http://www.nwcouncil.org/fw/subbasinplanning/granderonde/plan/ (July 2010).

Prentice, E. F., D. L. Park, T. A. Flagg, and S. McCutcheon. 1986. A study to determine the biological feasibility of a new fish tagging system, 1985–1986. Annual Progress Report. Bonneville Power Administration, Portland OR.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990. Equipment, methods, and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7: 335–340.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon. 1990. The effect of passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7: 317–322.

Ross, M. J., and C. F. Kleiner. 1982. Shielded-needle technique for surgically implanting radio-frequency transmitters in fish. The Progressive Fish-Culturist 44:41-43.

Simonson, T. D., J. Lyons, and P. D. Kanehl. 1994. Quantifying fish habitat in streams: transect spacing, sample size, and a proposed framework. North American Journal of Fisheries Society 14:607-615.

Stevens, J. 1996. Applied multivariate statistics for the social sciences, 3rd edition. Lawrence Erlbaum Associates, New Jersey.

Summerfelt, R. C., and L. S. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 216-218 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Van Dyke, E. S., D. L. Scarnecchia, B. C. Jonasson, and R. W. Carmichael. 2009. Relationship of winter concealment habitat quality on pool use by juvenile spring Chinook salmon in the Grande Ronde River Basin, Oregon USA. Hydrobiologia 625:27-42.

Vokoun, J. C. 2003. Kernel density estimates of linear home range for stream fishes: advantages and data requirements. North American Journal of Fisheries Management 23:1020-1029.

Wagner, G. N., and S. J. Cooke. 2005. Methodological approaches and opinions of researchers involved in the surgical implantation of telemetry transmitters in fish. Journal of Aquatic Animal Health 17:160-169.

Waters, B. F. 1976. A methodology for evaluating the effects of different steam flows on salmonids habitat. Pages 254-266 *in* J. F. Osborn and C. H. Allman, editors. Instream flow needs. American Fisheries Society, Bethesda, Maryland.

Weigel, J. 2002. Nearest neighbor 3.1. Arcview GIS arcscript. Available: www.esri.com. (July 2010).

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 555-590 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland.

Wydoski, R. S., and R. R. Whitney. 2003. Inland fishes of Washington, 2nd edition. American Fisheries Society, Bethesda, Maryland and University of Washington Press, Seattle.

Yanke, J. A. B. M. Alfonse, K. W. Bratcher, S. D. Favrot, J. P. Kimbro, J. W. Steele, I. P. Wilson, B. C. Jonasson, and R. W. Carmichael. 2008. Investigations into the early life history of naturally produced spring Chinook salmon in the Grande Ronde River Subbasin. Annual Progress Report 2008. Bonneville Power Administration, Portland, OR.

Table 1. Characteristics of radio-tagged juvenile spring Chinook salmon from Catherine Creek, Oregon. Mortalities during the study period were not used for analyses.

Tag Code	Transmitter frequency (MHz)	Date tagged	Tag mass (g)	Fork Length (mm)	Weight (g)	Number of relocations
11	166.300	10/28/2009	0.279	91	8.5	13
12	166.300	10/28/2009	0.273	94	9.1	11
13	166.300	10/28/2009	0.267	93	8.5	3
14	166.300	10/28/2009	0.270	91	8.6	11
15	166.300	10/30/2009	0.272	91	8.7	14
16	166.300	10/30/2009	0.269	94	8.8	17
17	166.300	10/31/2009	0.275	92	9.1	15
18	166.300	10/31/2009	0.264	93	8.8	14
19	166.340	10/31/2009	0.269	94	8.7	15
20	166.300	10/31/2009	0.277	93	8.6	16
21	166.340	10/31/2009	0.271	96	9.5	16
22	166.300	10/31/2009	0.272	92	8.6	8
23	166.300	10/31/2009	0.271	93	8.7	14
24	166.300	10/31/2009	0.272	94	8.8	13
25	166.300	10/30/2009	0.268	93	8.7	10
26	166.300	10/30/2009	0.269	93	8.5	Mort
27[a]	166.300	11/23/2009	0.275	98	9.6	7
27	166.300	10/30/2009	0.275	94	9.5	Mort
28	166.300	10/30/2009	0.270	95	9.4	1
29	166.300	10/30/2009	0.267	93	8.6	Mort
30	166.300	10/29/2009	0.269	99	11.1	10
31	166.300	10/29/2009	0.274	96	9.8	14
32	166.300	10/30/2009	0.272	91	8.5	Mort
33	166.300	10/30/2009	0.265	100	13.3	0
34	166.300	10/29/2009	0.274	102	11.3	10
35	166.300	10/28/2009	0.276	92	9.2	14
36	166.300	10/29/2009	0.273	95	9.2	12
37	166.300	10/30/2009	0.267	96	9.8	7
38	166.320	10/27/2009	0.265	99	10.7	11
39	166.320	10/27/2009	0.268	93	9.2	11
40	166.320	10/27/2009	0.267	94	8.8	9
41	166.320	10/26/2009	0.267	96	9.6	Mort
42	166.320	10/26/2009	0.268	98	10.2	0
43	166.320	10/21/2009	0.265	89	8.1	18
44	166.320	10/21/2009	0.271	90	10.1	Mort
45	166.320	10/26/2009	0.271	91	8.9	15

Table 1.—(Continued).

Tag Code	Transmitter frequency (MHz)	Date tagged	Tag mass (g)	Fork Length (mm)	Weight (g)	Number of relocations
46	166.320	10/26/2009	0.274	93	9.3	17
47	166.320	10/26/2009	0.278	93	9.4	17
48[a]	166.320	11/23/2009	0.269	95	9.2	7
48	166.320	10/24/2009	0.269	98	11.6	Mort
49	166.320	10/26/2009	0.272	96	10.6	14
50	166.320	10/26/2009	0.270	95	9.7	15
51	166.320	10/26/2009	0.271	94	9.7	15
52	166.320	10/22/2009	0.267	93	9.4	1
53	166.320	10/23/2009	0.270	91	9.2	11
54	166.320	10/26/2009	0.265	94	9.4	9
55	166.320	10/28/2009	0.274	91	8.9	15
56	166.320	10/24/2009	0.263	98	10.6	18
57	166.320	10/26/2009	0.266	91	8.9	13
58	166.320	10/20/2009		94	9.4	17
59	166.320	10/20/2009		95	9.2	15
60[a]	166.320	11/23/2009	0.285	100	10.8	2
60	166.320	10/20/2009	0.285	97	9.9	Mort
61	166.320	10/20/2009		93	8.9	11
62	166.320	10/20/2009		93	8.5	18
63	166.320	10/20/2009		93	9.3	24
64	166.320	10/20/2009		91	8.6	18
65	166.340	10/31/2009	0.270	94	9.1	15
66	166.340	10/31/2009	0.274	94	8.9	16
67	166.340	10/31/2009	0.265	96	9.2	14
68	166.340	10/31/2009	0.268	92	8.8	16
69	166.340	10/31/2009	0.273	96	9.6	13
70	166.340	10/31/2009	0.269	105	12.2	12
71	166.340	10/31/2009	0.265	94	8.7	13
72	166.340	10/31/2009	0.268	95	9.5	10
73	166.340	10/31/2009		102	10.6	14
74	166.340	10/31/2009	0.277	93	8.8	17
75	166.340	10/31/2009		92	8.5	6
76	166.340	10/31/2009		95	8.8	7
77	166.340	10/31/2009	0.269	95	9.4	8
78	166.340	10/31/2009	0.270	92	9.1	17
79	166.340	10/31/2009	0.266	94	8.8	13
80	166.340	10/31/2009	0.270	94	9.5	16
81	166.340	10/31/2009	0.267	96	10.0	19
82[a]	166.340	11/24/2009	0.268	95	10.3	12
82	166.340	10/31/2009	0.268	94	9.1	Mort

Table 1.—(Continued).

Tag Code	Transmitter frequency (MHz)	Date tagged	Tag mass (g)	Fork Length (mm)	Weight (g)	Number of relocations
83	166.340	10/31/2009	0.269	95	9.5	16
84	166.340	10/31/2009	0.268	95	9.2	16
85	166.340	10/31/2009	0.263	95	9.8	17
86	166.340	10/31/2009	0.272	97	10.3	Mort
87	166.340	10/31/2009	0.272	91	9.0	20
88	166.340	11/16/2009	0.265	96	9.7	11
89	166.340	11/16/2009	0.269	95	9.4	14
90	166.340	11/16/2009	0.274	103	11.9	14
91	166.300	11/26/2009	0.268	96	9.3	12
92	166.300	11/26/2009	0.268	95	8.9	10
93	166.300	11/26/2009	0.264	93	8.8	15
94	166.300	11/28/2009	0.266	95	9.2	Mort
95	166.300	11/30/2009	0.261	95	8.5	14
96	166.320	11/30/2009	0.268	93	8.5	0
97	166.320	11/30/2009	0.267	93	8.5	15
99	166.320	11/26/2009	0.269	94	8.7	7
100	166.320	12/01/2009	0.264	98	10.5	3
101	166.340	11/30/2009	0.265	94	8.5	15
102	166.340	11/30/2009	0.271	98	10.4	4
103	166.340	11/25/2009	0.269	95	9.3	12
104	166.340	11/26/2009	0.272	96	9.2	Mort
105	166.340	11/29/2009	0.269	97	9.4	14
Mean			0.269	94.6	9.4	12.2
SD			0.004	2.8	0.9	5.0

[a] Tags were deployed a second time after recovery from mortalities.

