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

FINAL REPORT

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Abstract

From 2009 to 2011, we identified overwintering reaches and characterized movement behavior and microhabitat suitability for radio-tagged fall migrant spring Chinook salmon *Oncorhynchus tshawytscha* parr in lower Catherine Creek, northeast Oregon. Primarily, fall migrant parr overwintered in portions of Catherine Creek residing between Union, OR and the mouth of Mill Creek from October through February. To a lesser extent, lower reaches of Catherine Creek and portions of the Grande Ronde River were occupied. Predominantly, movement was directed downstream; however, occasional upstream movement was observed. Median weekly linear range was high during fall migration, while sedentary behavior was prevalent during winter. Brief periods of increased movement were observed during winter and coincided with increased water temperatures. Within the identified overwintering reach, two distinctly different reaches (moderate and low gradient), pertaining to microhabitat availability, were occupied. Generally, free-flowing and surface ice microhabitat use univariate frequency distributions were not significantly different for both reaches. During surface ice conditions, microhabitat use was generally not significantly different between reaches; however, during free-flowing conditions microhabitat use was typically significantly different for all variables measured. Generally, microhabitat use and availability univariate frequency distributions were significantly different for all variables from both reaches (moderate and low gradient) indicating nonrandom habitat use. During free flowing conditions, deep water and slow currents near large woody debris and the bank were most suitable throughout overwintering reaches. Coarse substrates were most suitable in the moderate gradient reach, while fine substrates were most suitable in the low gradient reach. Principal component analyses (PCA) indicated that depth, velocity, substrate, and distance to cover were important microhabitat variable combinations in determining overwintering habitat use in moderate gradient reaches, while depth, velocity, substrate, distance to cover, and distance to bank were most important in low gradient reaches. Radiotelemetry techniques were advantageous toward documenting fall/winter movement and characterizing overwintering microhabitat suitability indices of fall migrant spring Chinook salmon parr. Results from this study suggest appropriate overwintering reaches and types of habitat restoration initiatives needed to successfully implement overwintering habitat improvement projects for spring Chinook salmon parr.

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Introduction

Quantitative characterization and understanding of overwintering movement and critical habitat are imperative toward effective implementation of holistic fisheries management (Cunjak 1996). Nevertheless, salmonid overwintering ecology research has been relatively overlooked by the scientific community, despite the considerable duration of winter and susceptibility of fish to mortality imposed by associated environmental conditions (Brown et al. 2011). Research specifically designed to advance knowledge of salmonid overwintering ecology in lotic environments is deficient, presumably owning to challenges (e.g., surface ice) associated with winter sampling (Swales et al. 1986; Huusko et al. 2007). Yet, modest information pertaining to salmonid overwintering ecology is available in the primary literature (e.g., Robertson et al. 2004; Van Dyke et al. 2009, 2010), albeit sparse compared to information disseminated through research conducted during spring, summer, and fall.

Generally, salmonids redistribute downstream, usually coinciding with fall decreasing water temperatures and increasing discharge, to overwinter (Huusko et al. 2007). Juvenile salmonid spatiotemporal shifts in reach occupancy (e.g., downstream emigration), during fall and early-winter, is the exhibition of a decreased importance of summer rearing (i.e., growth) habitat and increased importance of overwintering (i.e., energy conservation) habitat (Cunjak 1996; Brown et al. 2011). Winter water temperatures (i.e., ≤ 1 °C) result in decreased metabolic processes, subsequently decreasing swimming, feeding, intra- and inter-specific competition, and predator avoidance capabilities (Beamish 1978, Parsons and Smiley 2003, Brown et al. 2011). Decreased metabolic rate and associated redistribution to critical overwintering habitat, during fall and winter decreasing water temperatures, is likely a survival mechanism (Brown et al. 2011) that evolved in environments with consistent seasonality (Fausch and Young, 1995; Huusko et al. 2007).

Seasonally, juvenile salmonid behavior varies significantly; transitioning from active (e.g., feeding and competing) during summer to principally nocturnal and extremely inactive (e.g., aggregating and concealing) during winter (Hillman et al. 1992; Huusko et al. 2007). Overwintering salmonids display high-density aggregating behavior associated with winter water temperatures and relatively-warm groundwater influx; congregating possibly occurring as a squeezing effect due to limited suitable overwintering habitat resulting from low discharge and ice formation (Cunjak and Power 1986; Brown et al. 2011). During daytime, overwintering juvenile salmonids exhibit concealment behavior within unembedded coarse substrate interstitial spaces, likely to conserve energy during non-foraging periods and reduce predation risk (Huusko et al. 2007; Van Dyke et al. 2009). Significantly decreased caloric intake and metabolic rate by overwintering juvenile salmonids is principally associated with sedentary behavior, which is vital to overwintering survival.

Winter sedentary behavior accords with the restricted movement paradigm (RMP; Gerking 1959; Gowan et al. 1994), which states that fish, during favorable conditions, are predominantly sedentary, unless fulfilling necessary life history requirements (e.g., spawning migration and overwinter emigration). Sedentary behavior, although the norm for overwintering juvenile salmonids, is occasionally deviated from with extensive movements occurring throughout winter (Hiscock et al. 2002a). In lotic systems, juvenile salmonid winter movement is more likely to occur during unstable ice conditions, while sedentary behavior is commonly associated with stable ice conditions (Brown et al. 2000). Specifically, juvenile salmonid winter movement is associated with formation and accumulation of frazil and anchor ice (Brown et al. 2000; Simpkins et al. 2000). Typically, winter movement is nocturnal (Hillman et al. 1992; Hiscock et al. 2000b), however; daytime movement has been reported to occur during periods associated with surface ice (Gregory and Griffith 1996; Valdimarson and Metcalfe 1998). Increased movement associated with unstable ice conditions accelerates use of stored energy reserves and reduces the ability of overwintering juvenile salmonids to tolerate subsequent changes in habitat availability, yielding elevated overwintering mortality risk.

Highly suitable winter habitats of lotic fish are positions that minimize energetic cost, while simultaneously maximizing protection from environmental inconsistency (Cunjak 1996; Bonneau and Scarnecchia 1998; Lindstrom and Hubert 2004; Brown et al. 2011). Identification of unbiased temporally specific (e.g., winter) habitat suitability indices are crucial toward juvenile salmonid habitat protection and restoration efficacy. However, collection of unbiased winter habitat use data, representative of an entire juvenile salmonid population, is often complicated. Historically, snorkeling techniques have been employed to collect juvenile salmonid winter microhabitat use data; however, winter environmental conditions necessary to employ snorkeling techniques are severely specific, often to the point of prohibitive or yielding biased results. Typically, snorkel survey techniques designed to collect microhabitat use data necessitate shallow water, low turbidity, free-flowing conditions (e.g., no surface ice), and low velocity (Larimore and Garrels 1985, Winter 1996), which often precludes collection of population representative, spatiotemporally unbiased microhabitat use data. In addition, Bovee (1986) suggested that fright bias (i.e., disturbance) is the most serious form of error a researcher can commit when collecting fish microhabitat use. The act of snorkeling introduces fright bias prior to fish observations, resulting in microhabitat use data from fish occupying refugia or cover habitat instead of preferred habitat (Brignon et al. 2011). Furthermore, if habitat suitability indices are constructed from only perceived undisturbed fish, then only a portion of the population is being represented, yielding erroneous results (Peterson et al. 2005).

Despite innate biases, exacerbated by harsh winter environmental conditions, associated with microhabitat use data obtained through snorkel surveys, winter microhabitat use information has been reported for juvenile salmonids. Peterson et al. (2005) suggest that observations of undisturbed salmonids employing snorkeling techniques are questionable, and any subsequent habitat associations collected are likely biased. Brignon et al. (2011) suggest that snorkeling techniques are perhaps appropriate for collection of mesohabitat use data, but will likely yield invalid microhabitat use results, and recommend caution when extrapolating snorkeling results from "undisturbed" fish to a population level. Additionally, Hillman et al. (1992) reported that snorkeling techniques employed during water temperatures < 9.0°C accounted for less than 20% of juvenile salmonids actually present during the day, further indicating that snorkel survey techniques identify a fraction of juvenile salmonids present in lotic systems during winter. Recent technological advances and miniaturization of radio tag components are enabling fisheries researchers to collect accurate and precise data specific to small fish. Radiotelemetry has numerous advantages over other data collection techniques commonly employed to characterize juvenile fish movement (Hiscock et al. 2002a; Robertson et al. 2004) and habitat use and suitability (Larimore and Garrels 1985). In addition, radiotelemetry techniques permit researchers to quantitatively describe fish metrics, while minimizing fright, spatial, temporal, turbidity, depth, and surface ice biases (Larimore and Garrels 1985).

Minimally biased species- and season-specific movement and microhabitat suitability information is essential toward protection and recovery of depressed fish populations and critical habitat. Furthermore, knowledge and protection of threatened and endangered species during sensitive life cycle stages when mortality rates are high (e.g. overwintering parr), are paramount toward population recovery and persistence. Therefore, we studied overwintering ecology of spring/summer juvenile Chinook salmon *Oncorhynchus tshawytscha*, employing radiotelemetry techniques, with the following objectives: (1) to characterize fall and early-winter emigration to overwintering reaches, (2) to identify microhabitat use during free-flowing and surface ice conditions, and (3) to describe microhabitat suitability during free-flowing conditions.

Methods

Site Description

Our study was conducted within Grande Ronde Valley located in upper Grande Ronde River subbasin of the Blue Mountains Province in northeastern Oregon (Figure 1). Catherine Creek, a tributary of Grande Ronde River, supports a depressed population of ESA-listed Snake River spring/summer Chinook salmon. 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 2004). Catherine Creek juvenile Chinook salmon were selected for this study due to comparatively lower survival rates to the Snake and Columbia river hydrosystem than neighboring populations in northeastern Oregon (e.g., Lostine and Minam river populations; Jonasson et al. 2012).

Catherine Creek is a seventh-order river where it converges with Grande Ronde River and drains approximately 1,045 km^2. Catherine Creek, which is approximately 109.3 km long, originates in the southern slopes of the Wallowa Mountains at a maximum headwater elevation of 2,679 m and converges with the Grande Ronde River at an elevation of 816 m. Overwintering reaches of Catherine Creek have diverse flow and habitat regimes, being comprised of an upstream moderate gradient reach (0.621 % slope) and downstream low gradient reach (0.019 % slope; ArcMap 9.3). Gradient transition occurs in close proximity to the mouth of Pyles Creek (Figure 1). The moderate gradient reach, although severely degraded by channelization, supports riffle-run-pool sequences, while the low gradient reach is extremely entrenched and heavily silted due to agriculture and channelization, best characterized as homogenized run habitat devoid of complexity. The high gradient watershed that encompasses upper Catherine Creek is composed of mixed-coniferous forest, while downstream portions of the watershed are primarily dedicated to agriculture sustained by irrigation. Unstable icing conditions (i.e., numerous freezing and thawing events) are prevalent throughout Catherine Creek from November to April (Van Dyke et al. 2009).

Catherine Creek is partially impounded by three irrigation dams (upper and lower Davis and Elmer dams) from late-summer to mid-winter (Figure 1). Specifically, during 2009 and 2010, both upper and lower Davis dams concluded seasonal impoundment of Catherine Creek on December 1st and November 20th, respectively. During 2011, both upper and lower Davis dams were undergoing renovation; however, associated coffer dams were removed on October 27th. During 2009, a substantial beaver dam was present on Catherine Creek approximately 1.5 km upstream from the mouth of Mill Creek and impounded approximately 10 km of middle Catherine Creek. During 2010, spring flows removed the beaver dam, which was not reestablished during 2010 or 2011.

Radiotelemetry

During October–December (2009–2011), we radio-tagged 98, 129, and 73 naturally produced Catherine Creek juvenile Chinook salmon parr, respectively (Table 1). Coded radio tags (Lotek Wireless; Model NTQ-1) were programed with a 12 h/d duty cycle (signal transmission from 0900 to 2100) to extend tag life. Radio transmitters had an 18 mm trailing antenna and a mean weight of 0.265 g (SD, min–max; 0.006, 0.252–0.299). Radio transmitters operated between 166.300 and 166.380 MHz and were programmed with varied burst rates to reduce signal collision. During 2009, transmitters had a burst rate of 12 pluses per minute. To increase tag life during 2010 and 2011, burst rate was decreased to 6 pulses per minute. During 2009, tags had a typical life of 21 d (warranty life, 17 d); however, during 2010 and 2011, tags had a typical life of 33 d (warranty life, 26 d).

All tagged fish were collected using a rotary screw trap positioned immediately downstream from spawning reaches. Number of weekly tagged fish was approximately proportional to number of captured weekly total emigrants to preclude introduced temporal bias. Tagging occurred at the sampling location following 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 tagging, fish were placed into a 6 L container treated with 70 mg tricaine methanesulfonate (MS 222)/L buffered with sodium bicarbonate. Length (FL, mm), weight (0.1 g) and unique tag code were recorded for all tagged fish.

Fish weighing ≥ 8.5 g were selected for radio-tagging in an effort to limit transmitter to fish weight ratio to ≤ 3.0 %. This threshold is approximately equivalent to a minimum fork length of 90 mm. To obtain adequate sedation, fish were allowed to remain in anesthetizing fluid for an additional 60 s following fish exhibiting loss of equilibrium and reduced opercular rate (i.e., stage 4 anesthesia; Summerfelt and Smith 1990) (mean 5.6 minutes, SD 1.4). A fine foam pad coated with synthetic mucus restoring agent (PolyAqua; Kordon LLC, Hayward, CA) was used to stabilize fish ventral side up. During surgery, a plastic tube was used to continuously administer diluted anesthetic (MS-222, 35 mg/L) over the gills to immediately 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 4.8 minutes, SD 3.5). Upon complete recovery, fish were immediately released into a sheltered pool 50 m downstream of the capture location, which exhibited reduced velocities (Moore et al. 1990).

Radio-tagging protocol used was similar to that of Adams et al. (1998a, 1998b). A 5 mm incision was made anterior to the pelvic girdle 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 minimize internal injury. A trailing antenna outlet was created in the body wall using the shielded-needle technique (Ross and Kleiner 1982; Adams et al. 1998a, 1998b). 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. Following transmitter implantation, sterile, synthetic absorbable, monofilament surgical suture (Maxon 6–0) with a 9 mm 3/8 circle, tapered needle was used to close the incision with two interrupted sutures (Wagner and Cooke 2005). To reduce infection, completed sutures were coated with antibacterial ointment (Vetropolycin). Mean total surgery time for all radio-tagged juvenile Chinook salmon was 4.7 minutes (SD 1.7).

Considerable effort was made to obtain a weekly relocation, from October through February, for each radio-tagged fish following a 24 h recovery period (Martinelli et al. 1998). Weekly tracking of the study area was conducted during March 2009; however, insufficient operational tags precluded March tracking during 2010 and 2011. During 2009, the portion of Catherine Creek residing between the screw trap and mouth of Mill Creek (distance = 30 rkm) was tracked weekly. During 2010 and 2011, increased movement necessitated weekly tracking to the mouth of Indian Creek (distance = 93 rkm). In addition, lower reaches of Pyles Creek and Little Creek were tracked weekly. Periodically, lower reaches of Ladd, Mill, Warm, and Willow creeks were radio-tracked to relocate missing fish.

Mobile tracking was typically accomplished by foot or boat using a Lotek SRX-400 W5XG receiver and a three-element foldable Yagi antenna. Upon receiving a signal from a radio-tagged fish, geographic coordinates were obtained using a hand-held global positioning system unit (Garmin Rino *530HCx*). During 2010 and 2011, an ice auger was employed to obtain microhabitat use measurements when surface ice was present. 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), distance to bank (m), presence of anchor ice, and presence of frazil ice. Additional variables measured when microhabitat use data were collected under surface ice included percent surface ice (%) and surface ice thickness (m).

Significant effort (3,232 person hours) was required to accomplish necessary field work needed to address research objectives. Cumulatively (2009–2011), a total of 318 tracking sessions were completed, resulting in 2,762 relocations and 3,807 river km tracked. On average, 1.38 river km were tracked to obtain a single fish relocation.

Microhabitat Use and Availability

We collected few (i.e., weekly) relocations from many radio-tagged parr to minimize autocorrelation and pseudoreplication, thereby maintaining integrity of population level microhabitat use heterogeneity (Rogers and White 2007). Microhabitat use data were collected from at least 30 randomly selected parr weekly using triangulation techniques (Tables 2, 3). Microhabitat availability data were collected using line-transect survey techniques. Overwintering reaches used by radio-tagged emigrants were divided into lower, middle, and upper sections and availability data were collected from each section (Table 4; Figure 2). Availability data was collected from the middle and upper sections during winter 2010. Additional availability data were collected from the entire reach during winter 2012. All availability data were collected during free-flowing base flow conditions and pooled for subsequent analyses.

Microhabitat availability data were obtained from reaches occupied by tagged fish during flow conditions similar to those associated with microhabitat use. 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 50-m riparian land use (%; Table 5). 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 147 transects were surveyed yielding 1,816 survey points, resulting in approximately 12 points per transect.

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 ≤0.75 m. For depths >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 6). Nearest dominant cover type was visually determined by establishing the presence or absence of cover and then determining distance to fish location. Cover types used were no cover, large woody debris (LWD), small woody debris (SWD), root wad, emersed aquatic vegetation, submersed aquatic vegetation, terrestrial vegetation, undercut bank, and boulder (Table 7). Cover type was considered associated with fish occurrence when cover was ≤2 m from the fish location.

During 2010 and 2011, upon obtaining a triangulated fish location when surface ice was present, a 0.2 m diameter ice auger was used to access the river. Subsequently, ice coverage (%), ice thickness (m), anchor ice presence, and frazil ice presence were recorded. All variables measured during free-flowing conditions were measured during periods of surface ice.

Continuous hourly water temperature data were collected using HOBO Pendant Temperature Loggers (Onset Computer Corporation) from 1 October 2009 to 28 February 2012 at strategic locations along Catherine Creek (Figure 3). Discharge (cubic feet per second, cfs) was acquired from the Oregon Department of Water Resources gaging station 13320000 (available online at http://apps.wrd.state.or.us/apps/sw/hydro_near_real_time/display_hydro_graph.aspx?station_nbr=13320000) and converted to m^3/s.

Statistical Analysis

Tag Burden.—Because relative tag size can affect fish behavior, simple linear regression analyses were employed to compare tag burden to total downstream emigration distance (total linear range) to investigate for possible tag burden effect on movement. Similarly, simple linear regression analyses were used to compare tag burden to mean continuous microhabitat use variables (depth, bottom velocity, mean column velocity, dominant substrate, distance to cover, distance to bank). Because total linear range and microhabitat use data violated assumptions of normality and homoscedasticity, log transformation of data was performed prior to analyses. Multinomial logistic regression analyses were used to compare tag burden to categorical microhabitat use variable dominant cover. Microhabitat data were aggregated (seasonally and annually) prior to analyses, while movement data were analyzed annually.

Spatial Analysis.—Reach occupancy was characterized seasonally (fall and winter). Onset of winter was determined based on water temperature (≤ 1.0 °C) and ice presence, rather than using the astronomical designation (December 21–March 21) of winter (Huusko et al. 2007). Subsequently, winter began on 13, 20, and 2 November during 2009, 2010, and 2011, respectively. To avoid introduction of temporal bias, a mean date of 12 November was designated as the beginning of winter for movement and reach occupancy data analyses.

Median linear range was calculated for all tagged fish. Linear ranges were estimated using techniques 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://viewer.nationalmap.gov/viewer/nhd.html ?p=nhd), was then used to delineate the 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. Annual and seasonal (fall and winter) relocations were compared using the Kolmogorov-Smirnov two-sample test (K-S test).

Microhabitat.—Hartley's test was employed to determine if each microhabitat variable among study years for each reach (moderate and low) and season (fall and winter) could be pooled (Sokal and Rohlf 1998). Because homoscedasticity was prevalent among years, microhabitat use data were pooled prior to all use and suitability analyses; however, microhabitat use and availability data were seasonally (fall and winter) and spatially (moderate and low gradient) stratified for all microhabitat analyses. Moderate and low gradient reach microhabitat availability data were compared using the K-S test. Moderate and low gradient stream morphology and riparian land use availability data were compared using the Mann-Whitney rank sum test.