Table 2.—Summarized microhabitat use and availability for high and low gradient reaches of Catherine Creek where radio-tagged early migrant spring Chinook salmon were located.

	High gradient		Low gradient	
Variable and statistic	Use	Available	Use	Available
Temperature (C°)				
n	268		108	
Mean	3.28		2.78	
SE	0.14		0.19	
Min – max	0.00 – 10.00		0.00 – 8.00	
Dissolved oxygen (mg/L)				
n	205		61	
Mean	14.39		14.06	
SE	0.07		0.14	
Min – max	12.10 – 16.81		12.13 – 16.68	
Depth (m)				
n	255	395	108	300
Mean	0.61	0.24	0.83	0.52
SE	0.02	0.01	0.04	0.02
Min – max	0.04 – 2.20	0.00 – 1.02	0.20 – 2.0	0.00 – 2.00
Bottom velocity (m/s)				
n	243	395	102	300
Mean	0.07	0.20	0.06	0.08
SE	0.01	0.01	0.01	0.01
Min – max	0.00 – 0.74	0.00 – 1.50	0.00 – 0.41	0.00 – 0.45
Mean velocity (m/s)				
n	243	395	104	300
Mean	0.16	0.34	0.12	0.20
SE	0.01	0.02	0.01	0.01
Min – max	0.00 – 0.70	0.00 – 1.65	0.00 – 0.52	0.00 – 0.76
Dominant substrate				
n	267	395	105	300
Mode	Cobble	Gravel	Silt	Silt
SE	0.07	0.06	0.07	0.04
Min – max	CL – BR	CL – B	CL – B	CL – SD
Distance to bank (m)				
n	262	395	107	301
Mean	2.19	1.87	2.64	2.63
SE	0.09	0.07	0.20	0.13
Min – max	0.00 – 8.00	0.00 – 6.30	0.00 – 11.00	0.00 – 10.00
Cover				
n	268	395	108	300
Mode	Boulder	No cover	FWD	No cover
Distance to cover (m)				
n	240	268	107	172
Mean	0.50	0.58	0.33	0.31
SE	0.04	0.04	0.05	0.03
Min – max	0.00 – 2.00	0.10 – 2.00	0.00 – 2.00	0.00 – 2.00

Table 3.—Stream morphology and riparian land use obtained during microhabitat availability surveys conducted where radio-tagged early migrant spring Chinook salmon were located.

	Morphology			50-m riparian land use (%)		
Reach and statistic	Stream width (m)	Bank angle (°)	Undercut bank (m)	Forest	Agriculture	Developed
High gradient	7.93	47.75	0.02	25.33	64.50	10.17
Low gradient	12.14	48.06	0.01	0.00	91.67	8.33
Mean	10.04	47.91	0.02	12.67	78.09	9.25
CV (%)[a]	0.30	0.00	0.35	1.41	0.25	0.14

[a] (SD/mean) × 100.
[b] Upstream of Valley River confluence.

Table 4.—Characteristics of surveyed stream reaches in Catherine Creek used by radio-tagged early migrant spring Chinook salmon as overwintering habitat.

Stream reach and location		Upstream geographic coordinates (UTM)		Downstream geographic coordinates (UTM)	Reach length (m)	Number of transects	Number of survey points
High gradient							
Union	11T	0433044 5006485	11T	0432917 5006566	0.126	10	141
Recycling Center	11T	0430525 5006833	11T	0430425 5006812	0.126	10	124
Pyles Creek	11T	0428785 5007414	11T	0428523 5007559	0.108	10	132
Low gradient							
Davis Dam	11T	0427666 5009439	11T	0427661 5009765	0.18	10	97
Wilkinson Road	11T	0426936 5013741	11T	0426895 5013901	0.36	10	118
Godley Lane	11T	0430177 5016526	11T	0430253 5016489	0.084	7	86
Total					0.984	57	698

Table 5.—Particle size categories and associated continuous variables used to visually estimate dominant and subdominant surface substrate size for all radio-tagged fish relocations and habitat availability survey points.

Category	Particle size (mm)	Continuous variable
Bedrock		13
Large boulder	>1024	12
Medium boulder	508-1024	11
Small boulder	256-508	10
Large cobble	128-256	9
Small cobble	64-128	8
Very coarse gravel	32-64	7
Coarse gravel	16-32	6
Medium gravel	8-16	5
Fine gravel	2-8	4
Sand	0.062-2.0	3
Silt	0.004-0.062	2
Clay	<0.004	1

Table 6.—Cover categories, associated continuous variables, and cover abbreviations used to describe nearest dominant cover for each fish location and habitat availability survey point.

Cover category	Continuous variable	Cover abbreviation
No cover	1	NC
Coarse woody debris	2	CWD
Fine woody debris	3	FWD
Root wad	4	RW
Aquatic emersed vegetation	5	VAE
Submersed aquatic vegetation	6	VAS
Terrestrial vegetation	7	VT
Undercut bank	8	UB
Boulder	9	B

Table 7.—Detections of radio-tagged early migrant Catherine Creek juvenile Chinook salmon at stationary radio receivers positioned between Lower Davis Dam and Rhinehart Lane. Detection date and time associated with the initial detection for each code are reported in addition to the total number of detection.

Receiver location	Tag code	Date	Time	Number of detections
Lower Davis Dam	34	10/31/2009	18:43	3
	47	1/15/2010	7:16	60
	61	11/17/2009	18:22	1
	65	1/23/2010	6:06	1
	66	1/11/2010	17:20	1
	92	1/11/2010	5:45	1
Gekeler Lane	58	1/10/2010	7:46	3
Booth Lane	93	3/8/2010	14:26	1
Alicel Lane	No detections	N/A	N/A	N/A
Rhinehart Lane	No detections	N/A	N/A	N/A

Table 8.—Summarized weight, length, elapsed time, and absolute growth characteristics for recaptured PIT tagged and radio-tagged Catherine Creek juvenile spring Chinook salmon during fall and winter 2009-2010.

Group and Statistic	Time Interval (d)	Weight characteristics Capture (g)	Weight characteristics Recapture (g)	Weight characteristics Difference (g)	Length characteristics Capture (mm)	Length characteristics Recapture (mm)	Length characteristics Difference (mm)	Absolute Growth (g/d)
PIT tagged (n = 13)								
Mean	23.46	5.59	5.73	0.08	79.21	80.54	1.00	0.021
SE	7.41	0.28	0.28	0.15	1.26	1.23	0.28	0.017
Min	1.0	4.1	4.5	-0.90	71.0	73.0	0.00	-0.040
Max	94.0	8.3	7.9	1.10	91.0	91.0	3.00	0.200
Radio-tagged (n = 5)								
Mean	30.00	9.20	9.08	-0.39	93.40	94.40	1.00	-0.010
SE	15.69	0.23	0.22	0.30	0.68	0.75	0.45	0.006
Min	9.0	8.7	8.4	-1.60	91.0	93.0	0.00	-0.030
Max	92.0	9.8	9.8	0.03	95.0	97.0	2.00	0.003

Table 9.—Monthly and overwintering median, mean, standard error, minimum, and maximum linear range for radio-tagged Catherine Creek early migrant spring Chinook salmon.

Month and season	n	Median linear range (km)	Mean linear range (km)	SE	Min (km)	Max (km)
October	9	5.82	5.58	1.41	0.49	11.91
November	38	1.91	2.69	0.41	0.00	8.40
December	56	0.09	0.81	0.23	0.00	11.14
January	53	0.81	3.71	0.73	0.00	25.56
February	11	0.00	0.03	0.03	0.00	0.30
March	3	0.00	0.00	0.00	0.00	0.00
Fall – winter	81	10.83	12.96	1.05	2.82	56.77

Table 10.—Spatial (i.e., high and low gradient) summary of weekly relocation microhabitat data for radio-tagged Catherine Creek early migrant spring Chinook salmon and results of statistical comparisons between microhabitat use and availability. The Kolmogorov-Smirnov two-sample test was applied to continuous variables, while categorical variables were compared using a likelihood-ratio chi-square test. Mean is reported for variables depth, bottom velocity, mean column velocity, distance to bank and distance to cover, while mode is reported for dominant substrate and cover.

	N		Mean/Mode		SE			
Reach and variable	Use	Available	Use	Available	Use	Available	Statistic	*P*
High gradient								
Depth (m)	255	395	0.61	0.24	0.02	0.01	D = 0.5486	<0.0001
Bottom velocity (m/s)	243	395	0.07	0.20	0.01	0.01	D = 0.3259	<0.0001
Mean velocity (m/s)	243	395	0.16	0.34	0.01	0.02	D = 0.3386	<0.0001
Dominate substrate	267	395	5.00	4.00	0.07	0.06	D = 0.2503	<0.0001
Distance to bank (m)	262	395	2.19	1.87	0.09	0.07	D = 0.1637	0.0004
Cover	268	395	9.00	1.00	0.18	0.17	X^2 = 209.5994	<0.0001
Distance to cover (m)	240	268	0.50	0.58	0.04	0.04	D = 0.3284	<0.0001
Low gradient								
Depth (m)	108	300	0.83	0.52	0.04	0.02	D = 0.3604	<0.0001
Bottom velocity (m/s)	102	300	0.06	0.08	0.01	0.01	D = 0.1829	0.0123
Mean velocity (m/s)	104	300	0.12	0.20	0.01	0.01	D = 0.2456	0.0002
Dominate substrate	105	300	2.00	2.00	0.07	0.04	D = 0.2119	0.0019
Distance to bank (m)	107	301	2.64	2.63	0.20	0.13	D = 0.1806	0.0116
Cover	108	300	3.00	1.00	0.21	0.16	X^2 = 125.7392	<0.0001
Distance to cover (m)	107	172	0.33	0.31	0.05	0.03	D = 0.4105	<0.0001

Table 11.—Comparison statistics for high and low gradient microhabitat use of Catherine Creek early migrant juvenile spring Chinook salmon. The Komogorov-Smirnov two-sample test was conducted on continuous variables, and categorical variables were compared using a likelihood-ratio chi-square test.

Variable	Statistic	*P*
Depth (m)	0.320479	<0.0001
Bottom velocity (m/s)	0.147906	0.0863
Mean velocity (m/s)	0.151432	0.0709
Dominate substrate	0.823649	<0.0001
Distance to bank (m)	0.112685	0.2896
Cover	144.0807	<0.0001
Distance to cover (m)	0.116527	0.2434

Table 12.—Reach specific statistics and significance values from comparisons of retained microhabitat use and availability principal component scores. The Komogorov-Smirnov two-sample test was used to compare component scores.

Reach and principal component	*D* statistic	*P*-value
High gradient		
PC1	0.2335	<0.0001
PC2	0.4449	<0.0001
PC3	0.4993	<0.0001
Low gradient		
PC1	0.1830	0.0124
PC2	0.1745	0.0197

Table 13.—High gradient principal component eigenvector values (i.e., loadings), eigenvalues, and cumulative variance explained of microhabitat use and availability for radio-tagged juvenile Catherine Creek early migrant spring Chinook salmon.

	PCA axis		
Variable and statistic	1	2	3
Depth (m)	0.2247	0.2175	0.7891
Bottom velocity (m/s)	0.5389	-0.0557	-0.2937
Mean velocity (m/s)	0.5787	-0.0193	-0.1752
Dominate substrate	0.0555	0.7465	-0.4196
Distance to cover (m)	0.3533	-0.5387	-0.0579
Distance to bank (m)	0.4431	0.3189	0.2845
Eigenvalue	2.5703	1.1799	1.1112
Cumulative variance explained (%)	42.8	62.5	81.0

Table 14.—Low gradient principal component eigenvector values (i.e., loadings), eigenvalues, and cumulative variance explained of microhabitat use and availability for radio-tagged juvenile Catherine Creek early migrant spring Chinook salmon.

	PCA axis	
Variable and statistic	1	2
Depth (m)	0.3226	-0.5226
Bottom velocity (m/s)	0.5544	0.1328
Mean velocity (m/s)	0.5903	0.1328
Dominate substrate	0.1885	0.5224
Distance to cover (m)	0.4268	-0.3766
Distance to bank (m)	0.1499	0.5261
Eigenvalue	2.3567	1.4858
Cumulative variance explained (%)	39.3	64.0

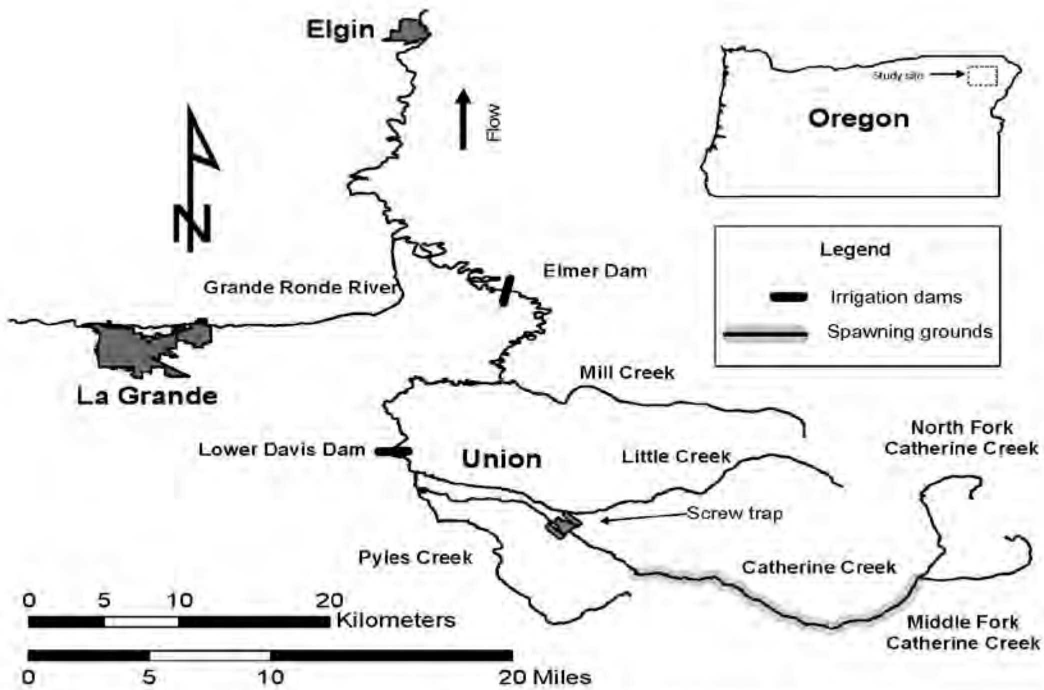

Figure 1.—Map of the Grande Ronde Valley with the study area bounded downstream by Elgin, OR and upstream by Union, OR.

(a) Rotary screw trap used to sample early migrant juvenile Chinook salmon.

(b) Surgical implantation of a radio transmitter into a juvenile Chinook salmon.

Figure 2.—Photos of the sampling and tagging techniques employed during the fall and winter of 2009/2010.

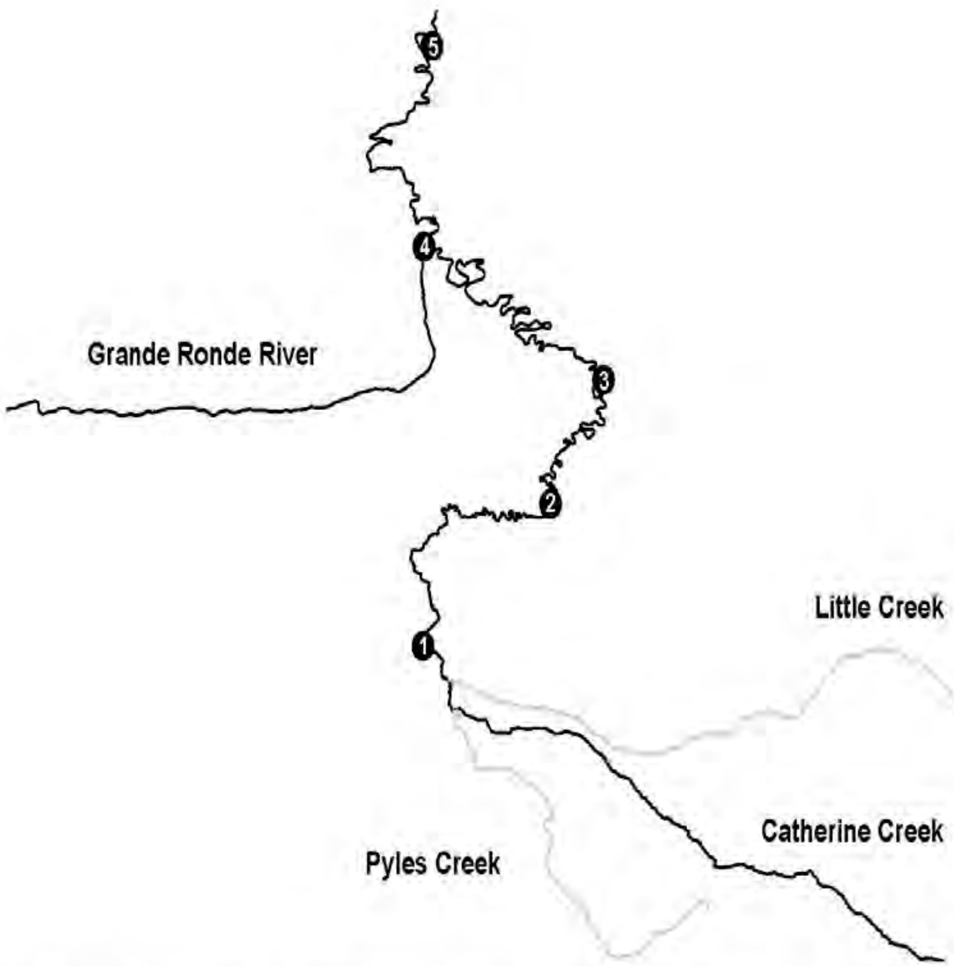

Figure 3.—Map of numbered stationary radio receiver locations installed to document downstream movement of Catherine Creek early migrant juvenile Chinook salmon overwintering in the Grand Ronde Valley. Numbered sites are in close proximity to (1) lower Davis Dam; (2) Gekler Lane; (3) Booth Lane; (4) Alicel Lane and (5) Rhinehart Lane.