A spatial difference in seasonal microhabitat use was examined for by comparing moderate and low gradient microhabitat use during free-flowing conditions. Additionally, winter microhabitat use was stratified and analyzed based on presence of surface ice. A spatial difference in microhabitat use was tested for by comparing moderate and low gradient microhabitat use associated with surface ice. To determine if surface ice affected habitat use, microhabitat use associated with free flowing conditions was compared to that associated with surface ice for both moderate and low gradient reaches during winter. All univariate frequency distribution comparisons on continuous fall and winter microhabitat use and availability data were conducted using a K-S test, while categorical use data were compared with an analogous likelihood-ratio chi-square test.

Moderate and low gradient seasonal microhabitat use data were compared to analogous microhabitat availability data. Microhabitat use and availability were compared to assess for non-random use for all variables (depth, bottom velocity, mean column velocity, dominant substrate, distance to cover, distance to bank, and cover). Substrate was treated as a continuous variable due to the continuity of substrate particle sizes, while cover was considered a categorical variable. 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 optimal microhabitat (Waters 1976; Bovee 1986).

Principal component analyses (PCA) were conducted on all continuous microhabitat variables (depth, bottom velocity, mean column velocity, dominant substrate, distance to cover, and distance to bank) to determine seasonal mesohabitat use associated with moderate and low gradient reaches. PCA allows collective interaction among multiple microhabitat variables to be investigated and ranked by importance by creating sequential uncorrelated linear combinations (i.e., principal 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 principal component scores. A K-S test was conducted on retained principal component scores to investigate for statistically significant differences between microhabitat use and availability. A significance level (α) of 0.05 was applied to all statistical tests.

Results

Radio tags were implanted into a total of 300 juvenile spring Chinook salmon fall emigrants (Table 1). Water temperatures during radio-tagging ranged from 0.0 °C to 14.0 °C. Radio-tagged fish had a mean length (FL) of 95.5 mm (SD, min–max; 5.8, 89–107) and mean weight of 9.8 g (SD, min–max; 1.1, 8.5–14.2). Implanted tags emitted a signal approximately 99.3 d (SD, min–max; 14.8, 46–123), 83.1 d (SD, min–max; 21.2, 35–118), and 81.6 d (SD, min–max; 24.3, 40–120) for fish consistently relocated during 2009, 2010, and 2011, respectively.

During 2009, 12 (12%) tagged fish were confirmed mortalities (e.g., bird and mink predation) or cases of tag expulsion (i.e., recovered tags). Two tags were recovered from irrigation ditches. Three (3%) tagged fish were never relocated. During 2010, no mortalities were confirmed by recovering tags; however, 6 (6.1%) tagged fish were never relocated. During 2011, 1 (1.4%) tag was recovered; however, source of tag loss could not be determined. Six (8.2%) tagged fish were never relocated. In aggregate, of the remaining 272 tagged fish, an average of 10.2 (SD, min–max; 4.8, 1–24) relocations were obtained per fish.

Of 272 fish that yielded relocations, the majority of these fish remained within the Catherine Creek drainage throughout the study period. Generally, relocations occurred within Catherine Creek; however, 8 (2.9%) fish were relocated occupying Little Creek, 3 (1.1%) fish ascended Pyles Creek, and 1 (0.4%) fish was relocated occupying Willow Creek. During 2009, overwinter occupancy of Grande Ronde River was not detected; however, a total of 21 (7.7%) fish were relocated occupying Grande Ronde River between the mouths of Catherine and Indian creeks during 2010 and 2011.

During 2009, 2010, and 2011, 30.8, 40.5, and 35.8% of weekly movements were ≥ 0.1 km, 18.9, 27.9, and 27.2% of weekly movements were ≥1.0 km, and 1.6, 6.0, and 12.0% of weekly movements were ≥10.0 km, respectively. Despite parr exhibiting predominantly sedentary behavior upon occupancy of overwintering reaches, the majority of tagged parr exhibited brief substantial movements during winter. During 2009, 2010, and 2011, 73.2, 81.3, and 78.8% of tagged parr exhibited occasional weekly movements (≥0.1 km) throughout the duration of radio tag activity (fall to late-winter), while 26.8, 18.7, and 21.2% of tagged parr exclusively exhibited sedentary behavior following occupancy of overwintering reaches, respectively.

In aggregate, during fall, mean water temperature for moderate gradient fish relocations was 5.99 °C (SD, min–max; 2.06, 2.20–10.10), and mean dissolved oxygen was 12.75 mg/L (SD, min–max; 0.96, 10.25–15.25). Mean water temperature for low gradient fish relocations was 5.25 °C (SD, min–max; 1.92, 2.40–9.80), and mean dissolved oxygen was 12.71 mg/L (SD, min–max; 0.69, 10.43–13.72). During winter, mean water temperature for moderate gradient fish relocations was 1.99 °C (SD, min–

max; 1.58, 0.00–6.00), and mean dissolved oxygen was 14.42 mg/L (SD, min–max; 0.92, 11.00–16.81). Mean water temperature for low gradient fish relocations was 1.95 °C (SD, min–max; 1.58, 0.00–8.00), and mean dissolved oxygen was 13.79 mg/L (SD, min–max; 1.01, 10.61–17.10).

Tag Burden

Average tag burden was 2.7% (SD, min–max; 0.003, 1.8–3.3%). Some (52, 17.3%) radio-tagged parr experienced tag burdens in excess of our pre-established 3.0% upper tag burden limit due to excessive tag weights (i.e., > 0.25 g; Table 1). Simple linear regression indicated that there was not a significant relationship between imposed tag burdens and microhabitat use for all continuous variables ($P > 0.05$; Figure 4). Similarly, multinomial logistic regression indicated that there was not a significant relationship between experienced tag burden and microhabitat use for categorical variable dominant cover ($P = 0.9000$; Figure 4). In general, simple linear regression indicated that there was not a significant relationship between overwintering total linear range and imposed tag burden ($P > 0.05$), except during 2011 ($P = 0.0495$) when total linear range tended to decrease as tag burden increased (Figure 5).

Linear Range and Reach Occupancy

Annually, distributions of overwintering parr relocations were significantly different ($P < 0.0001$; Figure 6). Seasonally, distributions of parr relocations during fall and winter were significantly different ($P < 0.0001$; Figure 7), indicating that a seasonal spatiotemporal shift occurs resulting in considerably different reach occupancy. Overall, during fall, a majority of relocations (n = 455, 69.9%) occurred in moderate gradient reaches, while 196 (30.1%) relocations occurred in low gradient reaches. However, during winter, a comparable number of relocations occurred in moderate (1,132, 53.0%) and low (1,004, 47.0%) gradient reaches (Figure 7). Of 46 relocations that occurred in Catherine Creek and Grande Ronde River tributaries, 3 (6.5%) occurred during fall and 43 (93.5%) occurred during winter.

Generally, monthly median linear range (i.e., movement) was considerably greater during fall than winter (Table 8). High fall monthly median linear ranges were associated with fish redistributing from summer rearing reaches to downstream overwintering reaches. Depressed winter monthly median linear ranges coincided with fish demonstrating sedentary behavior during winter. During each winter examined (2009–2011), brief peaks in monthly median linear range occurred (Table 8). Elevated winter movement was attributed to numerous fish briefly reinitiating downstream emigration. The majority of these mobile fish abandoned moderate gradient reaches upstream from the mouth of Pyles Creek and occupied low gradient reaches between the mouths of Pyles and Indian creeks.

Water temperature appeared to be a proximate migration stimulus associated with movement during fall migration and overwinter rearing (Figure 8). Weekly median linear range decreased and was associated with decreasing water temperatures during mid-

November when sedentary behavior became prevalent (Figure 8). Sedentary behavior coincided with water temperatures near 0 °C. Peaks in movement during winter (mid-January 2009; mid-December and mid-January 2010; January 2011) closely coincided with increasing water temperatures (2–4 °C; Figure 8). Several peaks in discharge occurred during winter; however, associated increases in movement were typically nonexistent. During 2010, a considerable mid-winter freshet occurred that was associated with an increase in movement; however, elevated water temperatures occurred simultaneously (Figure 8).

Movement was predominantly directed downstream; however, some upstream movement occurred during winter (Figure 9). During 2009, 2010 and 2011, 16 (1.8%), 12 (1.3%), and 1 (0.2%) upstream movements were detected, respectively. During our study, median weekly distance moved upstream was 0.20 km (SD, min–max; 0.73, 0.10–2.90). Two (7.7%) of 26 fish made considerable upstream movements and reoccupied overwintering habitat previously vacated during fall and early-winter.

Microhabitat

Microhabitat Availability.—Univariate frequency distributions for moderate and low gradient microhabitat availability were significantly different for all variables ($P < 0.05$; Tables 2, 3). The moderate gradient reach exhibited shallower depths with considerably swifter currents flowing over coarser substrates. Dominant substrates available in the moderate gradient reach ranged from clay to bedrock, while dominant available substrates ranged from clay to sand in the low gradient reach (Tables 2, 3). Dominant cover type within the moderate gradient reach was SWD, while “no cover” was the dominant cover type in the low gradient reach. Cover was absent from 19.2% and 46.3% of moderate and low gradient reaches, respectively. More than half of all microhabitat availability survey points were within 2.0 m of cover (80.8%, moderate gradient; 53.7%, low gradient; Tables 2, 3).

Moderate and low gradient stream and riparian morphology characteristics were significantly different for all variables ($P < 0.05$; Table 5), with the exception of percent developed riparian buffer ($P = 0.063$). The low gradient reach was significantly wider than the moderate gradient reach, and exhibited significantly shallower bank angle. Undercut bank presence was relatively deficient for both reaches; however, undercut bank distance was significantly greater in the moderate gradient reach. Percentage of riparian zone forested was significantly greater for the moderate gradient reach, while percentage of land devoted to agriculture was significantly greater for the low gradient reach. Percentage of developed riparian buffer was not significantly different between reaches. Despite considerable differences in riparian land use, the majority of land use was dedicated to agriculture with forested and developed categories each typically contributing 10% or less (Table 5).

Microhabitat Use Comparisons.—During 2010 and 2011, frazil ice was observed at 36 (6.2%) triangulated locations from which microhabitat use data was collected. Surface ice was present at 124 (21.3%) triangulated locations, while anchor ice was observed at 32 (5.5%) microhabitat use locations. For all triangulated locations from which ice thickness could be obtained (n = 112), mean thickness was 0.03 m (min–max, 0.01–0.25).

Fall and winter univariate frequency distributions were not significantly different for variables mean column velocity, substrate, and distance to cover in the moderate gradient reach, and depth, bottom velocity, substrate, cover, distance to cover, and distance to bank in the low gradient reach (Table 9). In the moderate gradient reach, parr tended to transition to deeper depths supporting swifter bottom velocities and LWD further from the bank during winter. In the low gradient reach, parr generally used deep depths supporting slow currents over fine substrates near LWD and the bank during fall and winter; however, parr did occupy significantly swifter mean column velocities during winter (Table 9).

Winter univariate frequency distributions of moderate gradient microhabitat use, associated with free-flowing and surface ice conditions, were not significantly different for all variables during winter ($P > 0.05$), with the exceptions of bottom velocity ($P = 0.0207$) and mean column velocity ($P = 0.0021$; Tables 10, 11; Figure 10). Juvenile Chinook salmon overwintering in moderate gradient reaches, regardless of ice presence, occupied deep water over coarse substrates near boulders, woody debris, and the bank (Tables 10, 11; Figure 10). Slower current velocities were utilized significantly greater during surface ice conditions (Figure 10). Winter univariate frequency distributions of low gradient microhabitat use, associated with free-flowing and surface ice conditions, were not significantly different for all variables ($P > 0.05$; Tables 10, 11; Figure 11). Juvenile Chinook salmon overwintering in low gradient reaches, regardless of ice presence, occupied deep water with slow currents over fine substrates near cover (LWD and terrestrial vegetation) and the bank (Tables 10, 11; Figure 11).

Winter univariate frequency distributions of moderate and low gradient microhabitat use, during surface ice presence, were not significantly different for all variables during winter ($P > 0.05$), with the exceptions of dominant substrate ($P < 0.0001$) and cover ($P = 0.0033$, Table 12; Figure 12). When surface ice was present, significantly smaller substrates (e.g., silt) were used in the low gradient reach (Figure 12). Use of terrestrial vegetation as cover was more prominent in the low gradient reach during surface ice conditions, while use of boulders occurred more frequently in moderate gradient reaches (Figure 12).

During fall and winter free-flowing conditions, microhabitat use variables depth, bottom velocity, mean column velocity, dominant substrate, cover type, and distance to cover were significantly different ($P < 0.05$) between low and moderate gradient reaches; while variable distance to bank was not significantly different ($P > 0.05$) between reaches (Tables 13, 14; Figures 13,14). Overwintering juvenile Chinook salmon occupied deeper water in low gradient reaches compared to moderate gradient reaches. Use of slow bottom and mean column velocities was prevalent in both reaches; however, use of velocities ranging from 0.0 to 0.1 m/s was significantly greater in the low gradient reach. Cobble was the modal dominant substrate used in the moderate gradient reach, while silt was the modal dominant substrate used in the low gradient reach. For both reaches, occupancy typically occurred near the bank (0–4 m). During fall, terrestrial vegetation and boulders were most frequently used as cover within the moderate gradient reach; LWD and terrestrial vegetation were predominantly used in the low gradient reach. During winter, woody debris and boulders were heavily used as cover in the moderate gradient reach, while woody debris and terrestrial vegetation were most used in the low gradient reach. Most fish relocations occurred in close proximity to cover for both low and moderate gradient reaches, with the majority being less than or equal to 0.50 m (Figures 13, 14).

Microhabitat Use and Availability Comparisons.— Fall and winter univariate frequency distributions of microhabitat use and availability were significantly different for all variables for both moderate and low gradient reaches ($P < 0.05$; Tables 15,16; Figures 15–18), with the exception of fall dominant substrate use ($P = 0.9992$, low gradient). Mean depth used was greater than that available for both moderate and low gradient reaches, indicating that spring Chinook salmon parr disproportionally occupy deep depths during fall migration and overwinter rearing. Moderate gradient bottom velocity mean use was slower than that available, indicating that parr occupy the slowest bottom velocities available, and to a lesser extent, a similar trend was present for the low gradient reach. A similar relationship of slower velocities being used than available was documented for variable mean column velocity for both low and moderate gradient reaches during fall and winter. Moderate gradient modal available dominant substrate was gravel, while utilized modal dominant substrate was cobble, indicating that coarser available substrates were occupied; silt was most commonly available and used by overwintering parr in the low gradient reach during fall and winter. Distance to bank mean use was smaller than the corresponding availability mean for both the moderate and low gradient reaches, indicating that overwintering parr disproportionally occupied habitat close to the bank during fall and winter. During fall, parr occupying the moderate gradient reach most frequently used boulders and terrestrial vegetation as cover; large and small woody debris and terrestrial vegetation were most commonly used in the low gradient reach, despite cover not being readily available in either reach (Table 15; Figures 15, 17). During winter, parr occupying the moderate gradient reach most frequently used large and small woody debris and boulders as cover; large and small woody debris and terrestrial vegetation were most commonly used in the low gradient reach, despite cover not being readily available in either reach (Table 16; Figures 16, 18). Extensive clusters of tumbleweed *Sisymbrium altissimum* and American waterweed *Elodea canadensis* were commonly available and heavily used in the low gradient reach, but not available in the moderate gradient reach. For both the moderate and low gradient reaches, distance to cover use means were less than microhabitat availability distance to cover means; indicating that overwintering parr, regardless of reach occupied, were consistently rearing close to cover during fall emigration and overwintering (Tables 15, 16).

Microhabitat Suitability.—Fall and winter univariate microhabitat suitability indices revealed suitable microhabitat during fall migration and overwintering periods for Catherine Creek spring Chinook salmon parr (Figures 19, 20). During fall and winter, deep depths (> 1.0 m) were most suitable in the moderate gradient reach, while moderate depths (0.75–1.0 m) were most suitable in the low gradient reach. Slow bottom velocities (0.0–0.1 m/s) were most suitable in all reaches occupied. Moderate mean column velocities (0.0–0.3 m/s) were most suitable in both reaches. Cobble and boulder substrates were most suitable within the moderate gradient reach, while clay and silt were most suitable in the low gradient reach. LWD, undercut bank, and root wad were most suitable cover types in the moderate gradient reach, while LWD was most suitable in the low gradient reach (Figures 19, 20). Moderate to small distances to cover (0.0–1.5 m) were most suitable in both moderate and low gradient reaches. Distances from bank ≤ 4.0 m were most suitable within both the moderate and low gradient reaches (Figures 19, 20).

Multivariate Analyses.—Within the moderate and low gradient reaches during fall and winter, parr occupied mesohabitat nonrandomly for components 1 and 2 ($P < 0.05$; Tables 17, 18). For the moderate gradient reach during fall and winter, PCA indicated that combinations of all continuous variables measured (depth, bottom velocity, mean column velocity, dominant substrate, distance to cover) were important in determining mesohabitat selection, with the exception of distance to bank (Tables 19, 20). For the low gradient reach during fall and winter, 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 mesohabitat selection (Tables 21, 22). For fall and winter, retained components 1 and 2 explained a cumulative variance of 58.2% and 64.5% for the moderate and low gradient reaches (Tables 19–22), respectively. For both reaches during fall and winter, distance to cover, bottom velocity, and mean column velocity loadings were large enough to indicate a significant influence on PC1. Additionally, depth had a loading indicating considerable influence on PC1 for the low gradient reach; however, the depth loading was too small to significantly influence PC1 for the moderate gradient reach. Loadings for dominant substrate were too small to significantly influence PC1; however, the dominant substrate loading contributed to PC2 for both reaches during fall and winter. Loadings for distance to bank were too small to indicate considerable influence on PC1 for both reaches, however were influential on PC2 for the low gradient reach during fall and winter (Tables 19–22).

During fall and winter, within the moderate gradient reach, parr typically occupied habitat exhibiting slow currents near cover (high PC1 scores), and rarely occupied swift currents with cover absent (low PC1 scores; Figures 21, 22). In addition, fish were associated with moderate substrates (e.g., cobble) when deep depths and slow bottom velocities co-occurred (moderate to low PC2 scores); fish rarely occupied shallow depths exhibiting swift velocities over coarse substrates (high PC2 scores; Figures 21, 22). Within the low gradient reach, overwintering parr occupied shallow to moderate depths when slow currents and cover co-occurred (low PC1 scores), and tended to avoid deep water when fast currents were present with the absence of cover (high PC1 scores; Figures 23, 24). In addition, parr occupying the low gradient reach were near the bank when moderate current velocities and fine substrates co-occurred (moderate PC2 scores; Figures 23, 24).

Discussion

Median linear range was substantially less during 2009 compared to 2010 and 2011. In general, water temperature, discharge regimes, and ice formation were similar among years studied. However, during 2009, irrigation dams impounded Catherine Creek longer than during 2010 and 2011 and, a beaver dam substantially impounded middle Catherine Creek. Several radio-tagged parr successfully negotiated irrigation (e.g., Davis and Elmer dams) and beaver dams during 2009, indicating these structures were not complete obstructions to emigration. We hypothesize that impounded reaches of Catherine Creek may have functioned as suitable overwintering habitat, contributing to decreased total linear range during 2009. Numerous salmonid studies have documented considerable use of beaver ponds during winter (Collen and Gibson 2001). Pollock et al. (2004) estimated an overall reduction of 86% in coho salmon *O. kisutch* smolt production potential for the Stillaguamish Watershed located in northwestern Washington, and attributed the majority of the reduction to loss of beaver ponds. Generally, juvenile salmonids exhibit sedentary behavior during winter when occupying stable habitat, such as pools and beaver ponds (Heggenes et al. 1991; Hilderbrand and Kershner 2000; Simpkins et al. 2000; Sanderson and Hubert 2009; Brown et al. 2011).

We documented predominantly sedentary behavior during periods of ice formation and presence (e.g., anchor and frazil ice). Our findings are contrary to research which reported that extensive salmonid winter movements are associated with frazil and anchor ice (Brown and Mackay 1995; Jakober et al. 1998; Brown 1999; Brown et al. 2000; Simpkins et al. 2000; Lindstrom and Hubert 2004), although accord with the notion that small juvenile salmonids can tolerate periods of anchor and frazil ice formation (Brown et al. 2011). For salmonids, juveniles and adults occupying lotic systems may react differently to environmental stochasticity during winter. Extensive winter movements during ice formation events can be energetically costly to fish, resulting in an elevated risk of mortality (Lucas and Baras 2001; Brown et al. 2011). Small juvenile salmonids may be able to satisfy overwintering habitat requirements by conducting small-scale localized movements to occupy habitat (e.g., ice shelves and substrate crevices) not available to larger adult salmonids, thus forgoing elevated probabilities of mortality associated with extensive movements during harsh winter hydrologic conditions (e.g., hanging ice dams).