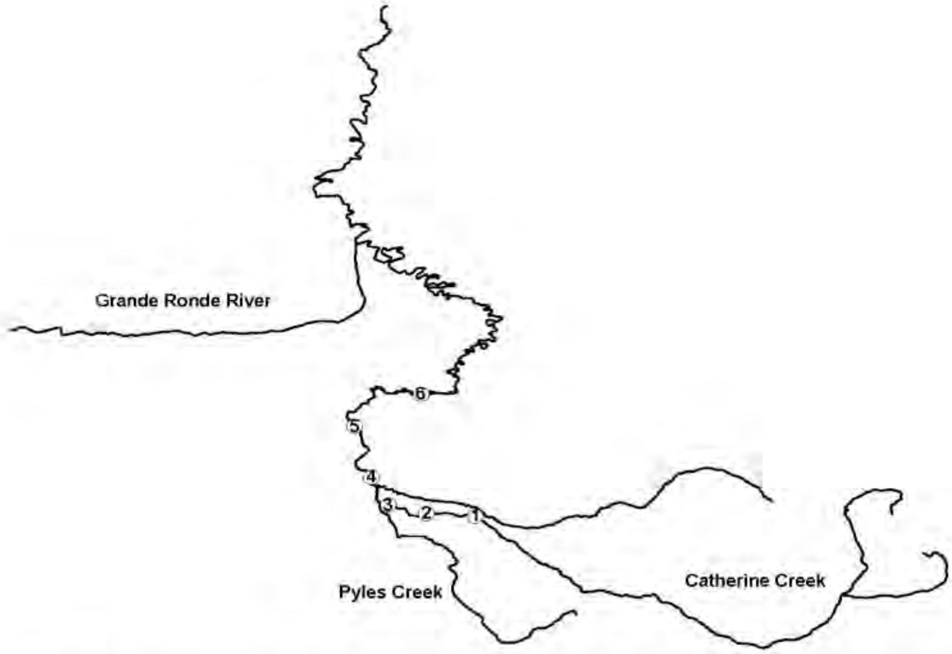

Figure 4.—Map of numbered stream reaches surveyed to quantify Catherine Creek early migrant juvenile Chinook salmon overwintering habitat availability. Numbered sites are in close proximity to (1) Union (Swackhammer fish ladder); (2) Union Recycling Center; (3) mouth of Pyles Creek; (4) HWY 203 Bridge; (5) Wilkinson Road and (6) Godley Lane.

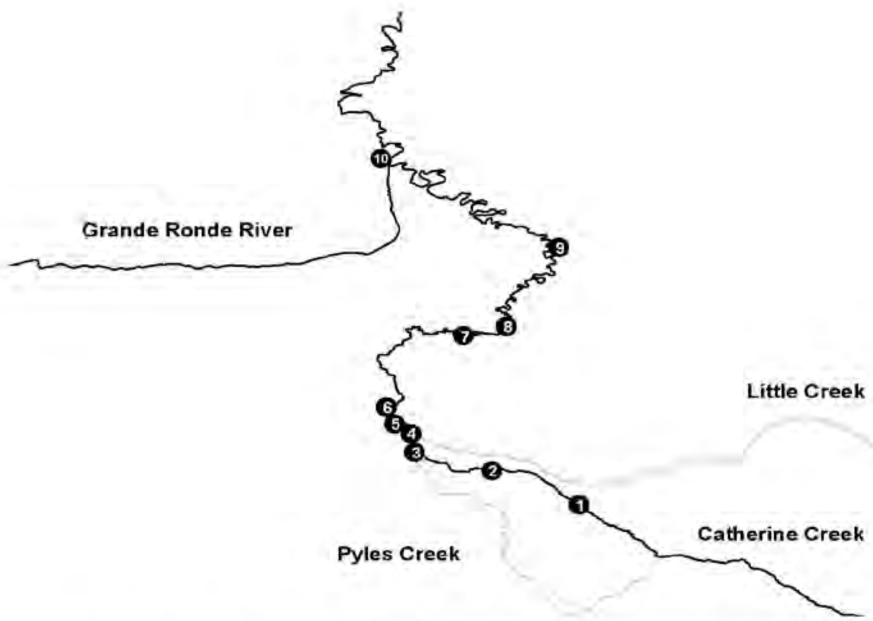

Figure 5.—Map of numbered temperature logger locations installed to document water temperatures associated with the fall migration and overwintering periods of Catherine Creek early migrant spring Chinook salmon. Numbered sites are in close proximity to (1) Catherine Creek screw trap; (2) 10th Street; (3) Miller Lane; (4) HWY 203; (5) lower Davis Dam (above); (6) lower Davis Dam (below); (7) Godley Lane; (8) Gekler Lane; (9) Booth Lane and (10) Alicel Lane.

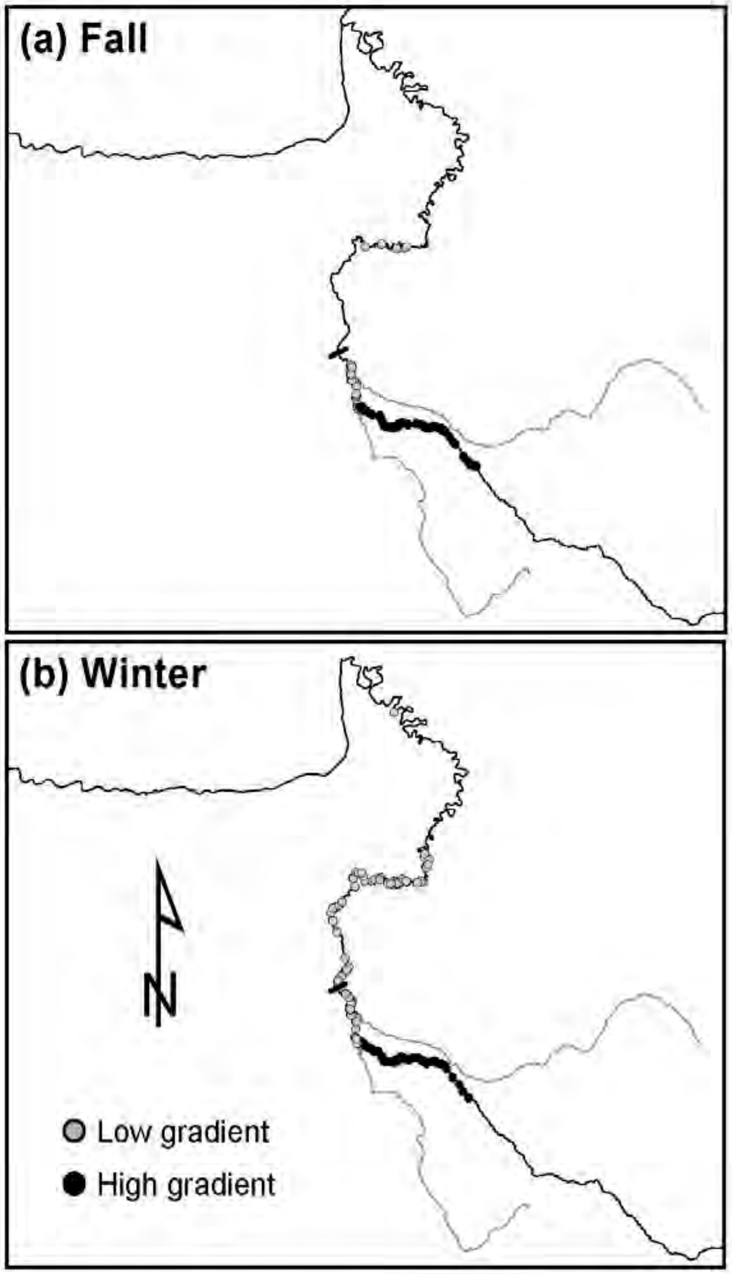

Figure 6.—Seasonal maps characterizing early migrant juvenile Chinook salmon relocations during fall migration and overwinter.

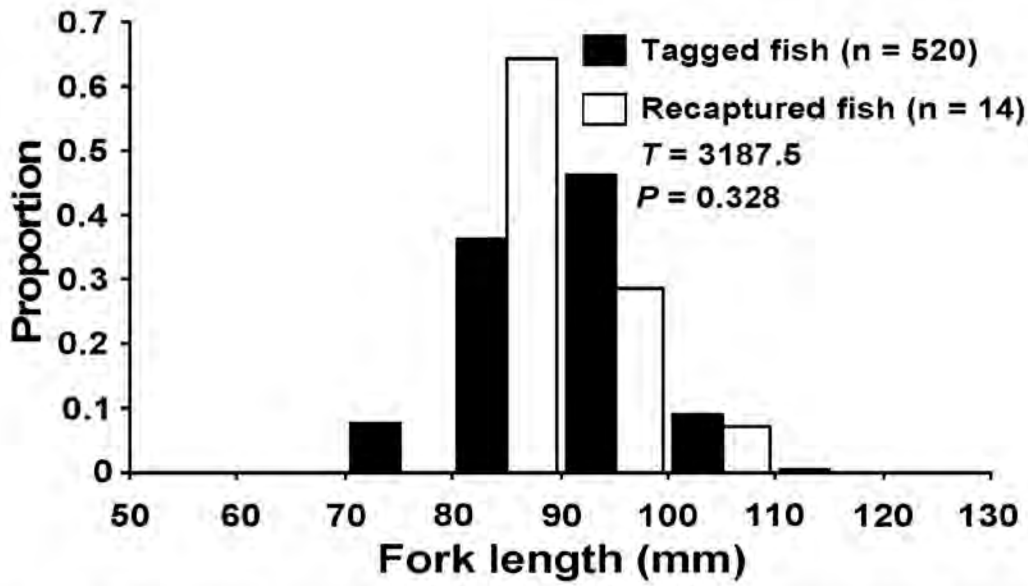

Figure 7.—Fork length comparison of PIT tagged Catherine Creek early migrant Chinook salmon sampled during the fall migration to recaptured PIT tagged fish from overwintering habitat. Recaptured PIT tagged fish were sampled from portions of Catherine Creek occupied by radio-tagged fish. Lengths were compared using the Mann-Whitney rank sum test.

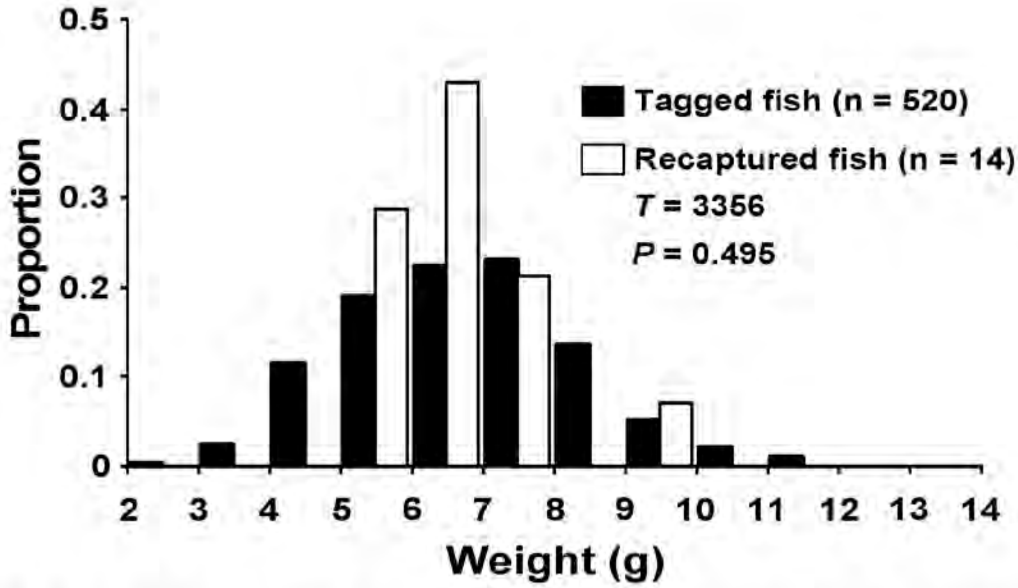

Figure 8.—Weight comparison of PIT tagged Catherine Creek early migrant Chinook salmon sampled during the fall migration to recaptured PIT tagged fish from overwintering habitat. Recaptured PIT tagged fish were sampled from portions of Catherine Creek occupied by radio-tagged fish. Weights were compared using the Mann-Whitney rank sum test.

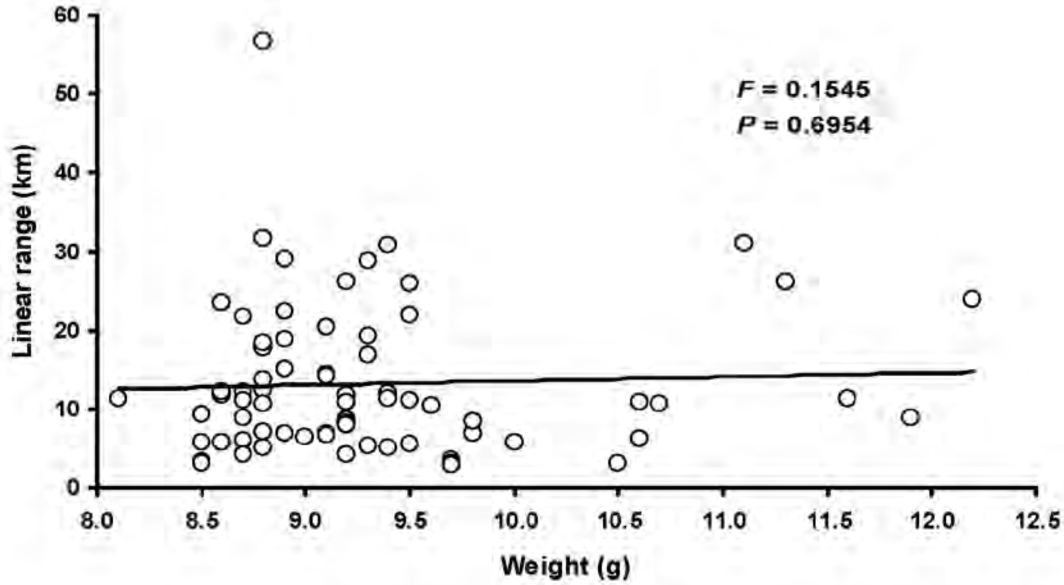

Figure 9.—Linear regression of weight and total linear range of radio-tagged early migrant juvenile spring Chinook salmon from Catherine Creek.

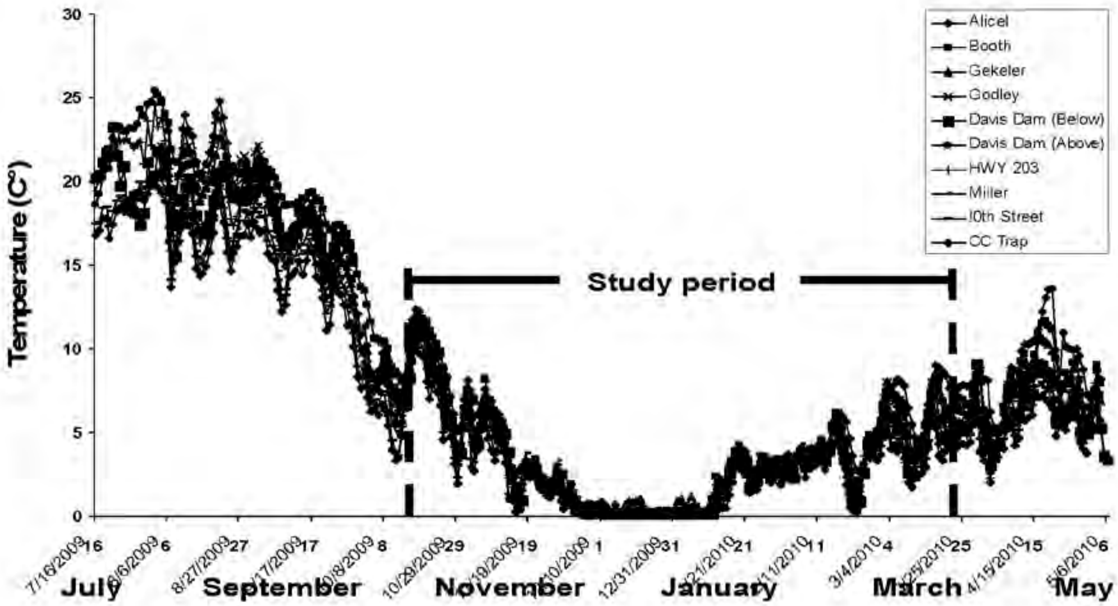

Figure 10.—Continuous water temperature data from lower Catherine Creek. The study period is designated by dashed lines and spans from late-October to late-March.

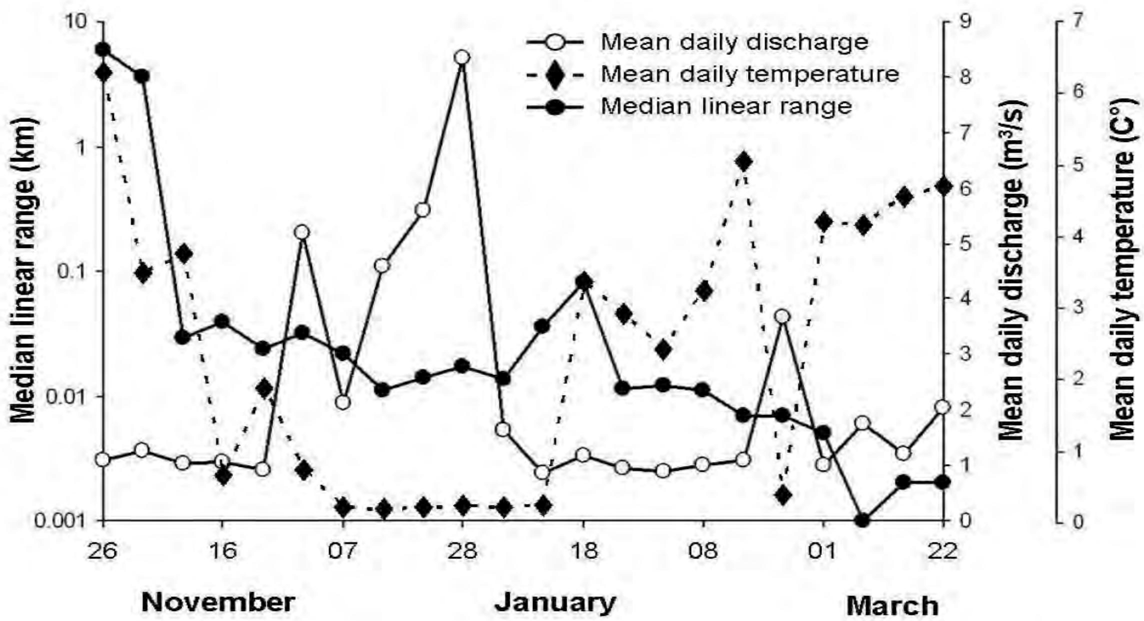

Figure 11.—Catherine Creek early migrant spring Chinook salmon median linear range per week during the fall migration and overwintering periods. Associated environmental variables discharge and water temperature are provided for comparison.