During our study, fall emigration and subsequent occupancy of downstream overwintering reaches tended to be associated with decreasing water temperatures. Other researchers have documented salmonid fall emigrations associated with decreasing water temperatures (Bjornn 1971; Chisholm et al. 1987; Brown and MacKay 1995; Fausch and Young 1995; Cunjak 1996; Jakober et al. 1998; Lindstrom and Hubert 2004). However, during winter, we consistently documented extensive downstream emigration associated with increasing water temperatures by previously sedentary overwintering parr. Extensive movements by salmonids during winter have been associated with frazil and anchor ice accumulation, high discharge events, and maturation state (Huusko et al. 2007). Recent research has associated increased salmonid overwintering movement with increasing water temperatures. We are unaware of research documenting population-level extensive downstream movement associated with increasing water temperatures during winter; however, an abundance of research has identified increasing water temperatures as a proximate environmental stimulus associated with juvenile salmonid sea-ward migration during early-spring (Bjornn 1971; Jonsson and Ruud-Hansen 1985; Whalen et al. 1999; Sykes et al. 2009; Tiffan et al. 2012). Several studies have shown that smolts initiate spring emigration earlier associated with increased water temperatures (Roper and Scarnecchia 1999; Whalen et al. 1999; Sykes et al. 2009), while others have reported that low water temperatures during spring may delay spring emigration (Raymond 1979; Achord et al. 1996). Significance and causality of our observation of increased water temperature being a proximate factor to considerable winter downstream movement by overwintering parr is unclear; however, establishing that overwintering parr exhibit extensive downstream movement associated with increased water temperatures is significant toward management and restoration actions. Annual variability in winter water temperatures may potentially coincide with annual variability in emigration distance and subsequent overwintering reach occupancy. Thus, downstream reaches that generally function as spring emigration corridors following winters with low stable water temperatures, may be critical overwintering reaches during winters with fluctuating water temperatures. Understanding behavioral (e.g., movement) heterogeneity inherent during critical life-cycle stages (e.g., overwintering) for Pacific salmon (*Oncorhynchus* spp.) is critical toward holistic management and recovery of these threatened and endangered species.

Generally, overwintering Chinook salmon parr microhabitat use during free-flowing and surface ice conditions were not significantly different; however, increased use of slower velocities and LWD was associated with moderate gradient surface ice conditions. Contrary to our findings, previous researchers have reported that adult trout occupy different mesohabitats (e.g., pools) during winter ice conditions (Jakober et al. 1998; Lindstrom and Hubert 2004). Unfortunately, research reporting winter microhabitat use comparisons between free-flowing and surface ice conditions is lacking for juvenile salmonids (Huusko et al. 2007). Furthermore, results of studies researching microhabitat use during free-flowing and ice conditions are inconsistent. Our finding of overwintering microhabitat use similarity between free-flowing and surface ice conditions, regardless of microhabitat availability (moderate and low gradient), may indicate that overwintering microhabitat preference by Chinook salmon parr is to a considerable degree spatiotemporally universal.

Our moderate gradient depth suitability index indicated deepest depths available ($\geq$ 1.0 m) were highly suitable for overwintering Chinook salmon parr, while our low gradient depth suitability index indicated depths available between 0.75 and 1.00 were most suitable. Allen (2000) reported that shallow to moderate depths (~0.3–0.9 m) were most suitable in the Yakima River basin, and that few parr were observed overwintering in depths >1.2 m. We routinely relocated radio-tagged parr in large overwintering aggregations occupying depths $\geq$1.0 m within the moderate gradient reach, despite quantitative microhabitat availability surveys indicating depths $\geq$1.0 m were rare. Dissimilar from the moderate gradient reach, our microhabitat availability surveys of the low gradient reach revealed that deep depths ($\geq$1.0) were prevalent in the thalweg and generally associated with swift currents and no cover. We postulate that available low gradient depths ≥1.0 m were less suitable for overwintering Chinook salmon parr because co-occurring variables created unsuitable overwintering conditions (e.g., high velocity and no cover). It is unclear why Allen (2000) infrequently observed overwintering Chinook salmon parr using depths >1.2 m, because reported microhabitat utilization functions were not adjusted for microhabitat availability.

Suitability indices indicated that cobble and boulders were most suitable in the moderate gradient reach, while clay, silt, and sand were highly suitable in the low gradient reach. Generally, our moderate gradient substrate utilization and suitability results accord with previous research results (Hillman et al. 1987; Allen 2000; Van Dyke et al. 2009). Contrary to our moderate gradient findings, Hillman et al. (1987) reported that overwintering Chinook salmon parr were predominantly observed over sand–gravel substrates in Red River, a highly sedimented north-central Idaho stream; however, artificially increasing cobble abundance increased use by overwintering Chinook salmon parr, indicating that coarser substrates were preferred. Van Dyke et al. (2009) reported that overwintering Chinook salmon parr biomass-density was positively associated with cobble abundance in three high gradient northeast Oregon streams. Allen (2000) reported that silt, cobble, and boulder were optimal Chinook salmon parr overwintering substrates owing to proportionally higher utilization; however, similar for depth, concluded that proportionally high use inferred high suitability, possibly accounting for our silt suitability disparity, as silt was less suitable within our moderate gradient reach.

Cover suitability indices indicated that LWD, undercut bank, and root wad were most suitable in the moderate gradient reach, while LWD was most suitable in the low gradient reach. Previous researchers have reported that salmonid overwintering habitat availability is largely dependent on LWD availability (Heifetz et al. 1986; Cederholm et al. 1997; Solazzi et al. 2000). Similarly, during our study (winter 2011–2012), an extensive log jam in lower Catherine Creek, which is essentially devoid of LWD cover (1% LWD availability), was occupied by multiple (12) overwintering radio-tagged parr from early-November to mid-January. During mid-January the log jam was mechanically removed to encourage unimpeded flow and prevent flooding of adjacent agriculture land during spring freshets; overwintering parr emigrated downstream and no parr were detected at this location during February 2012. Metabolic limitations experienced by overwintering parr impose numerous ecological consequences, resulting in increased susceptibility to mortality associated with forced swimming events and predation (Simpkins et al. 2004; Brown et al. 2011). Therefore, restoration and protection of LWD cover throughout Catherine Creek, and likely the Pacific Northwest, has the potential to reduce overwintering mortality of Chinook salmon parr by enhancing the quality and quantity of suitable overwintering habitat and subsequently decreasing winter movement.

Despite vast differences between moderate (high habitat complexity) and low (homogeneous habitat) gradient microhabitat availability within our study area, subsequent habitat suitability criteria results for variables depth, bottom velocity, mean column velocity, distance to cover, and distance to bank were very similar (high transferability) between reaches (abbreviated convergence approach; Bovee, 1986), with the exception of those for substrate and cover. Typically, collection of high quality species-specific microhabitat use and site-specific availability data are costly and time consuming (Newcomb et al. 2007); however, subsequent habitat suitability criteria, exhibiting a high degree of transferability, can be used throughout a species' regional geographic range (Bovee 1986). Contrarily, numerous researchers have demonstrated that habitat criteria exhibited low transferability (Sheppard and Johnson 1985; Bozek and Rahel 1992; Kwak et al. 1992; Waite and Barnhart 1992; Groshens and Orth 1993; Rosenfeld et al. 2005). Reasons that habitat suitability criteria may fail convergence analyses and ultimately exhibit poor transferability include prey availability differences (Rosenfeld et al.2005), intra- and interspecific competition (Schlosser 1987; Gatz et al. 1987), seasonal microhabitat use shifts (Hillman et al. 1987; Holecek et al. 2009), size class differences (Moyle and Baltz 1985), microhabitat availability differences (DeGraaf and Bain 1986), fish density differences (Rosenfeld 2005), predation differences (Orth 1987), homogeneous microhabitat availability (Bovee 1986; Freeman et al. 1997), and insufficient sample sizes (Thomas and Bovee 1993). However, successful convergence between our moderate and low gradient microhabitat suitability criteria and previously reported criteria (Hillman et al. 1987) is indicative of regional (i.e., Pacific Northwest) high transferability potential. Nevertheless, caution should be employed not to uncritically initiate across-stream use of general microhabitat models before possible convergence and transferability limitations are realized (Morin et al. 1986; Beecher 1987; Shirvell 1989; Bozek and Rahel 1992; McHugh and Budy 2004), preferably using techniques similar to those described by Newcomb et al. (2007).

Fish typically occupy locations (i.e., select habitat) based on concurrent and interrelated microhabitat conditions (Heggenes 1991; Mäki-Petäys et al. 2002). In general, our multivariate PCA analyses were in agreement with our univariate habitat suitability criteria, indicating that deep depths supporting slow velocities over coarse substrates near cover and the bank were highly suitable overwintering conditions. Additionally, our PCA analyses facilitated examination and prioritization of microhabitat cumulative interactions used by overwintering parr, indicating that deep depths exhibiting slow or no current and cover were preferentially occupied within the moderate gradient reach, while shallow to moderate depths supporting slow or absent currents and cover were occupied within the low gradient reach. Subsequently, habitat restoration designed to increase the quality and quantity of moderate gradient overwintering habitat in the Grande Ronde Valley, and potentially regionally, may focus on the implementation of pools, backwaters, side channels, and beaver ponds containing coarse substrates (e.g., cobble and boulder) and considerable cover (e.g., LWD and root wads). Similarly, low gradient overwintering habitat restoration efforts may benefit from increasing the quantity and quality of debris jams and beaver ponds containing substantial cover and facilitating low to absent currents.

An abundance of research has been conducted on Pacific salmon (Quinn 2005); however, harsh environmental conditions (e.g., surface ice) that persist throughout most of their current range has generally precluded research designed to characterize and describe overwintering movement and habitat use of stream-type Chinook salmon parr (Brown et al. 2011). Despite the vast amount of knowledge and understanding of Pacific salmon life history, many populations are threatened or endangered (Good et al. 2005, NMFS 2005). Historically, research and management efforts have been primarily focused on improving survival of smolts and adults migrating through the Snake River and Columbia River hydrosystem (NMFS 2008). A recent Biological Opinion by the National Marine Fisheries Service emphasized low survival of parr in Snake and Columbia river tributaries, and subsequently called for efforts to increase survival of these threatened populations outside the hydrosystem (NMFS 2008; 2010). Understanding the overwintering ecology, movement behavior, and critical overwintering habitat of Catherine Creek Chinook salmon parr may help guide holistic management and restoration activities locally and perhaps regionally.

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Table 1. Characteristics of radio-tagged Catherine Creek juvenile spring Chinook salmon during fall/winter 2009–2011.

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
11	166.300	3.28	10/28/2009	91	8.5	13
12	166.300	3.00	10/28/2009	94	9.1	11
13	166.300	3.14	10/28/2009	93	8.5	3
14	166.300	3.14	10/28/2009	91	8.6	11
15	166.300	3.13	10/30/2009	91	8.7	14
16	166.300	3.06	10/30/2009	94	8.8	17
17	166.300	3.02	10/31/2009	92	9.1	15
18	166.300	3.00	10/31/2009	93	8.8	14
19	166.340	3.09	10/31/2009	94	8.7	15
20	166.300	3.22	10/31/2009	93	8.6	16
21	166.340	2.85	10/31/2009	96	9.5	16
22	166.300	3.16	10/31/2009	92	8.6	8
23	166.300	3.11	10/31/2009	93	8.7	14
24	166.300	3.09	10/31/2009	94	8.8	13
25	166.300	3.08	10/30/2009	93	8.7	10
26	166.300	3.16	10/30/2009	93	8.5	Mort
27a	166.300	2.86	11/23/2009	98	9.6	7
27	166.300	2.89	10/30/2009	94	9.5	Mort
28	166.300	2.87	10/30/2009	95	9.4	1
29	166.300	3.10	10/30/2009	93	8.6	Mort
30	166.300	2.42	10/29/2009	99	11.1	10
31	166.300	2.80	10/29/2009	96	9.8	14
32	166.300	3.20	10/30/2009	91	8.5	Mort
33	166.300	1.99	10/30/2009	100	13.3	0
34	166.300	2.42	10/29/2009	102	11.3	10
35	166.300	3.00	10/28/2009	92	9.2	14
36	166.300	2.97	10/29/2009	95	9.2	12
37	166.300	2.72	10/30/2009	96	9.8	7
38	166.320	2.48	10/27/2009	99	10.7	11
39	166.320	2.91	10/27/2009	93	9.2	11
40	166.320	3.03	10/27/2009	94	8.8	9
41	166.320	2.78	10/26/2009	96	9.6	Mort
42	166.320	2.63	10/26/2009	98	10.2	0
43	166.320	3.12	10/21/2009	89	8.5	18
44	166.320	2.68	10/21/2009	90	10.1	Mort
45	166.320	3.04	10/26/2009	91	8.9	15
46	166.320	2.95	10/26/2009	93	9.3	17
47	166.320	2.96	10/26/2009	93	9.4	17
48a	166.320	2.92	11/23/2009	95	9.2	7
48	166.320	2.32	10/24/2009	98	11.6	Mort

Table 1. (Continued).

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
49	166.320	2.57	10/26/2009	96	10.6	14
50	166.320	2.78	10/26/2009	95	9.7	15
51	166.320	2.79	10/26/2009	94	9.7	15
52	166.320	2.84	10/22/2009	93	9.4	1
53	166.320	2.93	10/23/2009	91	9.2	11
54	166.320	2.82	10/26/2009	94	9.4	9
55	166.320	2.96	10/28/2009	91	8.9	15
56	166.320	2.58	10/24/2009	98	10.6	18
57	166.320	2.99	10/26/2009	91	8.9	13
58	166.320		10/20/2009	94	9.4	17
59	166.320		10/20/2009	95	9.2	15
60a	166.320	2.64	11/23/2009	100	10.8	2
60	166.320	2.88	10/20/2009	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	2.97	10/31/2009	94	9.1	15
66	166.340	3.08	10/31/2009	94	8.9	16
67	166.340	2.88	10/31/2009	96	9.2	14
68	166.340	3.05	10/31/2009	92	8.8	16
69	166.340	2.84	10/31/2009	96	9.6	13
70	166.340	2.20	10/31/2009	105	12.2	12
71	166.340	3.05	10/31/2009	94	8.7	13
72	166.340	2.82	10/31/2009	95	9.5	10
73	166.340	2.51	10/31/2009	102	10.6	14
74	166.340	3.15	10/31/2009	93	8.8	17
75	166.340	3.11	10/31/2009	92	8.5	6
76	166.340	3.02	10/31/2009	95	8.8	7
77	166.340	2.86	10/31/2009	95	9.4	8
78	166.340	2.97	10/31/2009	92	9.1	17
79	166.340	3.02	10/31/2009	94	8.8	13
80	166.340	2.84	10/31/2009	94	9.5	16
81	166.340	2.67	10/31/2009	96	10.0	19
82a	166.340	2.60	11/24/2009	95	10.3	12
82	166.340	2.95	10/31/2009	94	9.1	Mort
83	166.340	2.83	10/31/2009	95	9.5	16
84	166.340	2.91	10/31/2009	95	9.2	16
85	166.340	2.68	10/31/2009	95	9.8	17
86	166.340	2.64	10/31/2009	97	10.3	Mort
87	166.340	3.02	10/31/2009	91	9.0	20

Table 1. (Continued).

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
88	166.340	2.73	11/16/2009	96	9.7	11
89	166.340	2.86	11/16/2009	95	9.4	14
90	166.340	2.30	11/16/2009	103	11.9	14
91	166.300	2.88	11/26/2009	96	9.3	12
92	166.300	3.01	11/26/2009	95	8.9	10
93	166.300	3.00	11/26/2009	93	8.8	15
94	166.300	2.89	11/28/2009	95	9.2	Mort
95	166.300	3.07	11/30/2009	95	8.5	14
96	166.320	3.15	11/30/2009	93	8.5	0
97	166.320	3.14	11/30/2009	93	8.5	15
99	166.320	3.09	11/26/2009	94	8.7	7
100	166.320	2.51	12/01/2009	98	10.5	3
101	166.340	3.12	11/30/2009	94	8.5	15
102	166.340	2.61	11/30/2009	98	10.4	4
103	166.340	2.89	11/25/2009	95	9.3	12
104	166.340	2.96	11/26/2009	96	9.2	Mort
105	166.340	2.86	11/29/2009	97	9.4	14
1	166.300	2.90	10/11/2010	94	9.5	16
2	166.300	2.50	10/08/2010	98	10.8	15
4	166.300	2.63	10/12/2010	96	10.4	7
5	166.300	3.17	10/08/2010	90	8.6	15
6	166.300	2.61	10/12/2010	95	10.4	11
7	166.300	3.24	10/13/2010	95	9.2	14
8	166.300	3.17	10/19/2010	93	9.3	8
9	166.300	3.16	10/19/2010	96	9.3	12
10	166.300	2.83	10/19/2010	95	9.7	15
11	166.300	3.10	10/19/2010	93	8.9	7
12	166.300	2.70	10/19/2010	98	10.3	12
13	166.300	2.63	10/19/2010	95	9.9	13
14	166.300	2.52	10/19/2010	100	10.4	14
15	166.300	2.83	10/19/2010	94	9.3	18
16	166.300	2.99	10/20/2010	92	8.7	0
17	166.300	2.87	10/20/2010	91	8.8	16
18	166.300	2.65	10/20/2010	96	9.8	17
19	166.300	2.60	10/20/2010	96	10.0	15
20	166.300	2.74	10/20/2010	93	9.5	16
21	166.300	2.90	10/20/2010	93	9.2	8
22	166.300	2.93	10/20/2010	93	8.9	13
23	166.300	2.72	10/20/2010	93	9.6	13
24	166.300	2.83	10/20/2010	93	9.2	11
25	166.300	2.40	10/21/2010	99	10.8	11

Table 1. (Continued).

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
26	166.300	2.57	10/21/2010	97	10.2	14
27	166.300	2.65	10/21/2010	97	9.9	10
28	166.300	2.53	10/21/2010	98	10.3	16
29	166.300	2.73	10/21/2010	93	9.6	18
30	166.300	2.83	10/21/2010	94	9.2	17
31	166.300	3.02	10/21/2010	92	8.8	0
32	166.300	2.94	10/21/2010	92	8.8	13
33	166.300	2.45	10/21/2010	102	10.7	4
34	166.340	2.59	10/25/2010	95	10.1	11
35	166.340	1.96	10/25/2010	102	13.2	5
36	166.340	2.69	10/25/2010	98	9.8	4
37	166.340	2.74	10/25/2010	95	9.5	4
38	166.340	1.96	10/25/2010	106	13.3	3
39	166.340	2.74	10/25/2010	95	9.5	8
40	166.340	2.50	10/25/2010	96	10.5	4
41	166.340	3.01	10/26/2010	92	8.7	11
42	166.340	3.01	10/26/2010	92	8.7	10
43	166.340	2.57	10/26/2010	100	10.3	14
44	166.340	3.14	10/26/2010	93	8.5	13
45	166.340	2.45	10/26/2010	100	10.7	2
46	166.340	3.14	10/26/2010	91	8.5	6
47	166.340	2.50	10/26/2010	99	10.5	3
48	166.340	2.79	10/26/2010	94	9.4	1
49	166.340	3.02	10/27/2010	92	8.7	5
50	166.340	2.67	10/27/2010	97	9.8	12
51	166.340	2.30	10/27/2010	103	11.2	4
52	166.340	2.89	10/27/2010	93	9.1	15
53	166.340	2.76	10/27/2010	93	9.5	5
54	166.340	2.43	10/27/2010	98	10.7	13
55	166.340	2.34	10/27/2010	101	11.1	14
56	166.340	2.53	10/28/2010	96	10.4	10
57	166.340	2.72	10/28/2010	94	9.7	14
58	166.340	2.88	10/28/2010	93	9.2	11
59	166.340	2.46	10/28/2010	97	10.7	8
60	166.340	2.83	10/28/2010	93	9.3	0
61	166.340	2.75	10/28/2010	94	9.5	2
62	166.340	2.72	10/28/2010	93	9.5	11
63	166.340	2.77	10/28/2010	94	9.4	15
64	166.340	2.86	11/02/2010	93	9.0	7
65	166.340	2.51	11/02/2010	97	10.5	10
66	166.340	2.96	11/02/2010	92	8.8	12

Table 1. (Continued).

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
67	166.380	2.93	11/02/2010	92	9.0	3
68	166.380	2.99	11/03/2010	92	8.8	12
69	166.380	2.73	11/03/2010	95	9.6	2
70	166.380	2.69	11/02/2010	95	9.6	10
71	166.380	2.87	11/04/2010	94	9.0	12
72	166.380	3.04	11/04/2010	91	8.7	11
73	166.380	2.58	11/08/2010	95	10.2	13
74	166.380	2.16	11/08/2010	102	12.2	2
75	166.380	2.08	11/08/2010	107	12.6	16
76	166.380	2.51	11/08/2010	99	10.4	11
77	166.380	2.83	11/08/2010	93	9.2	13
78	166.380	2.51	11/08/2010	96	10.4	13
79	166.380	2.58	11/08/2010	98	9.9	0
80	166.380	2.60	11/08/2010	97	10.1	9
81	166.380	2.59	11/08/2010	99	10.1	1
82	166.380	2.95	11/09/2010	92	9.0	14
83	166.380	2.53	11/09/2010	96	10.1	7
84	166.380	2.88	11/09/2010	94	9.1	0
85	166.380	2.53	11/09/2010	96	10.4	11
86	166.380	2.63	11/09/2010	94	9.9	11
87	166.380	2.95	11/09/2010	93	8.9	11
88	166.380	2.93	11/09/2010	93	8.9	11
89	166.380	2.45	11/09/2010	96	10.5	11
90	166.380	2.34	11/09/2010	97	11.0	8
91	166.380	2.96	11/10/2010	93	8.8	11
92	166.380	2.39	11/10/2010	100	11.0	9
93	166.380	2.23	11/10/2010	102	11.7	12
94	166.380	2.62	11/10/2010	95	9.8	10
95	166.380	1.95	11/16/2010	106	13.3	12
96	166.380	2.68	11/16/2010	98	9.8	11
97	166.380	2.69	11/19/2010	94	9.7	13
98	166.380	2.63	11/19/2010	96	10.0	3
99	166.380	2.69	11/19/2010	95	9.8	9
100	166.380	2.65	11/22/2010	100	9.9	0
101	166.300	2.95	10/12/2010	94	9.3	9
102	166.300	2.71	10/14/2010	93	10.1	3
103	166.300	2.58	10/18/2010	97	10.8	8
104	166.300	2.47	10/20/2010	97	10.8	7
105	166.300	3.01	10/20/2010	92	8.8	9
106	166.300	2.96	10/21/2010	93	8.9	8
107	166.300	2.45	10/21/2010	103	10.8	1

Table 1. (Continued).

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
108	166.300	2.25	10/25/2010	100	11.5	3
109	166.300	2.57	10/25/2010	98	10.2	3
110	166.300	2.99	10/26/2010	93	8.6	9
111	166.300	3.09	10/26/2010	93	8.5	4
112	166.300	2.65	10/27/2010	96	9.7	1
113	166.340	2.96	10/27/2010	95	8.9	0
114	166.340	2.55	10/28/2010	95	10.1	4
115	166.340	2.32	10/28/2010	99	11.3	9
116	166.340	2.60	11/01/2010	98	10.0	9
117	166.340	2.52	11/01/2010	96	10.2	10
118	166.340	2.53	11/01/2010	97	10.3	6
119	166.340	2.69	11/09/2010	93	9.7	9
120	166.340	2.78	11/09/2010	94	9.4	7
121	166.340	2.78	11/10/2010	97	9.4	3
122	166.380	2.40	11/10/2010	96	10.9	5
123	166.380	2.85	11/10/2010	93	9.1	2
124	166.380	2.70	11/10/2010	95	9.9	8
125	166.380	2.51	11/10/2010	98	10.4	2
126	166.380	2.61	11/16/2010	97	9.9	9
127	166.380	2.68	11/16/2010	94	9.7	9
128	166.380	2.60	11/16/2010	98	10.0	7
129	166.380	2.75	11/19/2010	95	9.5	1
130	166.380	2.49	11/22/2010	99	10.5	5
1	166.300	2.44	10/05/2011	97	10.7	0
2	166.300	2.98	10/05/2011	93	9.0	15
3	166.300	2.94	10/06/2011	92	9.0	0
4	166.300	2.31	10/06/2011	101	11.3	10
5	166.300	2.95	10/06/2011	94	8.9	4
6	166.300	2.89	10/06/2011	96	9.2	14
7	166.300	3.09	10/06/2011	93	8.6	13
8	166.300	2.57	10/06/2011	96	10.3	11
9	166.300	3.01	10/07/2011	95	8.7	5
10	166.300	2.81	10/07/2011	94	9.2	11
11	166.300	2.97	10/07/2011	94	8.8	9
12	166.300	2.79	10/07/2011	97	9.4	4
13	166.300	2.92	10/07/2011	92	9.0	3
14	166.300	2.15	10/11/2011	103	12.1	11
15	166.300	2.75	10/11/2011	96	9.6	10
16	166.300	2.52	10/14/2011	98	10.4	7
17	166.300	3.03	10/12/2011	94	8.7	3
18	166.300	2.84	10/12/2011	93	9.2	6

Table 1. (Continued).

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
19	166.300	2.25	10/12/2011	102	11.9	8
20	166.300	2.93	10/12/2011	95	9.1	14
21	166.300	2.61	10/14/2011	97	10.0	8
22	166.300	2.71	10/14/2011	97	9.7	10
23	166.300	2.66	10/14/2011	98	10.0	7
24	166.300	2.68	10/17/2011	97	9.9	12
25	166.300	3.00	10/17/2011	91	8.8	2
26	166.340	2.91	10/17/2011	93	9.1	1
27	166.340	2.93	10/17/2011	94	9.0	12
28	166.340	2.87	10/17/2011	95	9.0	17
29	166.340	2.82	10/17/2011	93	9.3	9
30	166.340	2.44	10/17/2011	99	10.7	6
31	166.340	2.45	10/18/2011	99	10.7	15
32	166.340	2.99	10/18/2011	93	8.7	4
33	166.340	2.95	10/18/2011	94	9.0	5
34	166.340	2.83	10/18/2011	95	9.2	3
35	166.340	2.93	10/18/2011	93	8.8	14
36	166.340	2.41	10/19/2011	102	11.1	15
37	166.340	2.76	10/19/2011	96	9.5	2
38	166.340	2.85	10/19/2011	97	9.2	4
39	166.340	2.31	10/19/2011	101	11.2	8
40	166.340	2.08	10/19/2011	105	12.6	Mort
41	166.340	3.06	10/24/2011	94	8.5	7
42	166.340	2.83	10/24/2011	97	9.2	2
43	166.340	2.53	10/24/2011	99	10.2	3
44	166.340	3.03	10/24/2011	90	8.6	10
45	166.340	2.26	10/25/2011	102	11.4	0
46	166.340	2.48	10/25/2011	100	10.6	1
47	166.340	2.59	10/25/2011	98	10.2	10
48	166.340	2.66	10/25/2011	95	10.0	15
49	166.340	2.66	10/25/2011	95	9.9	0
50	166.340	2.55	10/25/2011	98	10.3	9
51	166.380	1.97	10/26/2011	107	13.1	11
52	166.380	2.64	10/26/2011	97	9.9	13
53	166.380	2.13	10/26/2011	103	12.2	4
54	166.380	1.93	10/26/2011	106	13.5	7
55	166.380	2.34	10/26/2011	104	11.3	16
56	166.380	2.80	10/31/2011	95	9.5	14
57	166.380	2.92	10/31/2011	93	8.8	3
58	166.380	3.01	10/31/2011	92	8.5	12
59	166.380	2.93	11/02/2011	95	9.1	10

Table 1. (Continued).

Tag code	Transmitter frequency (MHz)	Tag burden (%)	Date tagged	Fork length (mm)	Weight (g)	Number of relocations
60	166.380	2.83	11/02/2011	94	9.2	10
61	166.380	3.05	11/02/2011	92	8.8	2
62	166.380	2.52	11/02/2011	98	10.6	15
63	166.380	2.53	11/02/2011	98	10.6	0
64	166.380	2.87	11/07/2011	96	9.2	10
65	166.380	2.44	11/07/2011	98	10.8	2
66	166.380	2.91	11/07/2011	94	9.0	6
67	166.380	2.80	11/07/2011	94	9.3	8
68	166.380	2.75	11/07/2011	93	9.5	10
69	166.380	1.90	11/08/2011	104	13.9	13
70	166.380	2.91	11/14/2011	94	8.8	10
71	166.380	2.70	11/14/2011	94	9.8	0
72	166.380	3.09	11/14/2011	93	8.6	11
73	166.380	2.61	11/21/2011	98	10.0	11

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

Table 2. Fall microhabitat use and availability for moderate and low gradient reaches of Catherine Creek where radio-tagged fall migrant spring Chinook salmon were relocated.

	Moderate gradient		Low gradient	
Variable and statistic	Use	Available	Use	Available
Temperature (°C)				
n	242		57	
Mean	5.99		5.25	
SD	2.06		1.92	
Min–max	2.20–10.10		2.40–9.80	
Dissolved oxygen (mg/L)				
n	199		52	
Mean	12.75		12.71	
SD	0.96		0.69	
Min–max	10.25–15.25		10.43–13.72	
Depth (m)				
n	247	793	66	1,020
Mean	0.63	0.27	0.89	0.81
SD	0.30	0.24	0.41	0.67
Min–max	0.10–2.00	0.00–1.30	0.25–2.50	0.00–3.20
Bottom velocity (m/s)				
n	233	793	66	1,020
Mean	0.07	0.16	0.03	0.08
SD	0.09	0.19	0.05	0.09
Min–max	0.00–0.46	0.00–1.50	0.00–0.24	0.00–0.45
Mean velocity (m/s)				
n	233	793	66	1,020
Mean	0.17	0.30	0.07	0.36
SD	0.16	0.30	0.08	0.37
Min–max	0.00–0.84	0.00–2.00	0.00–0.41	0.00–1.60
Dominant substrate				
n	246	793	65	1,020
Mode	Cobble	Gravel	Silt	Silt
SD	1.00	1.28	0.86	0.73
Min–max	Clay–Boulder	Clay–Bedrock	Clay–Cobble	Clay–Sand
Distance to bank (m)				
n	241	793	66	1,020
Mean	1.97	5.27	2.47	9.82
SD	1.44	3.79	2.08	7.74
Min–max	0.00–10.00	0.00–13.90	0.00–10.00	0.00–26.60
Cover				
n	247	793	66	1,020
Mode	Boulder	SWD	LWD	No cover
Distance to cover (m)				
n	218	642	56	548
Mean	0.60	0.63	0.50	0.52
SD	0.62	0.62	0.58	0.60
Min–max	0.00–2.00	0.00–13.90	0.10–2.00	0.00–2.00

Table 3. Winter microhabitat use and availability for moderate and low gradient reaches of Catherine Creek where radio-tagged fall migrant spring Chinook salmon were relocated.

	Moderate gradient		Low gradient	
Variable and statistic	Use	Available	Use	Available
Temperature (°C)				
n	249		349	
Mean	1.99		1.95	
SD	1.58		1.58	
Min–max	0.00–6.00		0.00–8.00	
Dissolved oxygen (mg/L)				
n	230		293	
Mean	14.42		13.79	
SD	0.92		1.01	
Min–max	11.00–16.81		10.61–17.10	
Depth (m)				
n	250	793	366	1,020
Mean	0.64	0.27	0.82	0.81
SD	0.38	0.24	0.36	0.67
Min–max	0.04–2.20	0.00–1.30	0.12–2.50	0.00–3.20
Bottom velocity (m/s)				
n	238	793	356	1,020
Mean	0.09	0.16	0.06	0.08
SD	0.13	0.19	0.09	0.09
Min–max	0.00–0.74	0.00–1.50	0.00–0.57	0.00–0.45
Mean velocity (m/s)				
n	237	793	359	1,020
Mean	0.18	0.30	0.12	0.36
SD	0.20	0.30	0.12	0.37
Min–max	0.00–0.96	0.00–2.00	0.00–0.65	0.00–1.60
Dominant substrate				
n	254	793	367	1,020
Mode	Cobble	Gravel	Silt	Silt
SD	1.10	1.28	0.85	0.73
Min–max	Clay–Bedrock	Clay–Bedrock	Clay–Boulder	Clay–Sand
Distance to bank (m)				
n	258	793	369	1,020
Mean	2.21	5.27	2.34	9.82
SD	1.44	3.79	1.81	7.74
Min–max	0.00–8.00	0.00–13.90	0.00–12.00	0.00–26.60
Cover				
n	258	793	366	1,020
Mode	LWD	SWD	SWD	No cover
Distance to cover (m)				
n	230	642	318	548
Mean	0.59	0.63	0.47	0.52
SD	0.63	3.17	2.31	0.60
Min–max	0.00–2.00	0.00–13.90	0.10–2.00	0.00–2.00

Table 4. Characteristics of surveyed stream reaches in Catherine Creek used by radio-tagged fall migrant spring Chinook salmon during fall and winter 2009–2011.

Stream reach and location		Upstream geographic coordinates (UTM)		Downstream geographic coordinates (UTM)	Reach length (km)	Number of transects	Number of survey points
Moderate 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	0.180	10	97
Wilkinson Road	11T	0426936 5013741	11T	0426895 5013901	0.360	10	118
Godley Lane	11T	0430177 5016526	11T	0430253 5016489	0.084	7	86
Market Lane	11T	0430381 5026666	11T	0430034 5026387	0.503	10	116
Alicel	11T	0427139 5029092	11T	0427427 5029448	0.459	10	136
Hull	11T	0425812 5034492	11T	0426250 5034593	0.455	10	114
Total					2.401	87	1,064

Table 5. Moderate and low gradient stream morphology and riparian land use availability statistics representative of reaches occupied by overwintering Catherine Creek juvenile Chinook salmon overwintering in the Grande Ronde Valley. Moderate and low gradient reach variables were compared using the Mann-Whitney rank sum test.

	Morphology			50-m riparian land use (%)		
Reach and statistic	Stream width (m)	Bank angle (°)	Undercut bank (m)	Forest	Agriculture	Developed
Moderate gradient						
Median	9.3	85	0.0	10	80	0
Min–Max	4.1–14.0	0–180	0.0–0.5	0–100	0–100	0–100
Low gradient						
Median	14.8	110	0.0	0	97	0
Min–Max	6.9–26.7	0–170	0.0–0.2	0–100	60–100	0–30
U statistic	708.0	8,702.0	9,562.5	7,152.5	6,822.5	9,605.5
P-value	<0.001	0.015	<0.001	<0.001	<0.001	0.063

Table 6. Particle size categories and associated continuous variables used to visually estimate dominant and subdominant substrate size for parr relocations and habitat availability.

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 7. Cover categories, associated categorical variables, and cover abbreviations used to describe nearest dominant cover for parr relocations and habitat availability.

Cover category	Continuous variable	Cover abbreviation
No cover	1	NC
Large woody debris	2	LWD
Small woody debris	3	SWD
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 8. Monthly and total median, 1st quartile, 3rd quartile, minimum, and maximum linear range for radio-tagged Catherine Creek fall migrant spring Chinook salmon from 2009 to 2011.

Year, month and season	n	Median linear range (km)	1st Quartile (km)	3rd Quartile (km)	Min (km)	Max (km)
2009–2010						
October	9	5.80	0.50	8.78	0.50	11.86
November	38	1.91	0.16	4.78	0.00	8.38
December	57	0.05	0.00	0.69	0.00	11.14
January	54	0.78	0.00	6.95	0.00	25.55
February	11	0.00	0.00	0.02	0.00	0.30
March	3	0.00	0.00	0.00	0.00	0.00
Fall–winter	82	10.74	6.27	17.45	2.85	56.74
2010–2011						
October	2	7.10	6.97	7.22	6.85	7.35
November	57	5.48	1.47	10.01	0.00	67.80
December	59	0.10	0.00	1.68	0.00	18.33
January	31	0.74	0.00	6.30	0.00	75.83
February	4	0.00	0.00	0.00	0.00	0.01
Fall–winter	123	17.43	9.26	27.80	0.11	113.18
2011–2012						
October	9	9.12	7.05	10.46	4.24	23.04
November	38	0.07	0.00	8.96	0.00	66.46
December	20	0.00	0.00	0.01	0.00	15.86
January	12	0.01	0.00	0.06	0.00	30.76
February	2	0.00	0.00	0.00	0.00	0.00
Fall–winter	66	20.31	6.83	34.67	0.00	90.12

Table 9. Seasonal (fall and winter) microhabitat use, classified by moderate and low gradient, for radio-tagged Catherine Creek fall migrant spring Chinook salmon parr. 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		SD			
Reach and variable	Fall	Winter	Fall	Winter	Fall	Winter	Statistic	*P*
Moderate gradient								
Depth (m)	247	250	0.63	0.64	0.30	0.38	D = 0.1269	0.0365
Bottom velocity (m/s)	233	238	0.07	0.09	0.09	0.13	D = 0.1450	0.0142
Mean velocity (m/s)	233	237	0.17	0.18	0.16	0.20	D = 0.0601	0.7897
Dominate substrate	246	254	Cobble	Cobble	1.00	1.10	D = 0.0785	0.4242
Distance to bank (m)	241	258	1.97	2.21	1.44	1.44	D = 0.1383	0.0170
Cover	247	258	Boulder	LWD			X^2 = 58.2393	<0.0001
Distance to cover (m)	218	230	0.57	0.58	0.63	0.64	D = 0.0489	0.9235
Low gradient								
Depth (m)	66	366	0.89	0.82	0.41	0.36	D = 0.1222	0.3739
Bottom velocity (m/s)	66	356	0.03	0.06	0.05	0.09	D = 0.1811	0.0520
Mean velocity (m/s)	66	359	0.07	0.12	0.08	0.12	D = 0.2076	0.0164
Dominate substrate	65	367	Silt	Silt	0.86	0.85	D = 0.0117	1.0000
Distance to bank (m)	66	369	2.47	2.34	2.08	1.81	D = 0.0791	0.8750
Cover	66	366	LWD	SWD			X^2 = 12.7414	0.0787
Distance to cover (m)	56	318	0.48	0.44	0.59	0.55	D = 0.0467	0.9997

Table 10. Winter moderate and low gradient microhabitat use, classified by surface ice presence, for relocated Catherine Creek fall migrant spring Chinook salmon parr.

	Moderate gradient		Low gradient	
Variable and statistic	Ice absent	Ice present	Ice absent	Ice present
Temperature (°C)				
n	210	39	265	84
Mean	2.33	0.15	2.52	0.14
SD	1.48	0.26	1.38	0.25
Min–max	0.00–6.00	0.00–1.00	0.00–8.00	0.00–1.30
Dissolved oxygen (mg/L)				
n	191	39	217	76
Mean	14.46	14.21	13.79	13.78
SD	0.92	0.89	1.01	1.01
Min–max	11.00–16.81	12.15–16.33	10.66–16.68	10.61–17.10
Depth (m)				
n	211	39	283	83
Mean	0.65	0.63	0.83	0.78
SD	0.38	0.40	0.36	0.37
Min–max	0.04–2.20	0.10–1.60	0.14–2.50	0.12–1.85
Bottom velocity (m/s)				
n	207	31	275	81
Mean	0.10	0.04	0.06	0.04
SD	0.14	0.08	0.10	0.06
Min–max	0.00–0.74	0.00–0.27	0.00–0.57	0.00–0.23
Mean velocity (m/s)				
n	207	30	278	81
Mean	0.19	0.09	0.13	0.10
SD	0.20	0.14	0.13	0.10
Min–max	0.00–0.96	0.00–0.52	0.00–0.65	0.00–0.65
Dominant substrate				
n	217	37	282	85
Mode	Cobble	Cobble	Silt	Silt
SD	1.08	1.16	0.88	0.72
Min–max	Clay–Bedrock	Clay–Boulder	Clay–Boulder	Clay–Gravel
Distance to bank (m)				
n	219	39	284	85
Mean	2.25	1.95	2.44	2.02
SD	1.49	1.13	1.88	1.50
Min–max	0.00–8.00	0.30–4.00	0.00–12.00	0.00–8.00
Cover				
n	219	39	284	82
Mode	Boulder	LWD	SWD	LWD
Distance to cover (m)				
n	197	33	245	73
Mean	0.55	0.83	0.46	0.49
SD	0.61	0.72	0.54	0.51
Min–max	0.00–2.00	0.00–2.00	0.10–2.00	0.10–2.00

Table 11. Spatial (moderate and low gradient) winter microhabitat use, classified according to surface ice presence, for radio-tagged Catherine Creek fall migrant spring Chinook salmon parr. 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		SD			
Reach and variable	Present	Absent	Present	Absent	Present	Absent	Statistic	*P*
Moderate gradient								
Depth (m)	39	211	0.63	0.65	0.40	0.38	D = 0.0933	0.9367
Bottom velocity (m/s)	31	207	0.04	0.10	0.08	0.14	D = 0.2911	0.0207
Mean velocity (m/s)	30	207	0.09	0.19	0.14	0.20	D = 0.3618	0.0021
Dominate substrate	37	217	Cobble	Cobble	1.16	1.08	D = 0.1020	0.8973
Distance to bank (m)	39	219	1.95	2.25	1.13	1.49	D = 0.0959	0.9211
Cover	39	219	LWD	Boulder			X^2 = 10.4173	0.1661
Distance to cover (m)	33	197	0.83	0.55	0.72	0.61	D = 0.1960	0.1571
Low gradient								
Depth (m)	83	283	0.78	0.83	0.37	0.36	D = 0.1539	0.0955
Bottom velocity (m/s)	81	275	0.04	0.06	0.06	0.10	D = 0.1232	0.2980
Mean velocity (m/s)	81	278	0.10	0.13	0.10	0.13	D = 0.1473	0.1314
Dominate substrate	85	282	Silt	Silt	0.72	0.88	D = 0.0295	1.0000
Distance to bank (m)	85	284	2.02	2.44	1.50	1.88	D = 0.1347	0.1860
Cover	82	284	LWD	SWD			X^2 = 9.9020	0.1942
Distance to cover (m)	73	245	0.49	0.46	0.51	0.54	D = 0.1057	0.4756

Table 12. Comparison statistics for moderate and low gradient microhabitat use, associated with surface ice, of Catherine Creek fall migrant juvenile spring Chinook salmon. The Kolmogorov-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)	0.213469	0.1780
Bottom velocity (m/s)	0.156113	0.6454
Mean velocity (m/s)	0.281481	0.0623
Dominate substrate	0.772019	<0.0001
Distance to bank (m)	0.082353	0.9935
Cover	19.5786	0.0033
Distance to cover (m)	0.221388	0.1499

Table 13. Comparison statistics for moderate and low gradient fall microhabitat use for Catherine Creek fall migrant juvenile spring Chinook salmon. The Kolmogorov-Smirnov two-sample test was conducted on continuous variables; categorical variables were compared using a likelihood-ratio chi-square test.