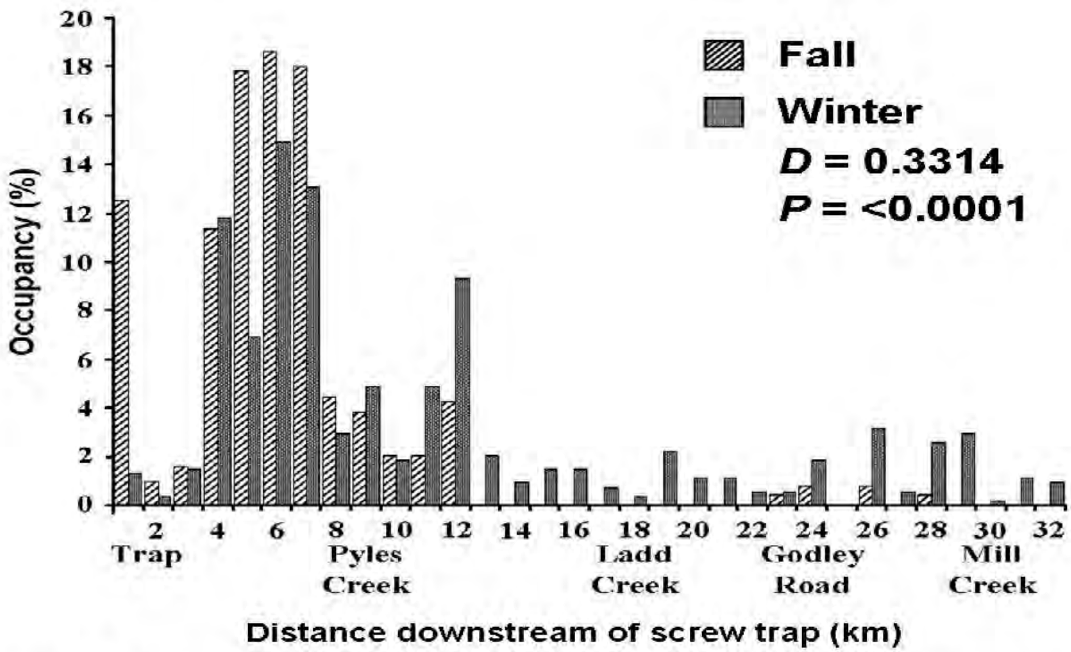

Figure 12.—Fall and winter occupancy by Catherine Creek early migrant spring Chinook salmon. Generated numbered reaches initialize at the Catherine Creek rotary screw trap and end at the confluence of the historic Grande Ronde River and Catherine Creek. Fall and winter relocations were compared using the Kolmogorov-Smirnov two-sample test.

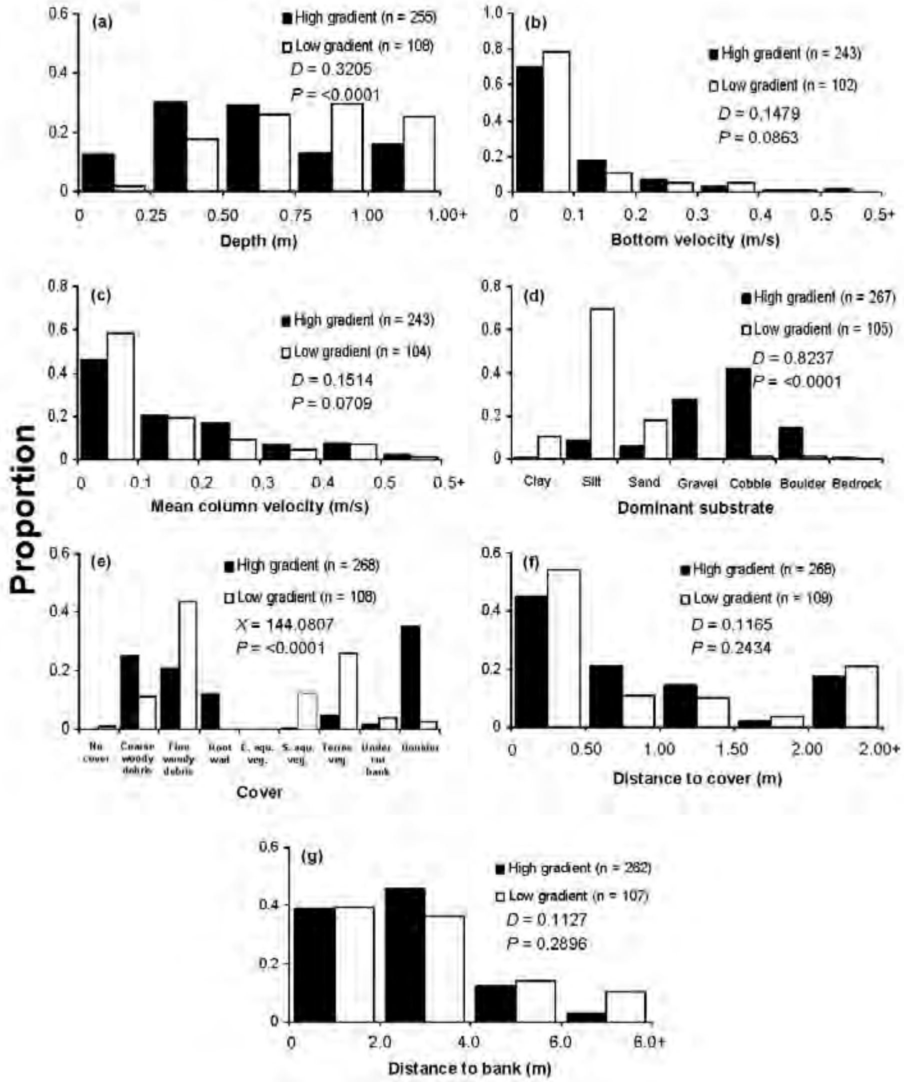

Figure 13.—Catherine Creek spring Chinook salmon high and low gradient microhabitat use variables depth (a), bottom velocity (b), mean column velocity (c), dominant substrate (d), cover (e), distance to cover (f), and distance to bank (g) and associated statistics. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

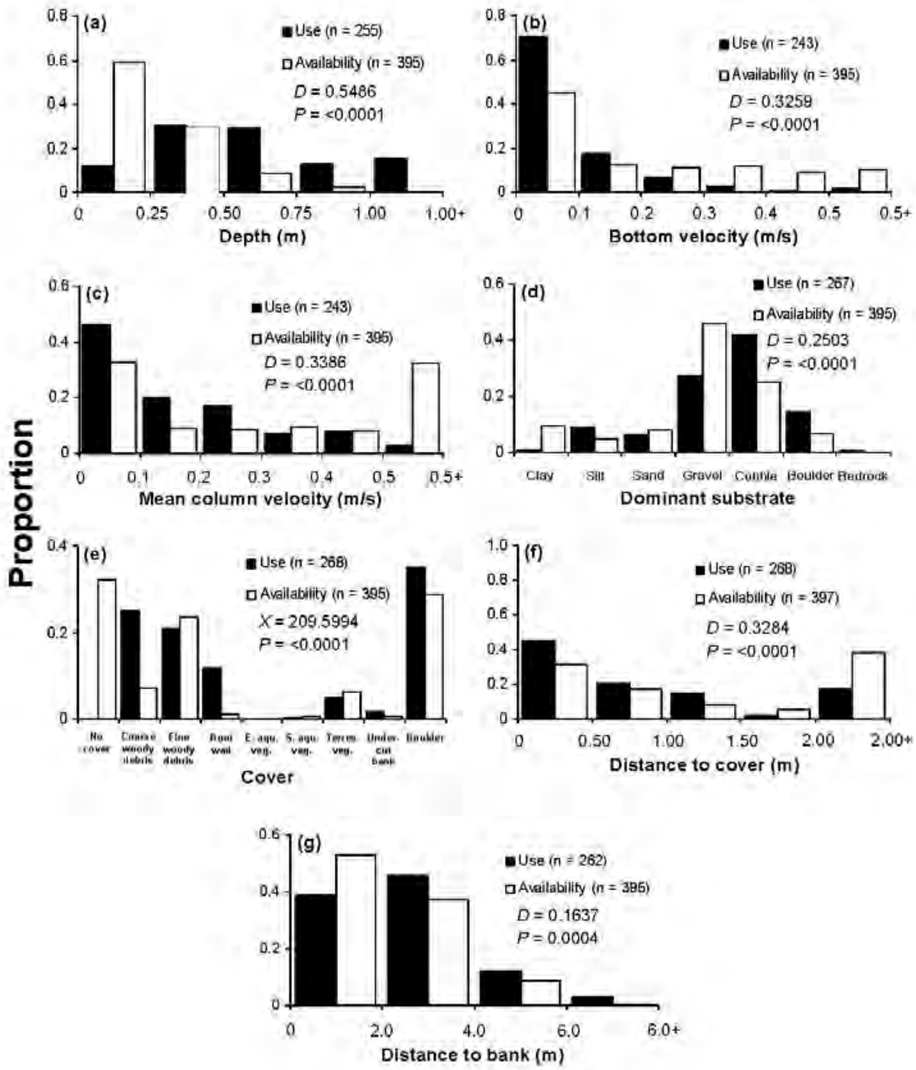

Figure 14.—Catherine Creek spring Chinook salmon high gradient microhabitat use and availability frequency distributions and associated statistics for variables depth (a), bottom velocity (b), mean column velocity (c), dominant substrate (d), cover (e), distance to cover (f) and distance to bank (g). Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