Variable	Statistic	*P*
Depth (m)	0.353883	<0.0001
Bottom velocity (m/s)	0.275849	0.0008
Mean velocity (m/s)	0.295292	0.0003
Dominate substrate	0.851345	<0.0001
Distance to bank (m)	0.116434	0.4836
Cover	84.5962	<0.0001
Distance to cover (m)	0.238866	0.0052

Table 14. Comparison statistics for moderate and low gradient winter microhabitat use for Catherine Creek fall migrant juvenile spring Chinook salmon. The Kolmogorov-Smirnov two-sample test was conducted on continuous variables; categorical variables were compared using a likelihood-ratio chi-square test.

Variable	Statistic	*P*
Depth (m)	0.273106	<0.0001
Bottom velocity (m/s)	0.131454	0.0338
Mean velocity (m/s)	0.154502	0.0069
Dominate substrate	0.840115	<0.0001
Distance to bank (m)	0.087674	0.2979
Cover	177.0084	<0.0001
Distance to cover (m)	0.223744	<0.0001

Table 15. Spatial (moderate and low gradient) fall microhabitat use and availability for radio-tagged Catherine Creek fall migrant spring Chinook salmon and results of statistical comparisons of 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		SD			
Reach and variable	Use	Available	Use	Available	Use	Available	Statistic	*P*
Moderate gradient								
Depth (m)	247	793	0.63	0.27	0.30	0.24	$D = 0.5780$	<0.0001
Bottom velocity (m/s)	233	793	0.07	0.16	0.09	0.19	$D = 0.2771$	<0.0001
Mean velocity (m/s)	233	793	0.17	0.30	0.16	0.30	$D = 0.2644$	<0.0001
Dominate substrate	246	793	Cobble	Gravel	1.00	1.28	$D = 0.3291$	<0.0001
Distance to bank (m)	241	793	1.97	5.27	1.44	3.79	$D = 0.4853$	<0.0001
Cover	247	793	Boulder	SWD			$X^2 = 160.9935$	<0.0001
Distance to cover (m)	218	642	0.60	0.63	0.62	0.62	$D = 0.2376$	<0.0001
Low gradient								
Depth (m)	66	1,020	0.89	0.81	0.41	0.67	$D = 0.3369$	<0.0001
Bottom velocity (m/s)	66	1,020	0.03	0.08	0.05	0.09	$D = 0.2852$	<0.0001
Mean velocity (m/s)	66	1,020	0.07	0.36	0.08	0.37	$D = 0.4873$	<0.0001
Dominate substrate	65	1,020	Silt	Silt	0.86	0.73	$D = 0.0474$	0.9992
Distance to bank (m)	66	1,021	2.47	9.82	2.08	7.74	$D = 0.5533$	<0.0001
Cover	66	1,020	LWD	No cover			$X^2 = 114.8543$	<0.0001
Distance to cover (m)	56	548	0.50	0.52	0.58	0.60	$D = 0.3115$	<0.0001

Table 16. Spatial (moderate and low gradient) winter microhabitat use and availability for radio-tagged Catherine Creek fall migrant spring Chinook salmon and results of statistical comparisons of 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		SD			
Reach and variable	Use	Available	Use	Available	Use	Available	Statistic	*P*
Moderate gradient								
Depth (m)	250	793	0.64	0.27	0.38	0.24	$D = 0.4817$	<0.0001
Bottom velocity (m/s)	238	793	0.09	0.16	0.13	0.19	$D = 0.1871$	<0.0001
Mean velocity (m/s)	237	793	0.18	0.30	0.20	0.30	$D = 0.2657$	<0.0001
Dominate substrate	254	793	Cobble	Gravel	1.10	1.28	$D = 0.2506$	<0.0001
Distance to bank (m)	258	793	2.21	5.27	1.44	3.79	$D = 0.4728$	<0.0001
Cover	258	793	LWD	SWD			$X^2 = 152.3677$	<0.0001
Distance to cover (m)	230	642	0.59	0.63	0.63	0.62	$D = 0.2003$	<0.0001
Low gradient								
Depth (m)	366	1,020	0.82	0.81	0.36	0.67	$D = 0.2437$	<0.0001
Bottom velocity (m/s)	356	1,020	0.06	0.08	0.09	0.09	$D = 0.1113$	0.0029
Mean velocity (m/s)	356	1,020	0.12	0.36	0.12	0.37	$D = 0.3544$	<0.0001
Dominate substrate	359	1,020	Silt	Silt	0.85	0.73	$D = 0.0393$	<0.0001
Distance to bank (m)	369	1,021	2.34	9.82	1.81	7.74	$D = 0.5737$	<0.0001
Cover	366	1,020	SWD	No cover			$X^2 = 286.1890$	<0.0001
Distance to cover (m)	318	548	0.47	0.52	0.54	0.60	$D = 0.3435$	<0.0001

Table 17. Reach specific statistics and significance values from comparisons of retained fall microhabitat use and availability principal component scores. The Kolmogorov-Smirnov two-sample test was used to compare component scores.

Reach and principal component	*D* statistic	*P*-value
Moderate gradient		
PC1	0.2437	<0.0001
PC2	0.3071	<0.0001
Low gradient		
PC1	0.4348	<0.0001
PC2	0.2600	0.0005

Table 18. Reach specific statistics and significance values from comparisons of retained winter microhabitat use and availability principal component scores. The Kolmogorov-Smirnov two-sample test was used to compare component scores.

Reach and principal component	*D* statistic	*P*-value
Moderate gradient		
PC1	0.2274	<0.0001
PC2	0.2204	<0.0001
Low gradient		
PC1	0.3717	<0.0001
PC2	0.2579	<0.0001

Table 19. Moderate gradient principal component eigenvector values (i.e., loadings), eigenvalues, and cumulative variance explained of fall microhabitat use and availability for radio-tagged juvenile Catherine Creek fall migrant spring Chinook salmon.

	PCA axis	
Variable and statistic	1	2
Depth (m)	0.2234	-0.5866
Bottom velocity (m/s)	0.5770	0.2556
Mean column velocity (m/s)	0.6226	0.0598
Dominate substrate	0.0536	0.7376
Distance to cover (m)	0.4345	-0.2065
Distance to bank (m)	-0.1947	0.0177
Eigenvalue	2.2327	1.2610
Cumulative variance explained (%)	37.2	58.2

Table 20. Moderate gradient principal component eigenvector values (i.e., loadings), eigenvalues, and cumulative variance explained of winter microhabitat use and availability for radio-tagged juvenile Catherine Creek fall migrant spring Chinook salmon.

	PCA axis	
Variable and statistic	1	2
Depth (m)	0.2234	-0.5866
Bottom velocity (m/s)	0.5770	0.2556
Mean column velocity (m/s)	0.6226	0.0598
Dominate substrate	0.0536	0.7376
Distance to cover (m)	0.4345	-0.2065
Distance to bank (m)	-0.1947	0.0177
Eigenvalue	2.2327	1.2610
Cumulative variance explained (%)	37.2	58.2

Table 21. Low gradient principal component eigenvector values (i.e., loadings), eigenvalues, and cumulative variance explained of fall microhabitat use and availability for radio-tagged juvenile Catherine Creek fall migrant spring Chinook salmon.

	PCA axis	
Variable and statistic	1	2
Depth (m)	0.5422	-0.2206
Bottom velocity (m/s)	0.3440	0.5285
Mean velocity (m/s)	0.5626	-0.0564
Dominate substrate	0.1391	0.6281
Distance to cover (m)	0.4559	-0.0176
Distance to bank (m)	0.2097	-0.5235
Eigenvalue	2.7496	1.1192
Cumulative variance explained (%)	45.8	64.5

Table 22. Low gradient principal component eigenvector values (i.e., loadings), eigenvalues, and cumulative variance explained of winter microhabitat use and availability for radio-tagged juvenile Catherine Creek fall migrant spring Chinook salmon.

	PCA axis	
Variable and statistic	1	2
Depth (m)	0.5422	-0.2206
Bottom velocity (m/s)	0.3440	0.5285
Mean velocity (m/s)	0.5626	-0.0564
Dominate substrate	0.1391	0.6281
Distance to cover (m)	0.4559	-0.0176
Distance to bank (m)	0.2097	-0.5235
Eigenvalue	2.7496	1.1192
Cumulative variance explained (%)	45.8	64.5

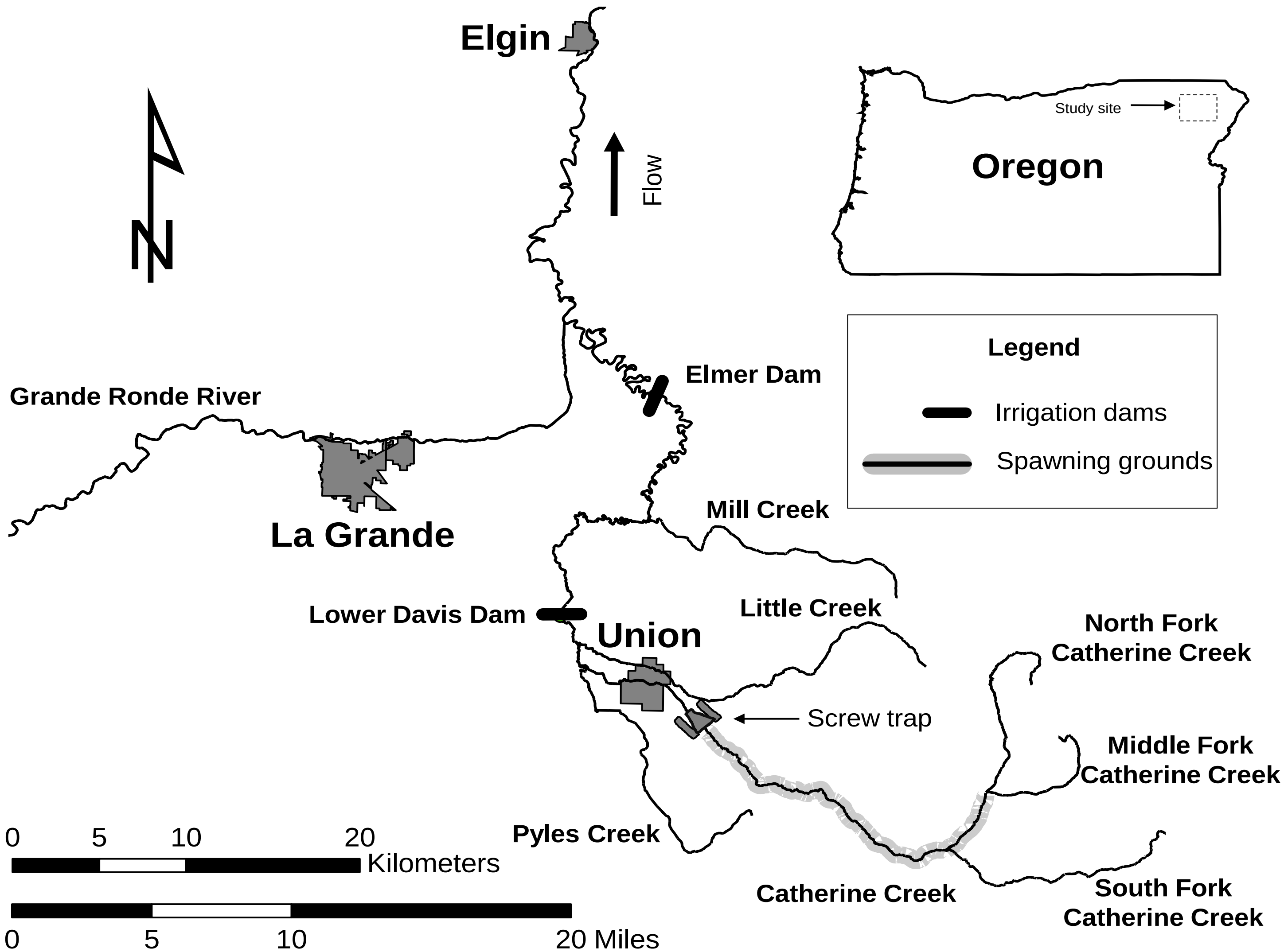

Figure 1. Study area map of Grande Ronde Valley bounded downstream by Elgin, OR and upstream by Union, OR.

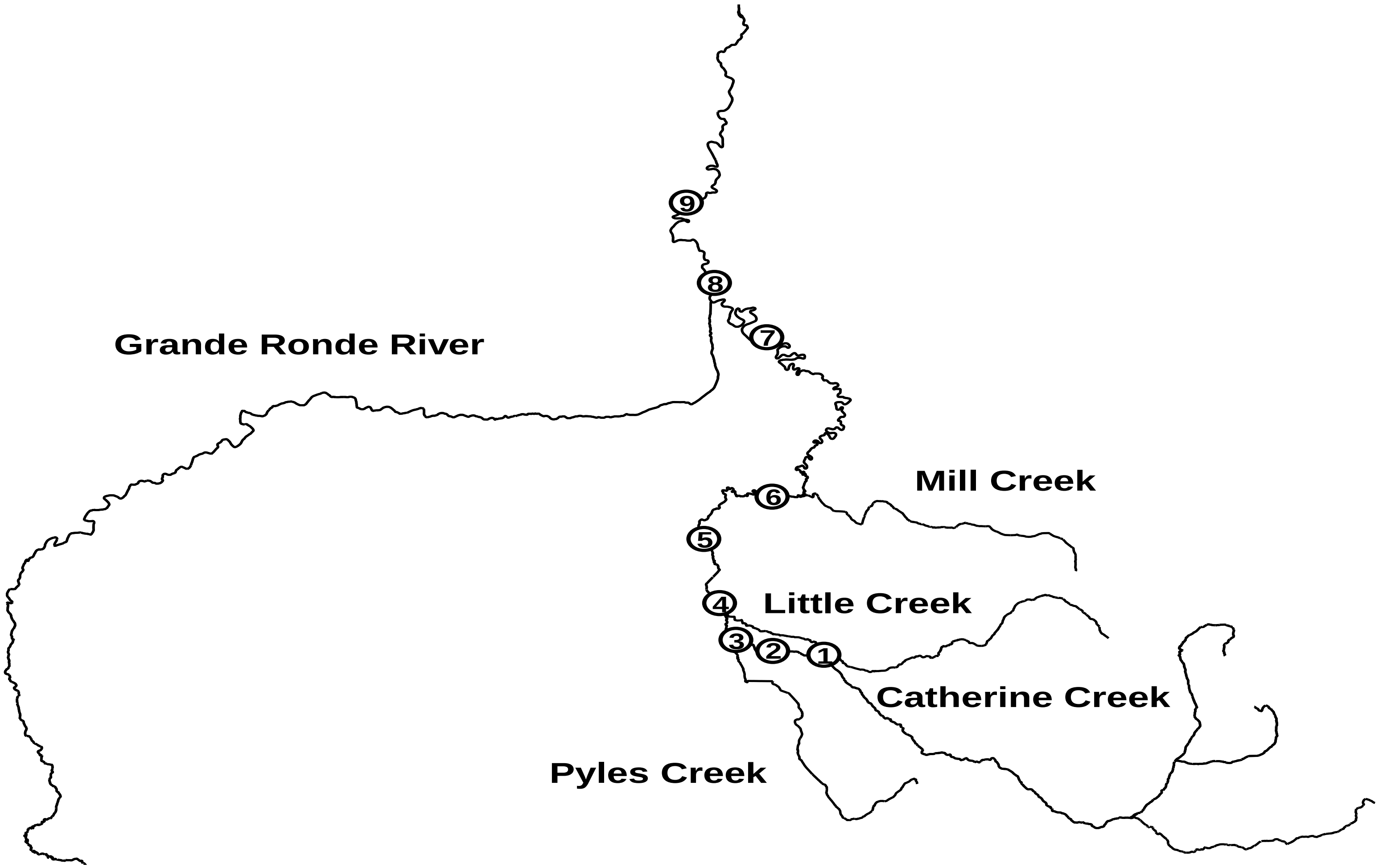

Figure 2. Map of stream reaches surveyed to quantify Catherine Creek fall migrant juvenile spring Chinook salmon overwintering habitat availability. Numbered sites are in close proximity to (1) Union (Swackhammer fish ladder); (2) Union Recycling Center; (3) mouth of Pyles Creek; (4) HWY 203 Bridge; (5) Wilkinson Road; (6) Godley Lane; (7) Market Lane; (8) Alicel Lane; and (9) Hull Lane.

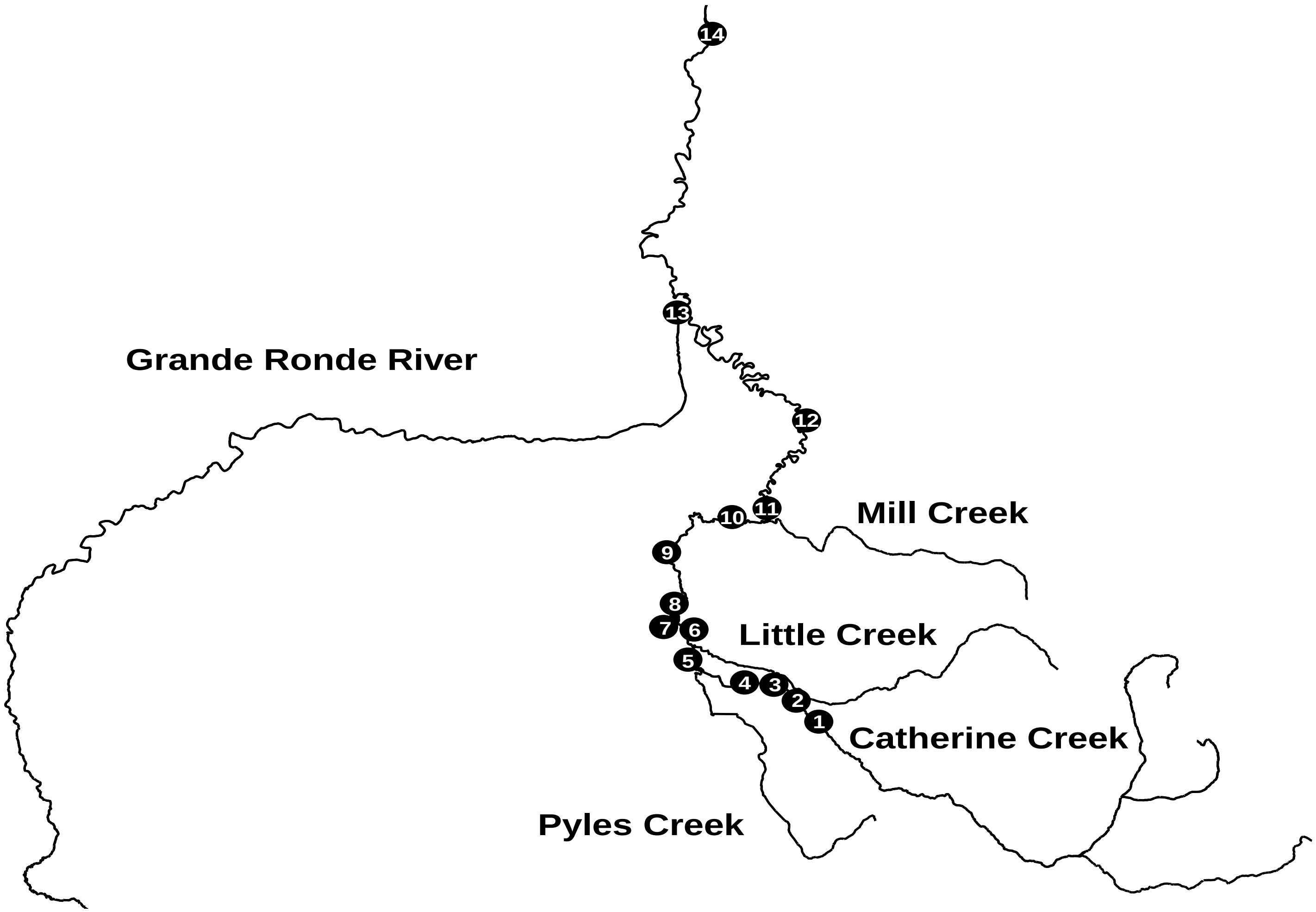

Figure 3. Map of temperature logger locations installed to document water temperatures associated with fall migration and overwintering periods for Catherine Creek fall migrant spring Chinook salmon. Numbered sites are in close proximity to (1) Catherine Creek screw trap; (2) Swackhammer Diversion; (3) 10th Street; (4) Union Recycle Center; (5) Miller Lane; (6) HWY 203; (7) lower Davis Dam (above); (8) lower Davis Dam (below); (9) Wilkenson Lane; (10) Godley Lane; (11) Gekeler Lane; (12) Booth Lane; (13) Alicel Lane; and (14) Elgin.