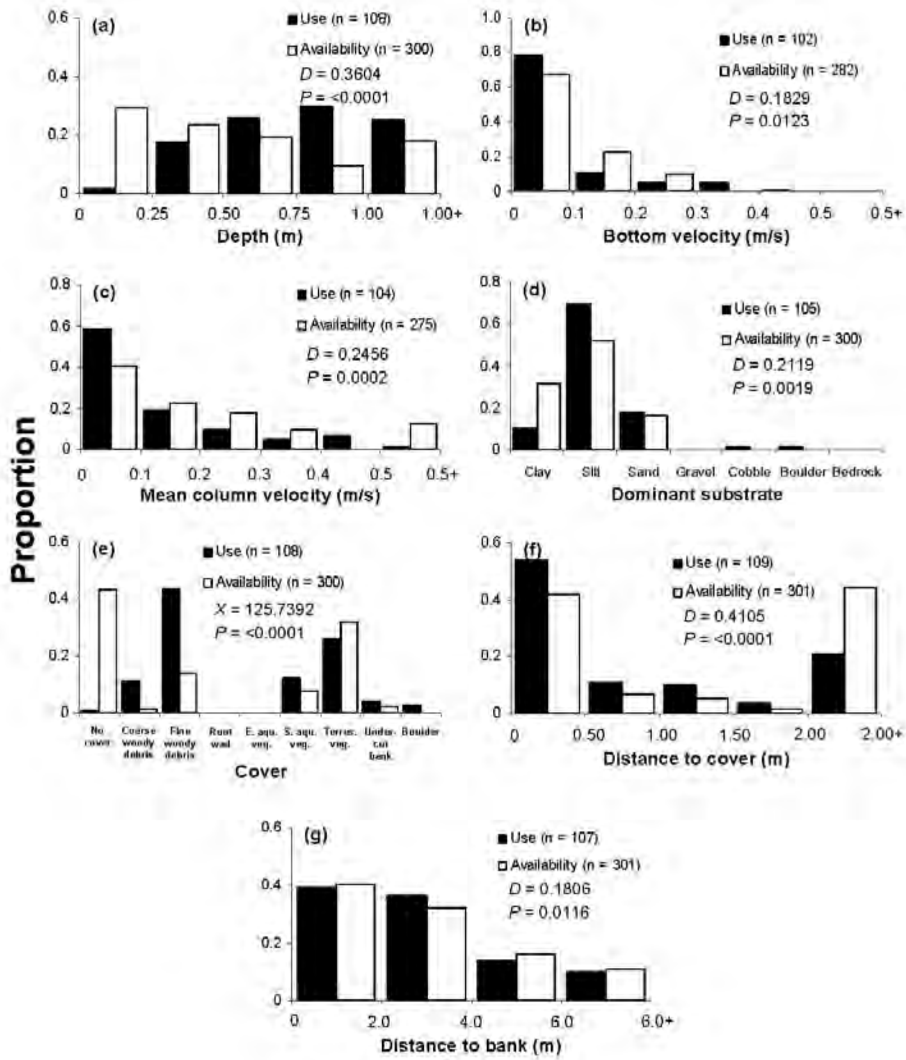

Figure 15.—Catherine Creek spring Chinook salmon low gradient microhabitat use and availability frequency distributions and associated statistics for variables depth (a), bottom velocity (b), mean column velocity (c), dominant substrate (d), cover (e), distance to cover (f) and distance to bank (g). Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

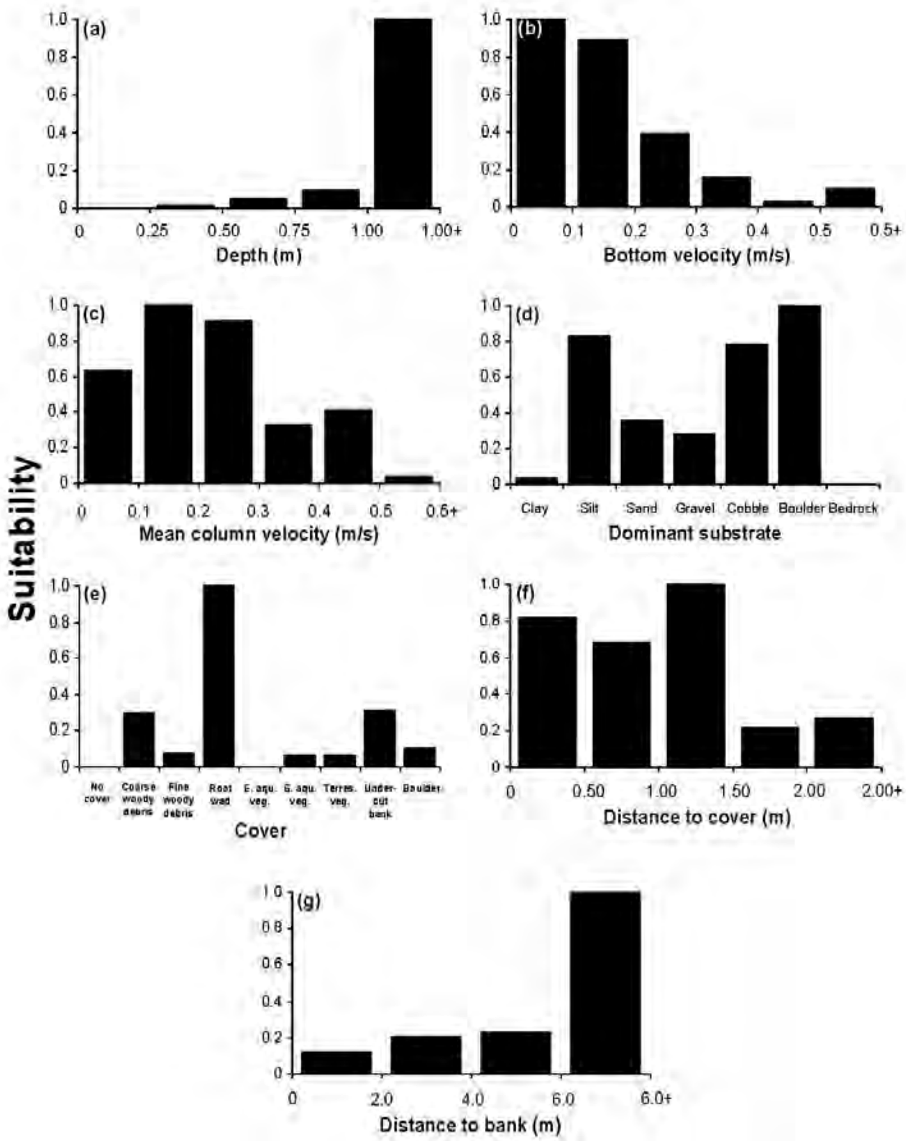

Figure 16.—Catherine Creek spring Chinook salmon high gradient microhabitat suitability indexes for variables depth (a), bottom velocity (b), mean column velocity (c), dominant substrate (d), cover (e), distance to cover (f) and distance to bank (g).