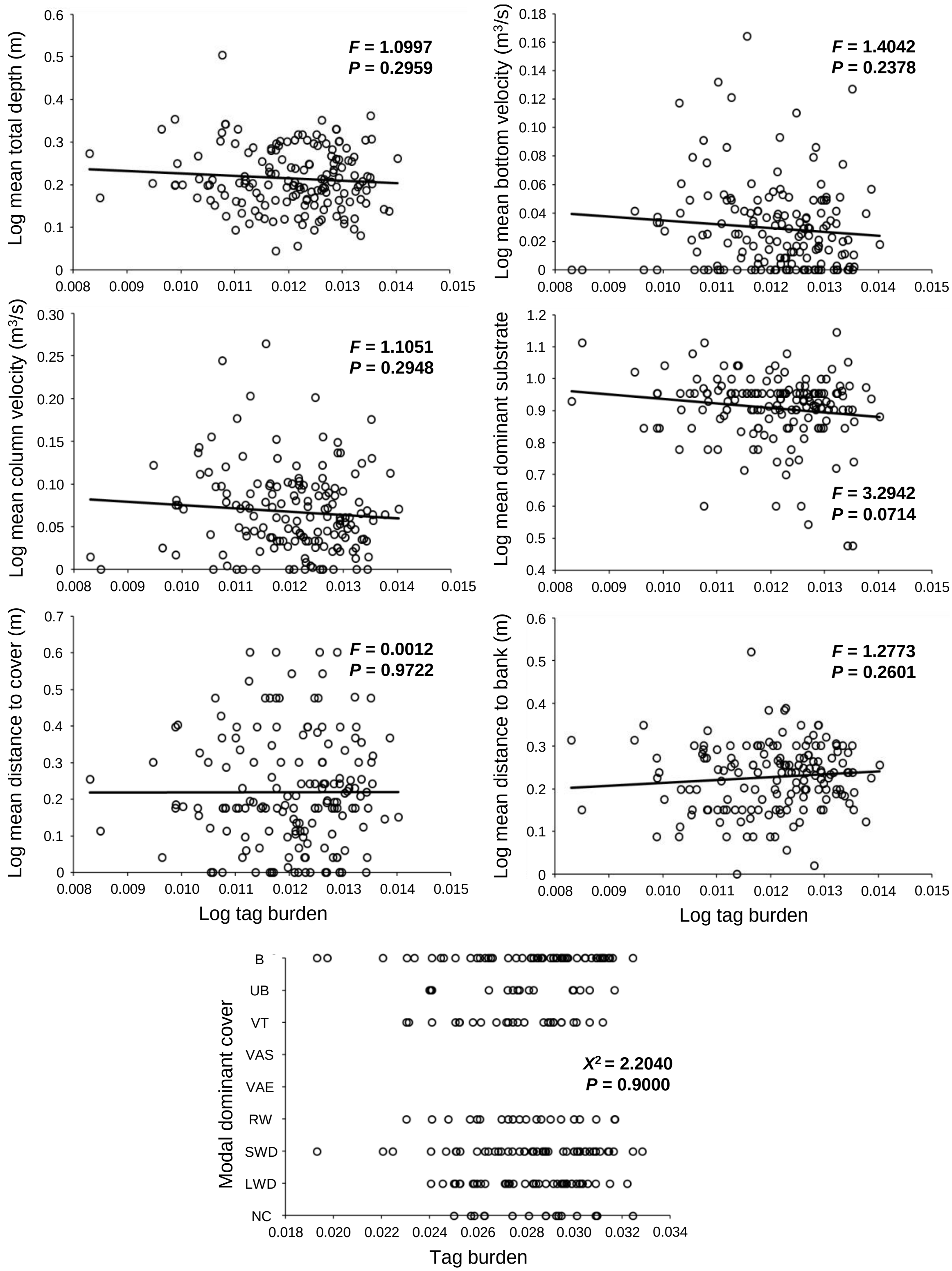

Figure 4. Linear regressions between juvenile Chinook salmon tag burden (log transformed) and mean microhabitat use for continuous variables (log transformed) in the moderate gradient reach of Catherine Creek, Oregon. Categorical variable modal dominant cover and tag burden were compared using multinomial logistic regression.

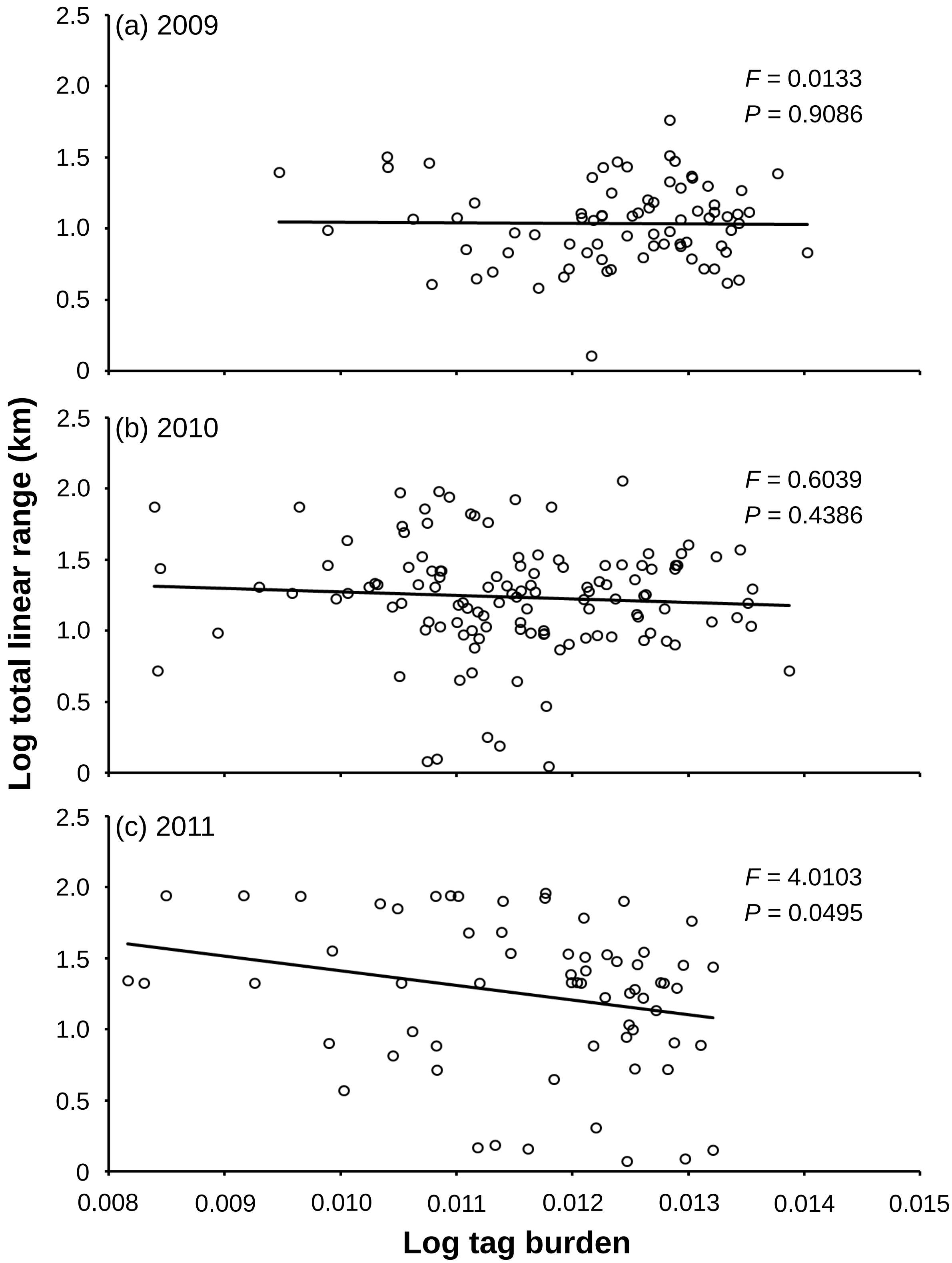

Figure 5. Linear regressions between juvenile Chinook salmon tag burden (log transformed) and overwintering total linear range (log transformed) in the Grande Ronde Valley, Oregon.

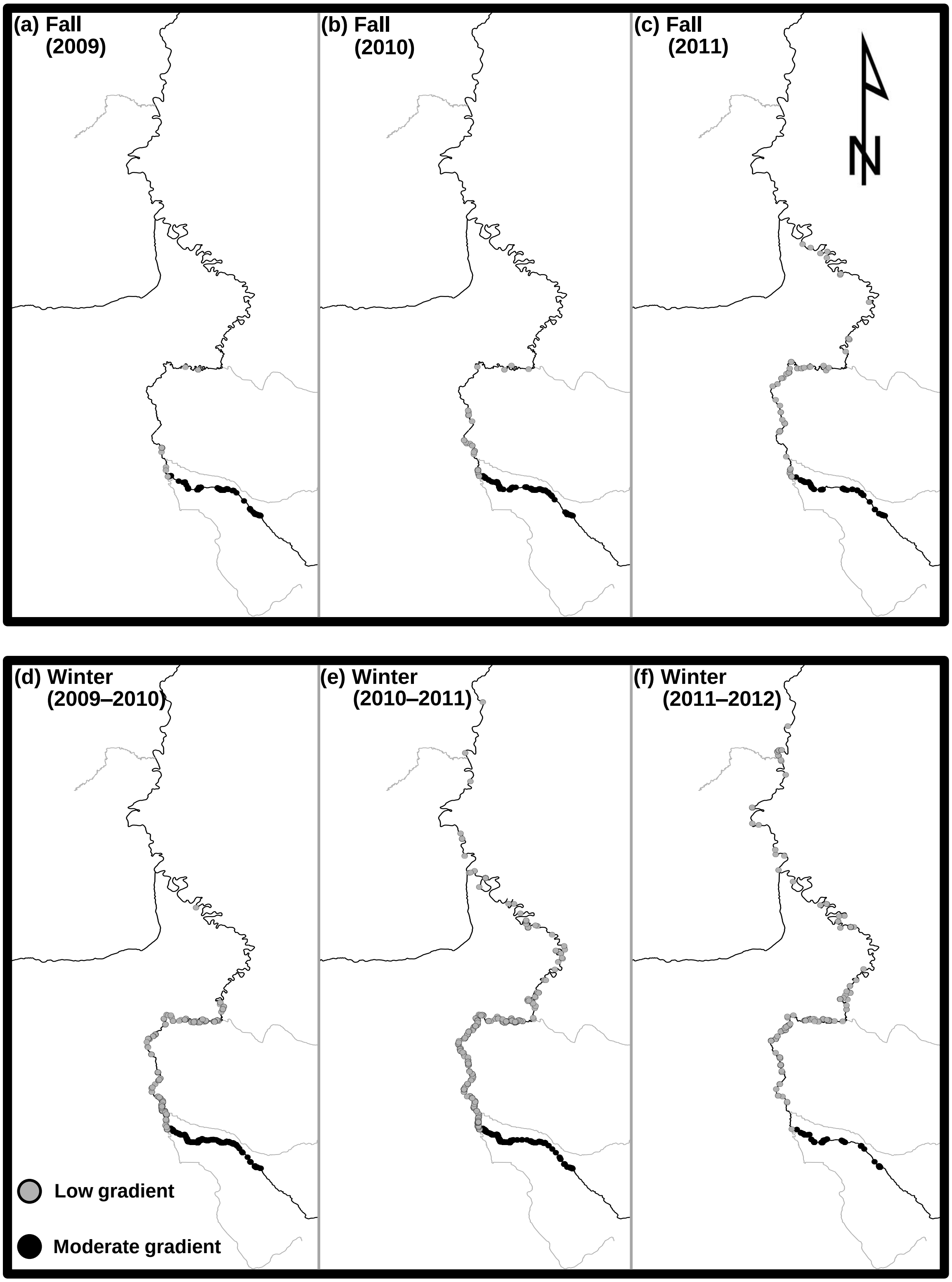

Figure 6. Seasonal maps characterizing fall migrant juvenile spring Chinook salmon relocations during fall migration and overwinter during fall (a) 2009, (b) 2010, and (c) 2011 and winter (d) 2009–2010, (e) 2010–2011, and (f) 2011–2012.

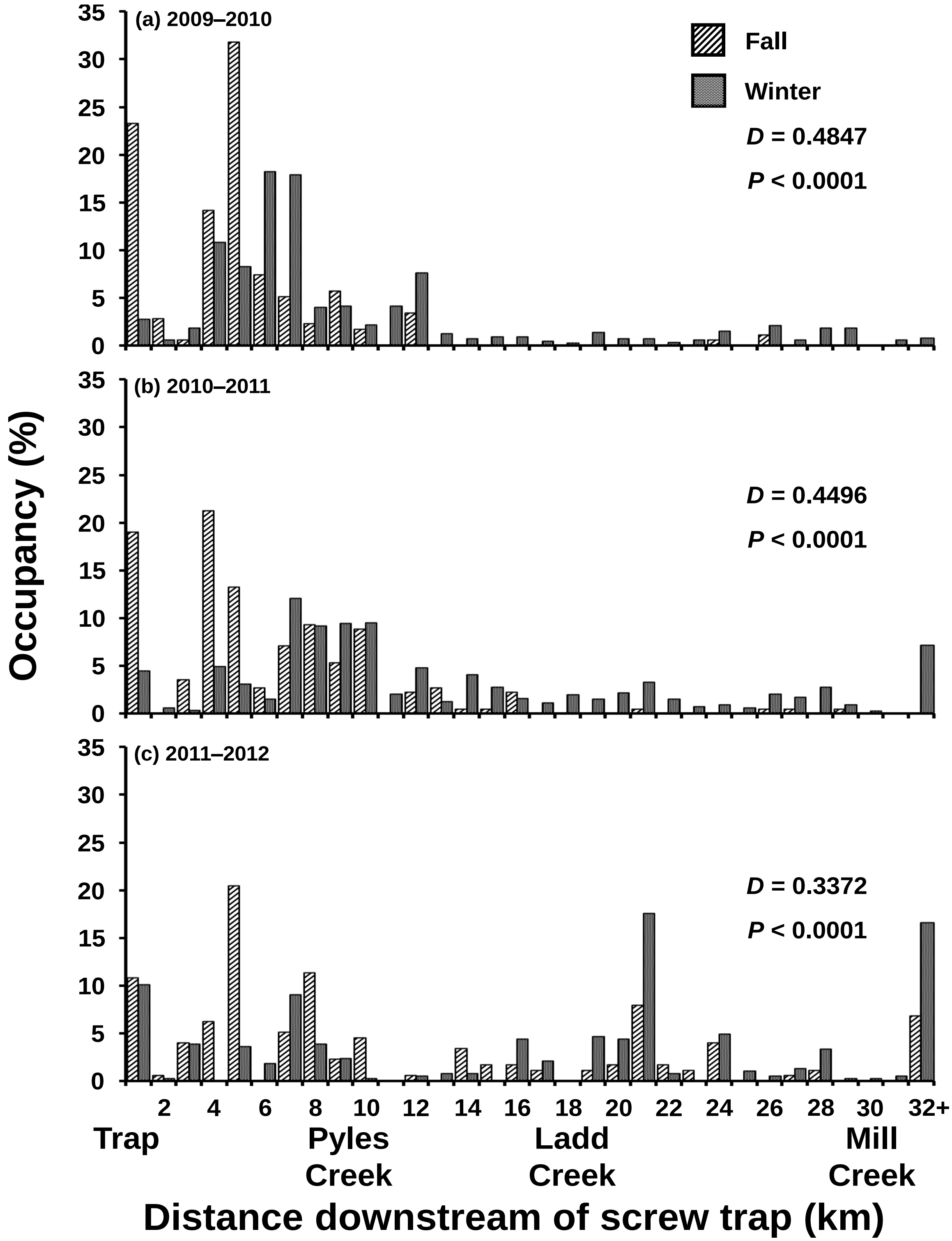

Figure 7. Fall and winter occupancy by Catherine Creek fall migrant spring Chinook salmon during (a) 2009–2010, (b) 2010–2011, and (c) 2011–2012. Fall and winter relocations were compared using the Kolmogorov-Smirnov two-sample test.

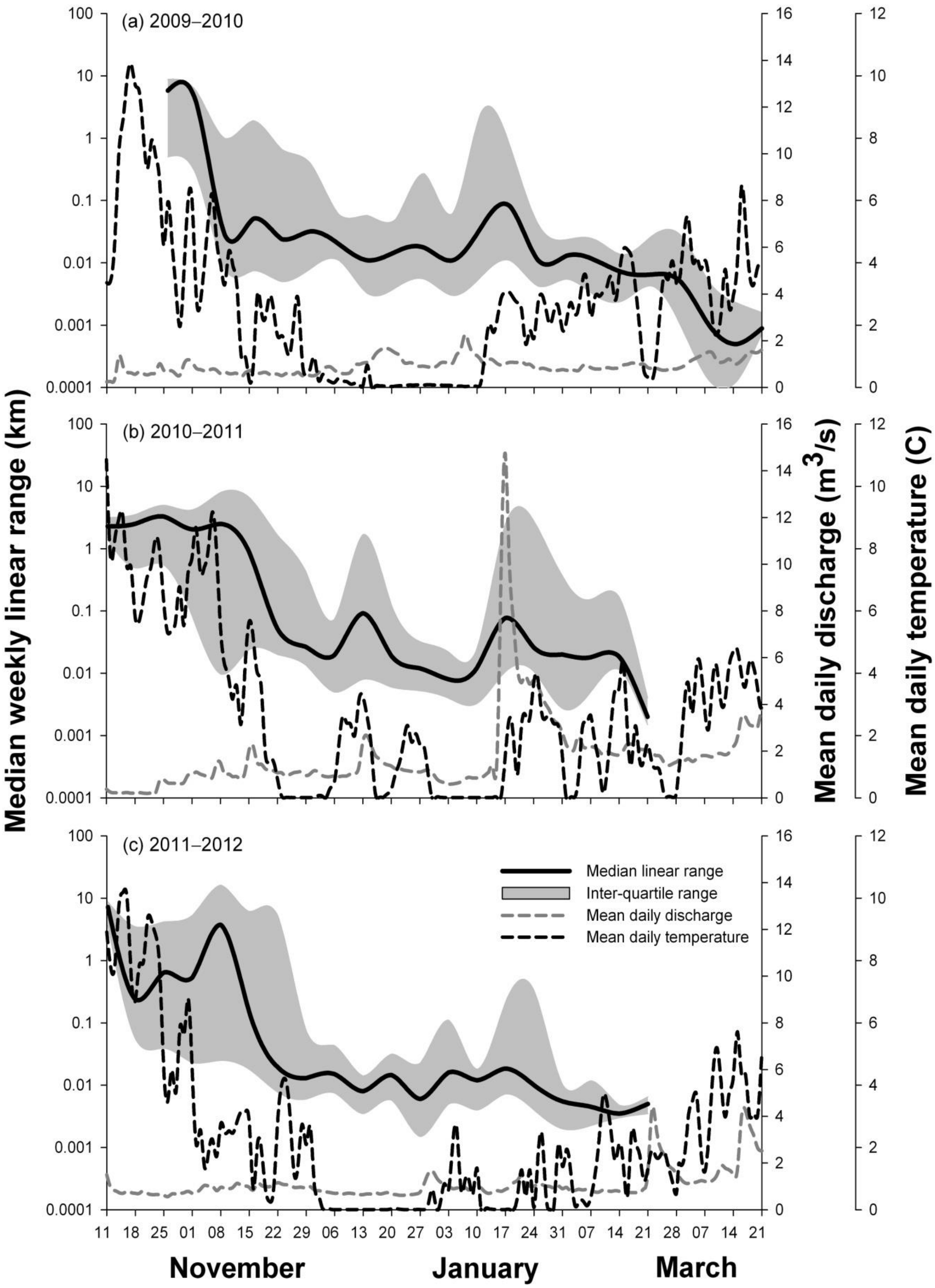

Figure 8. Catherine Creek fall migrant spring Chinook salmon weekly median linear range during fall migration and overwintering periods. Associated environmental variables discharge and water temperature are provided for comparison.