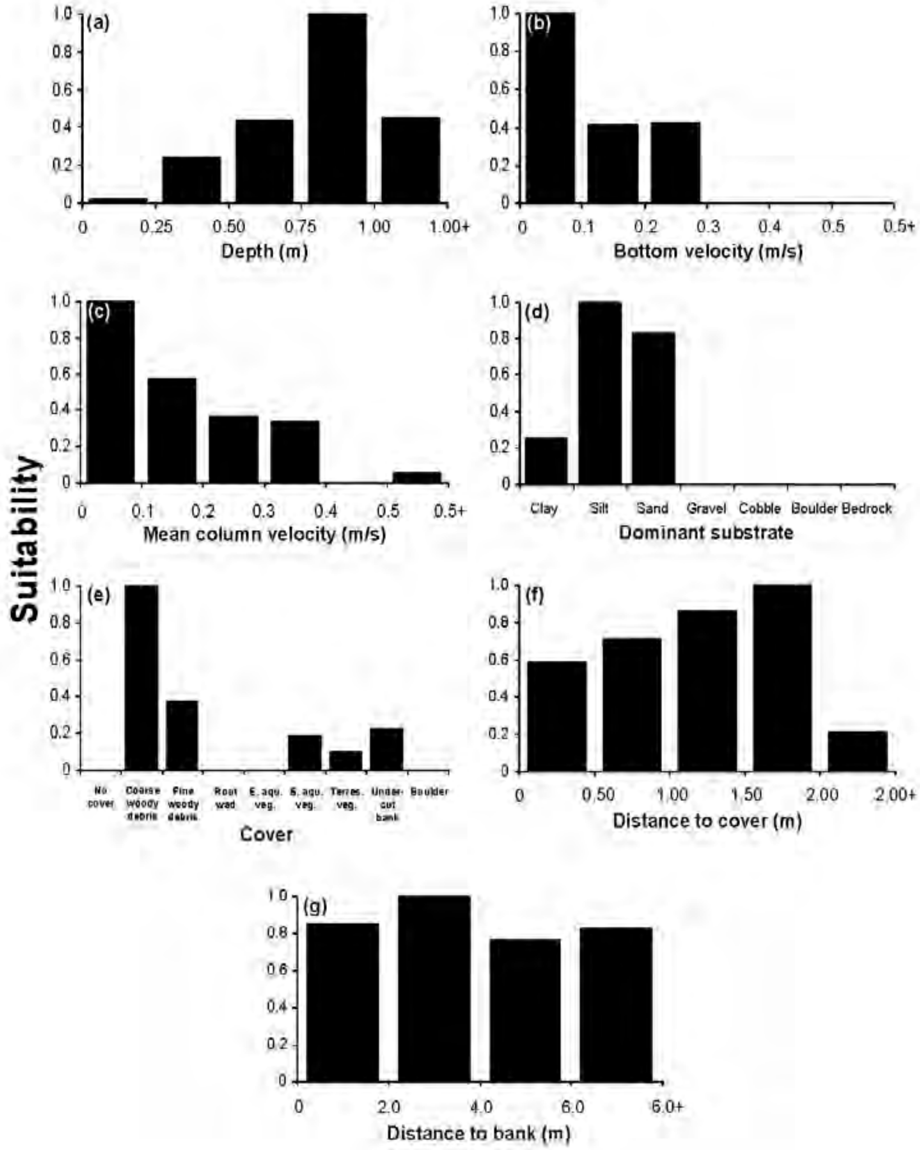

Figure 17.—Catherine Creek spring Chinook salmon low gradient microhabitat suitability indexes for variables depth (a), bottom velocity (b), mean column velocity (c), dominant substrate (d), cover (e), distance to cover (f) and distance to bank (g).

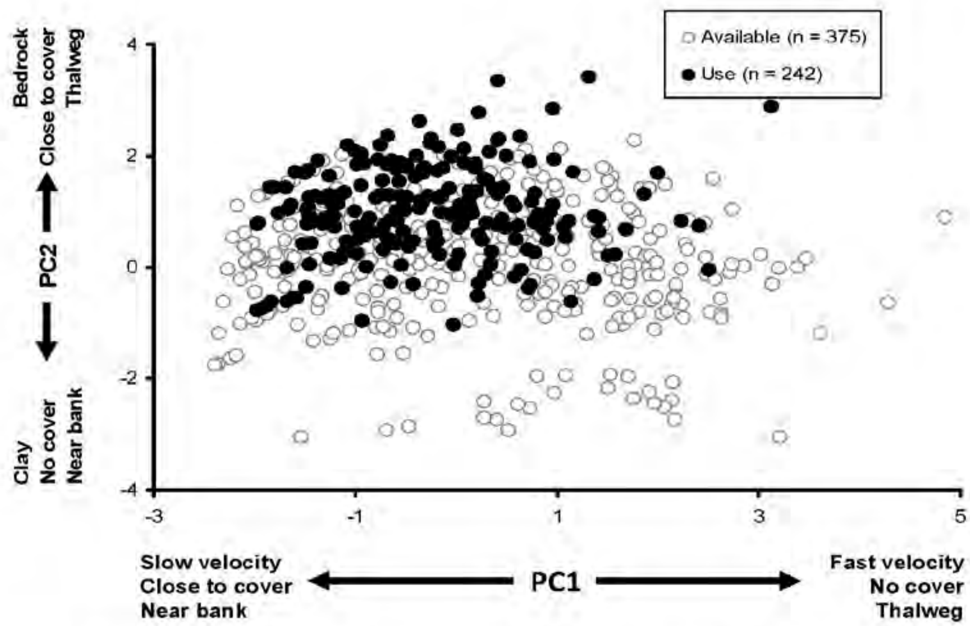

Figure 18.—Plot of juvenile early migrant spring Chinook salmon principal component scores for high gradient microhabitat use and availability, describing microhabitat variable combinations for principal components 1 and 2 that are most important in defining fall migration and overwintering macrohabitat.

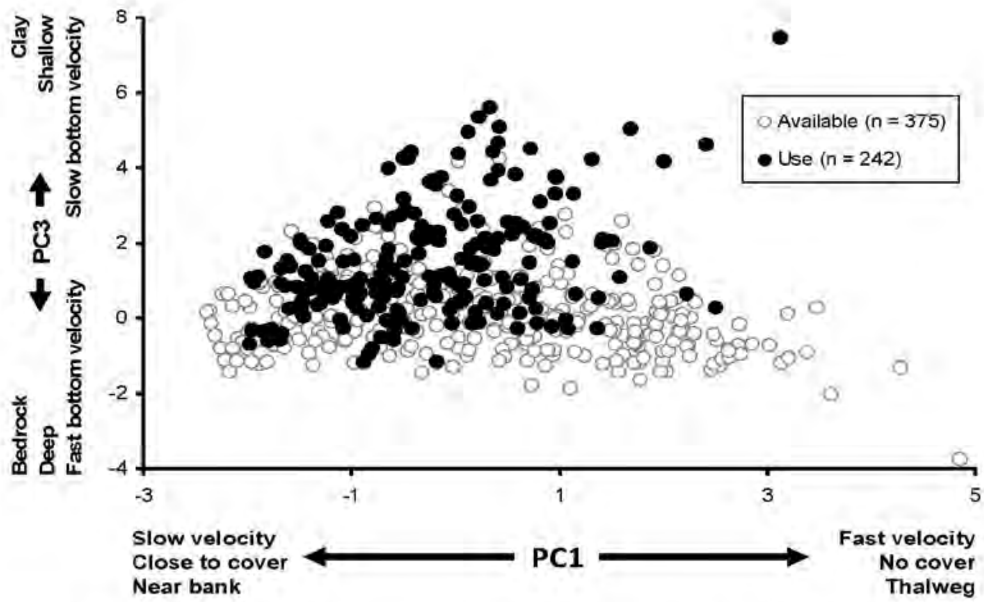

Figure 19.—Plot of juvenile early migrant spring Chinook salmon principal component scores for high gradient microhabitat use and availability, describing microhabitat variable combinations for principal components 1 and 3 that are most important in defining fall migration and overwintering macrohabitat.

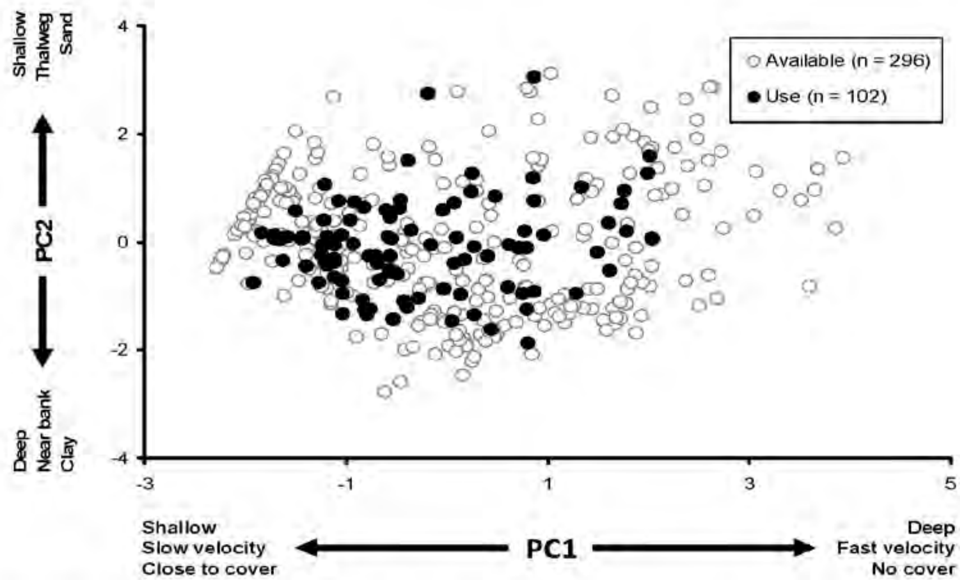

Figure 20.—Plot of juvenile early migrant spring Chinook salmon principal component scores for low gradient microhabitat use and availability, describing microhabitat variable combinations for principal components 1 and 2 that are most important in defining fall migration and overwintering macrohabitat.