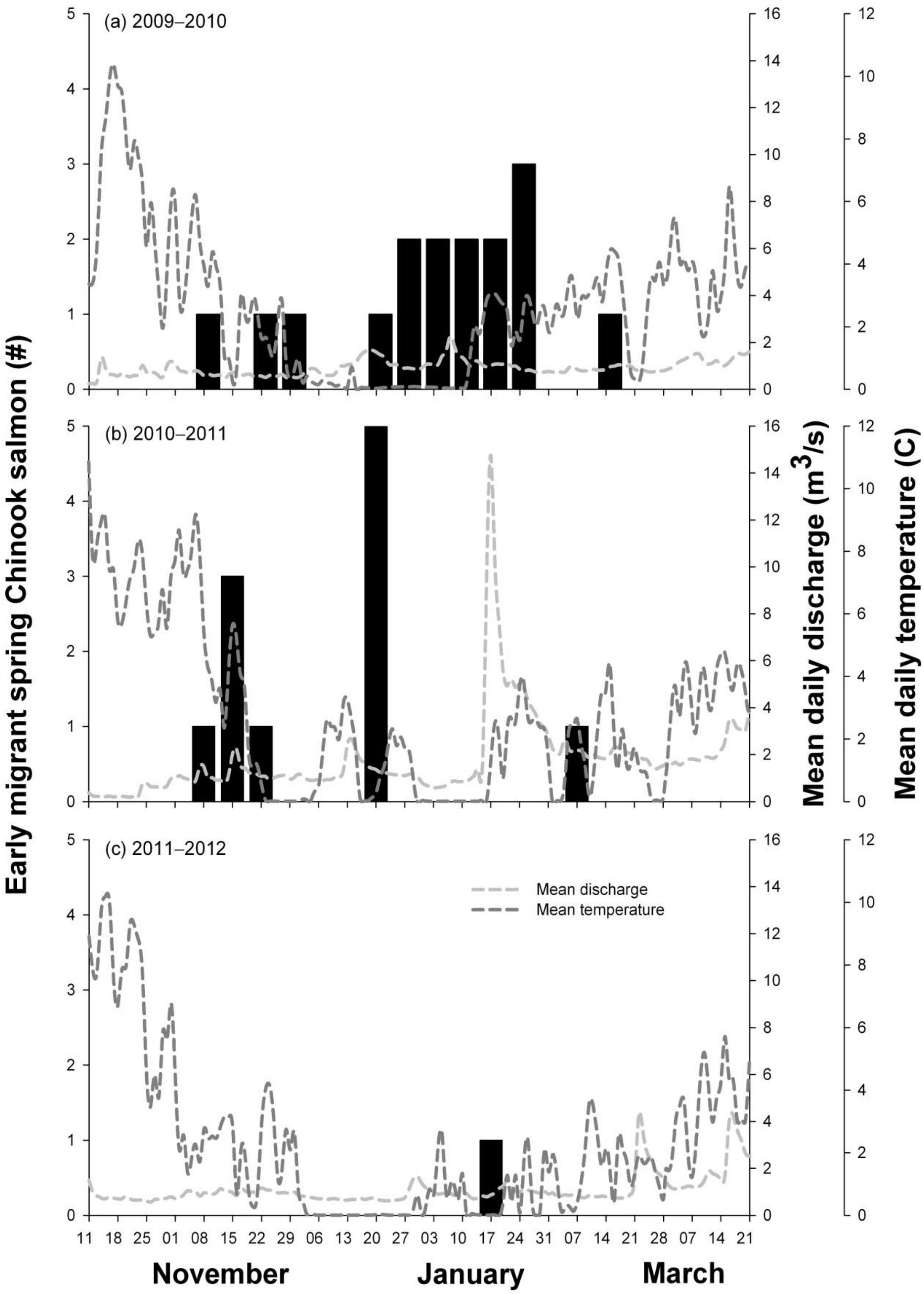

Figure 9. Weekly number of Catherine Creek fall migrant spring Chinook salmon that made a considerable upstream movement following occupying overwintering habitat. Associated environmental variables discharge and water temperature are provided for comparison.

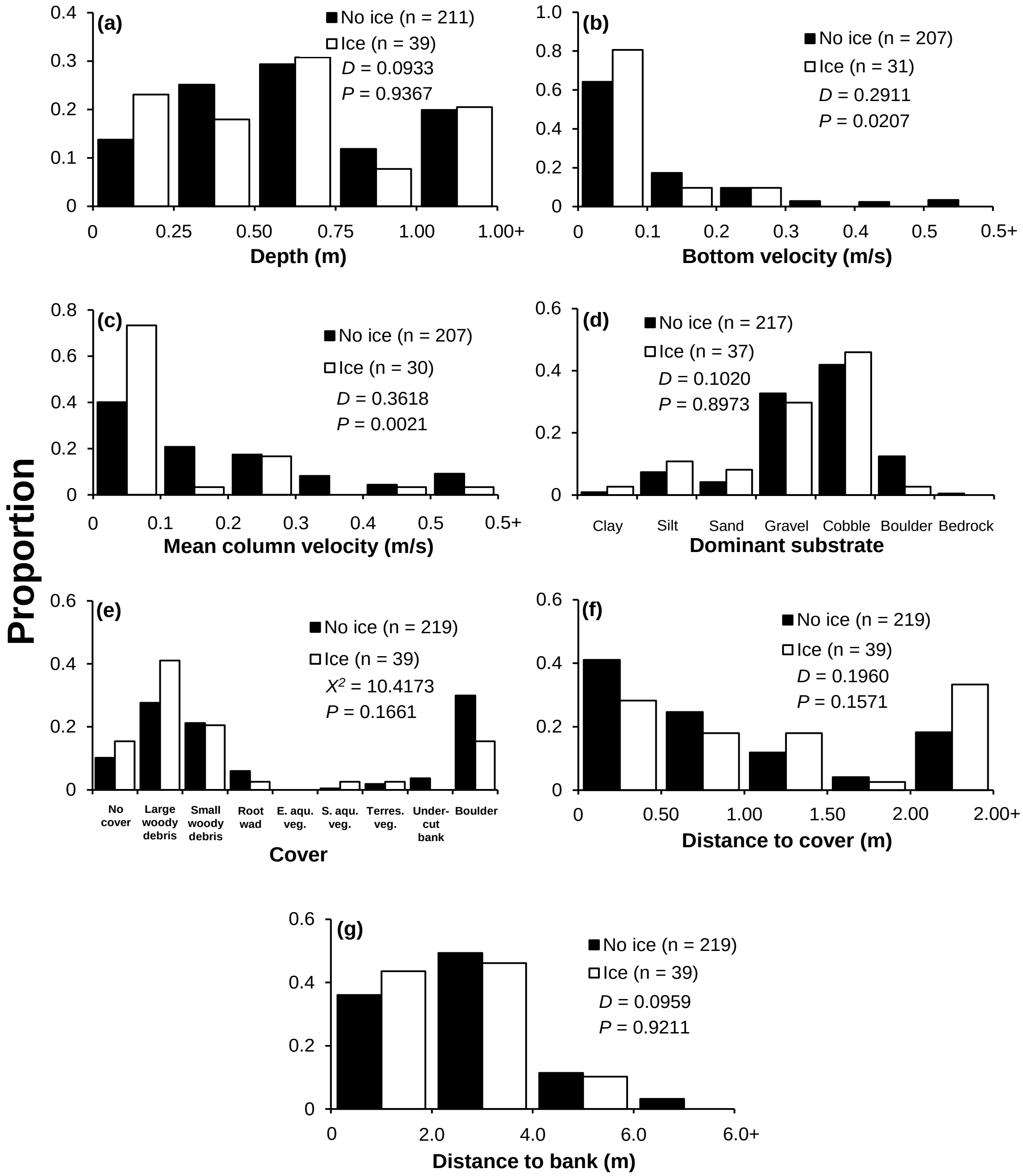

Figure 10. Catherine Creek spring Chinook salmon moderate gradient microhabitat use variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with surface ice presence/absence during winter. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

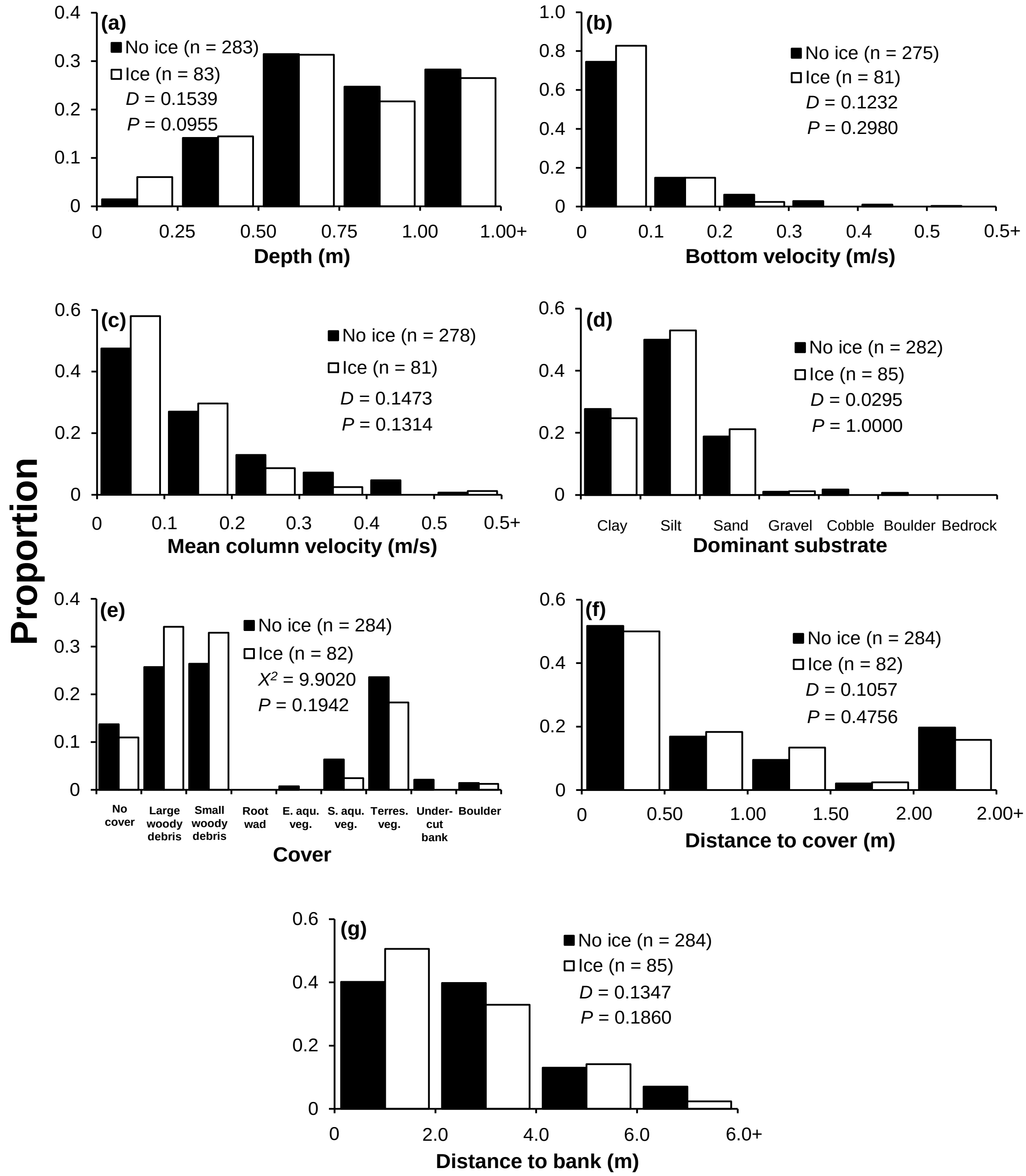

Figure 11. Catherine Creek spring Chinook salmon low gradient microhabitat use variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with surface ice presence/absence during winter. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

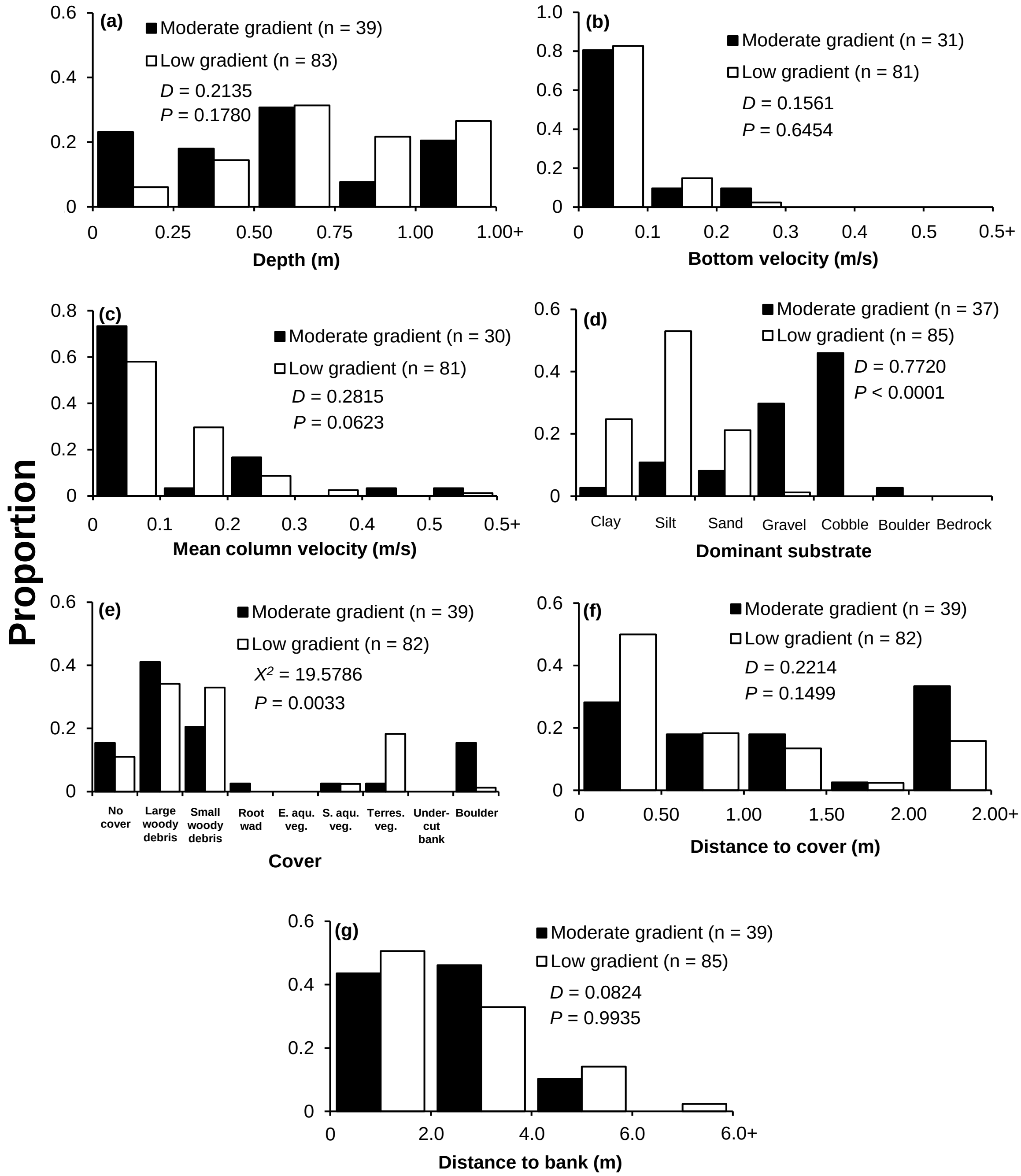

Figure 12. Catherine Creek spring Chinook salmon moderate and low gradient microhabitat use variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with surface ice during winter. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

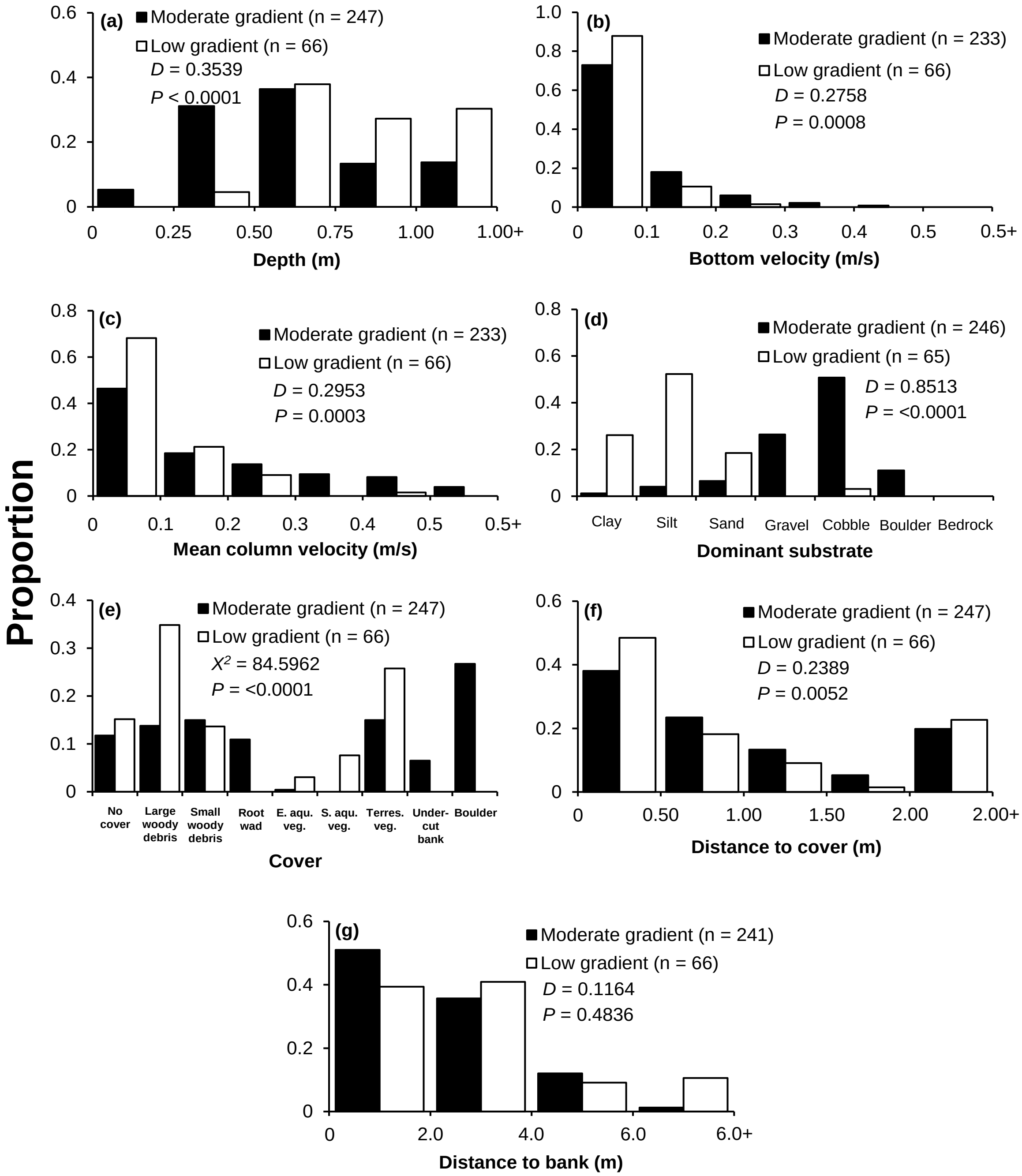

Figure 13. Catherine Creek spring Chinook salmon moderate and low gradient microhabitat use variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with free-flowing stream conditions during fall.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

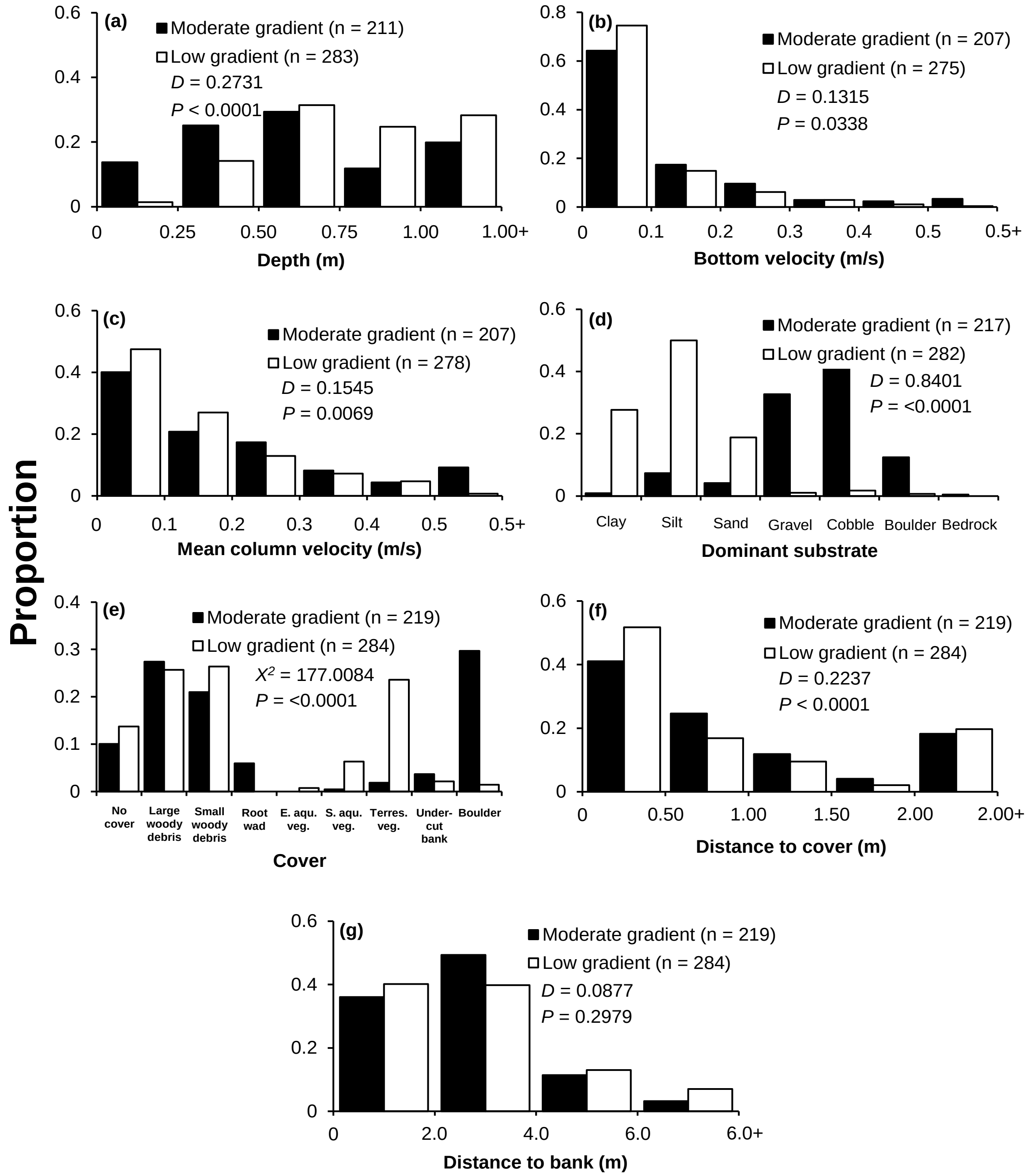

Figure 14. Catherine Creek spring Chinook salmon moderate and low gradient microhabitat use variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with free-flowing stream conditions during winter. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

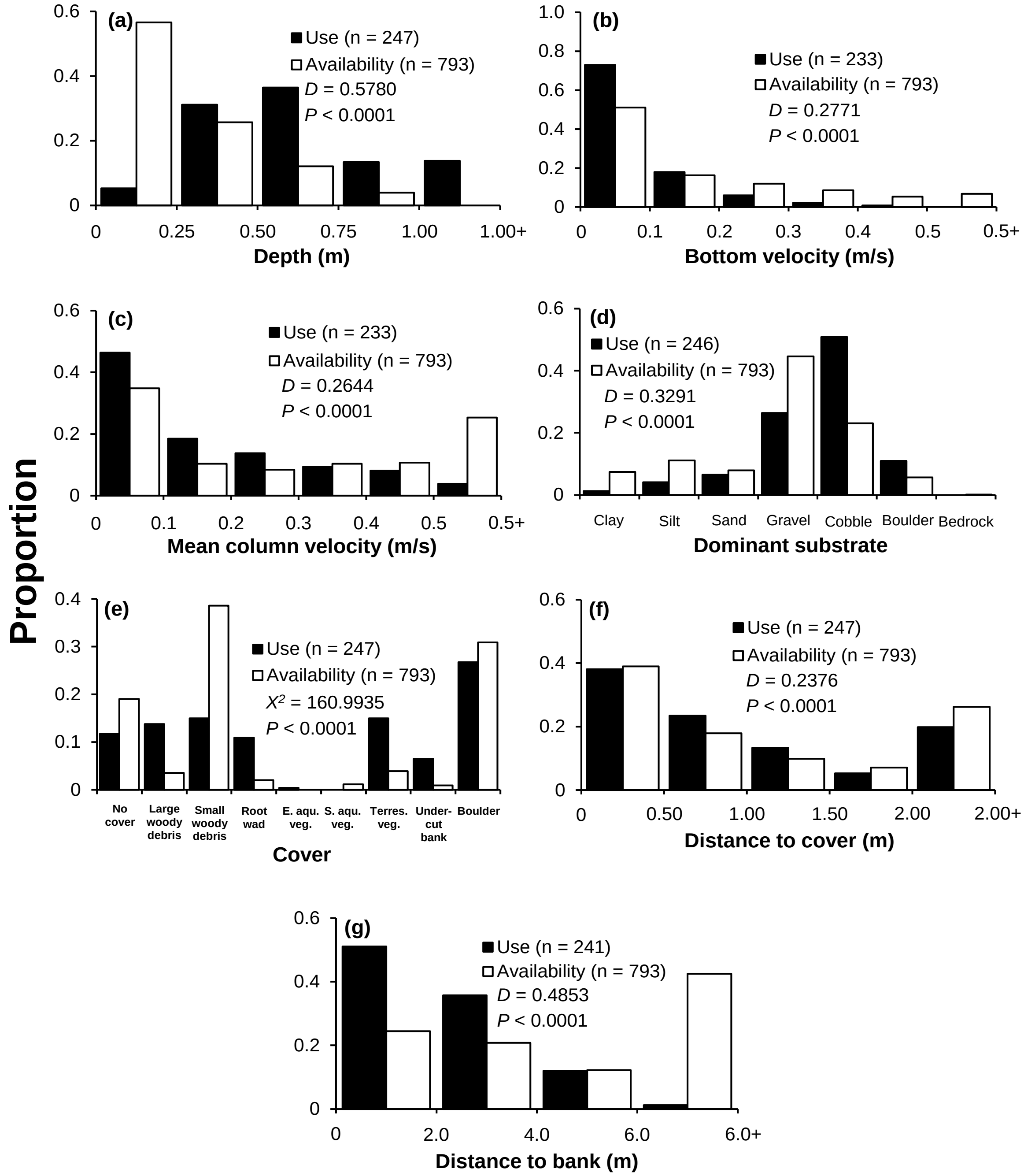

Figure 15. Catherine Creek spring Chinook salmon moderate gradient microhabitat use and availability frequency distributions and associated statistics for variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to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

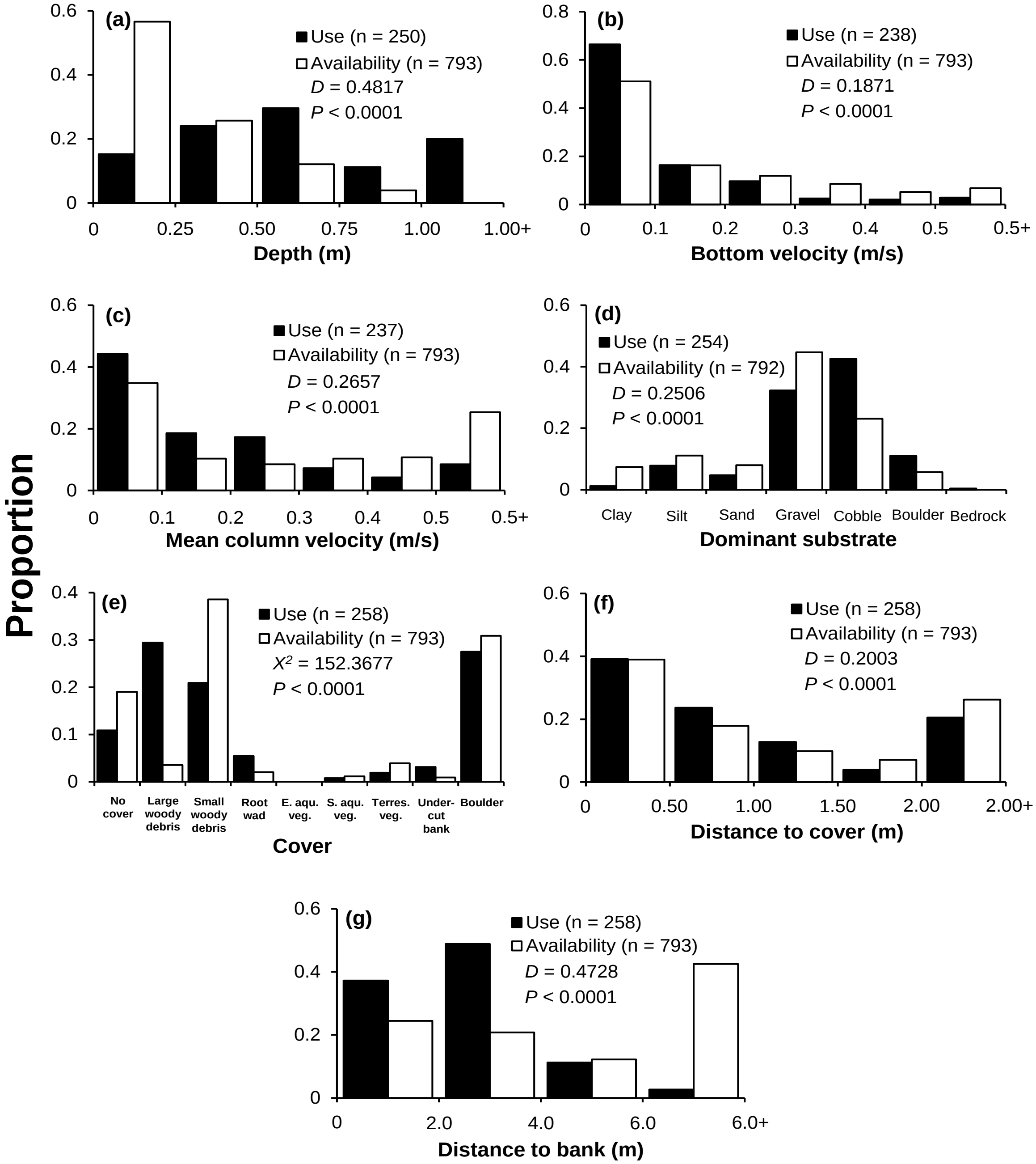

Figure 16. Catherine Creek spring Chinook salmon moderate gradient microhabitat use and availability frequency distributions and associated statistics for variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with free-flowing and surface ice stream conditions during winter. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

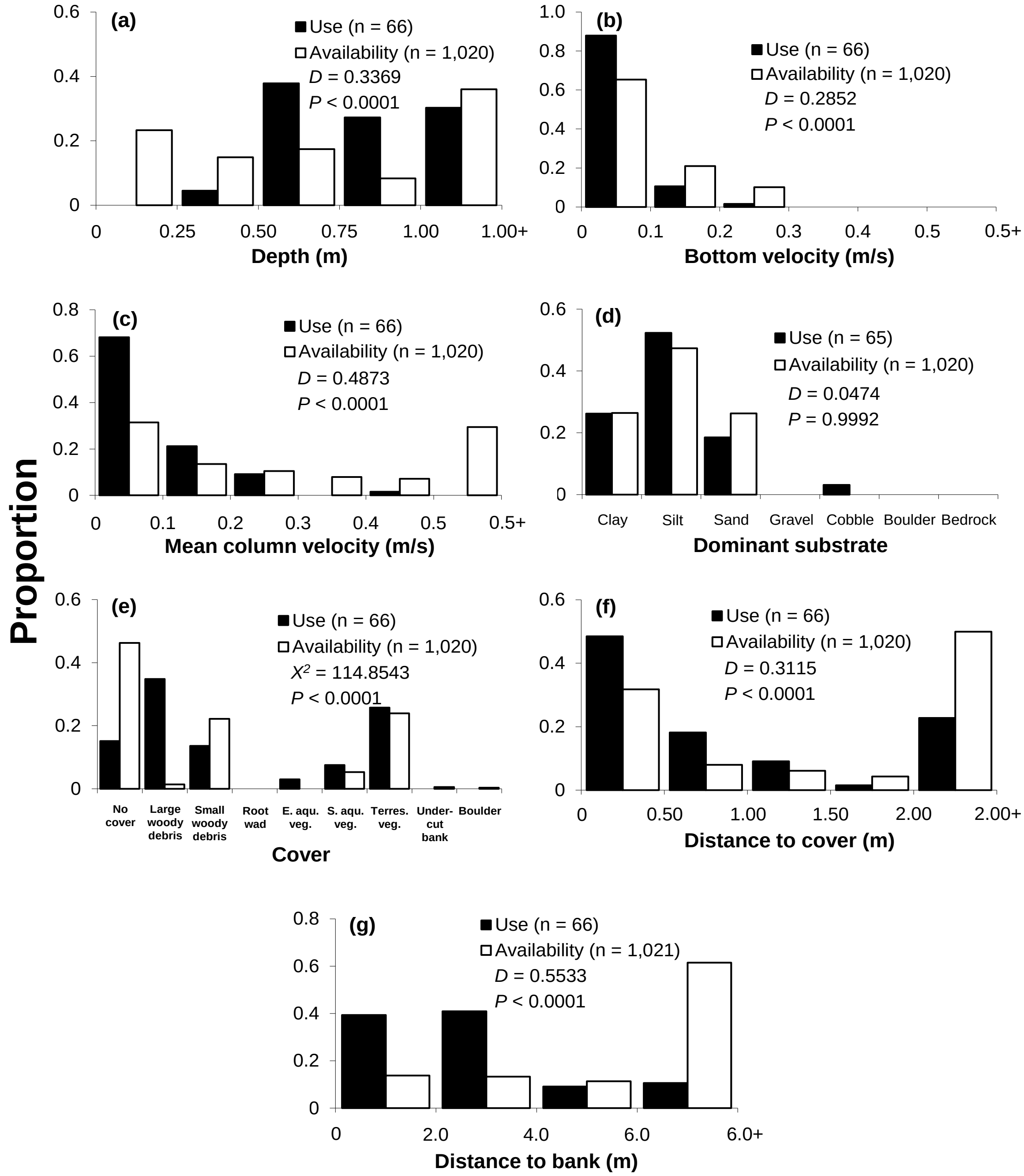

Figure 17. Catherine Creek spring Chinook salmon low gradient microhabitat use and availability frequency distributions and associated statistics for variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with free-flowing stream conditions during fall. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

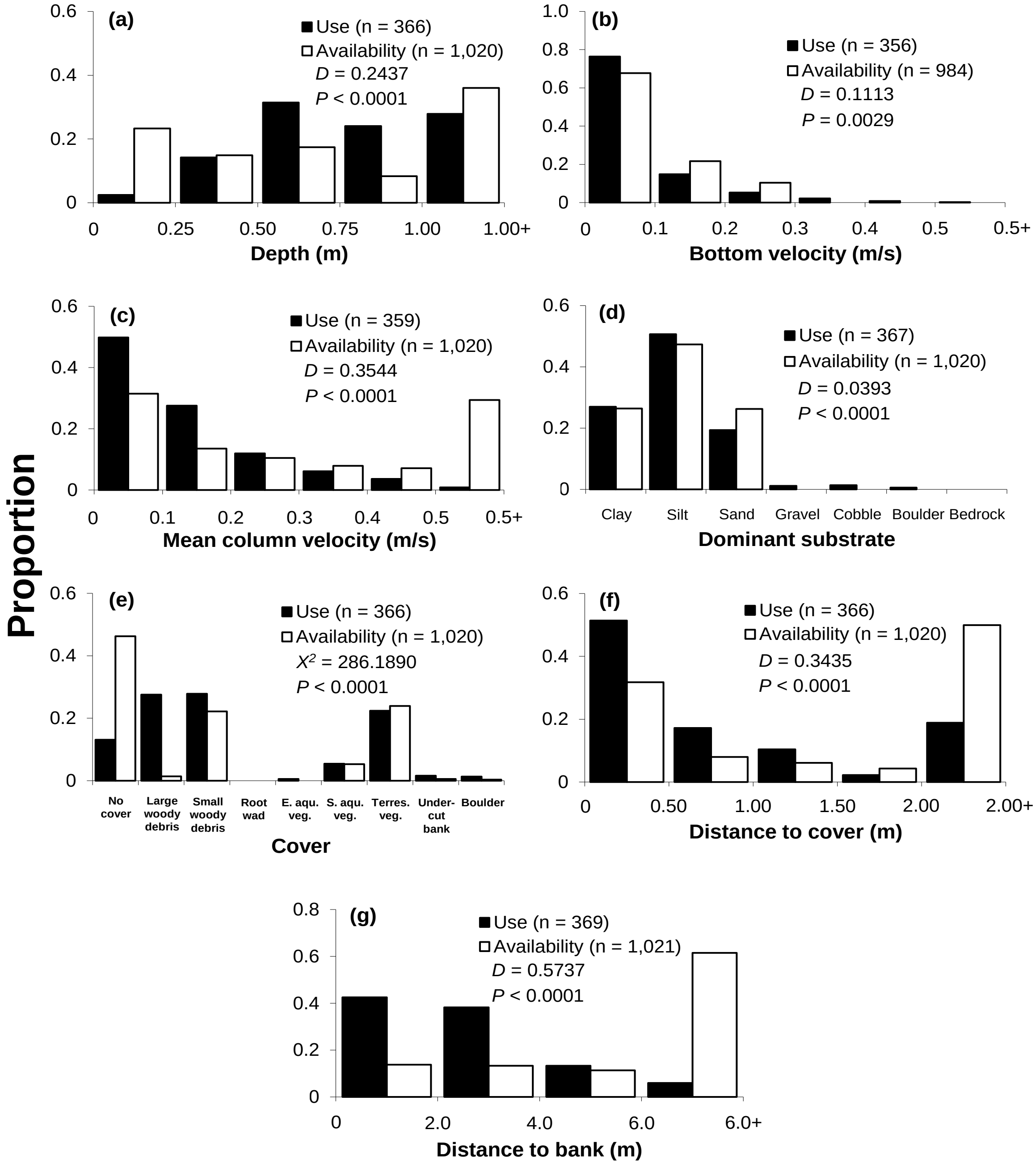

Figure 18. Catherine Creek spring Chinook salmon low gradient microhabitat use and availability frequency distributions and associated statistics for variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank associated with free-flowing and surface ice stream conditions during winter. Continuous variables were compared using a Kolmogorov-Smirnov two-sample test; categorical variables were compared using a likelihood-ratio chi-square test.

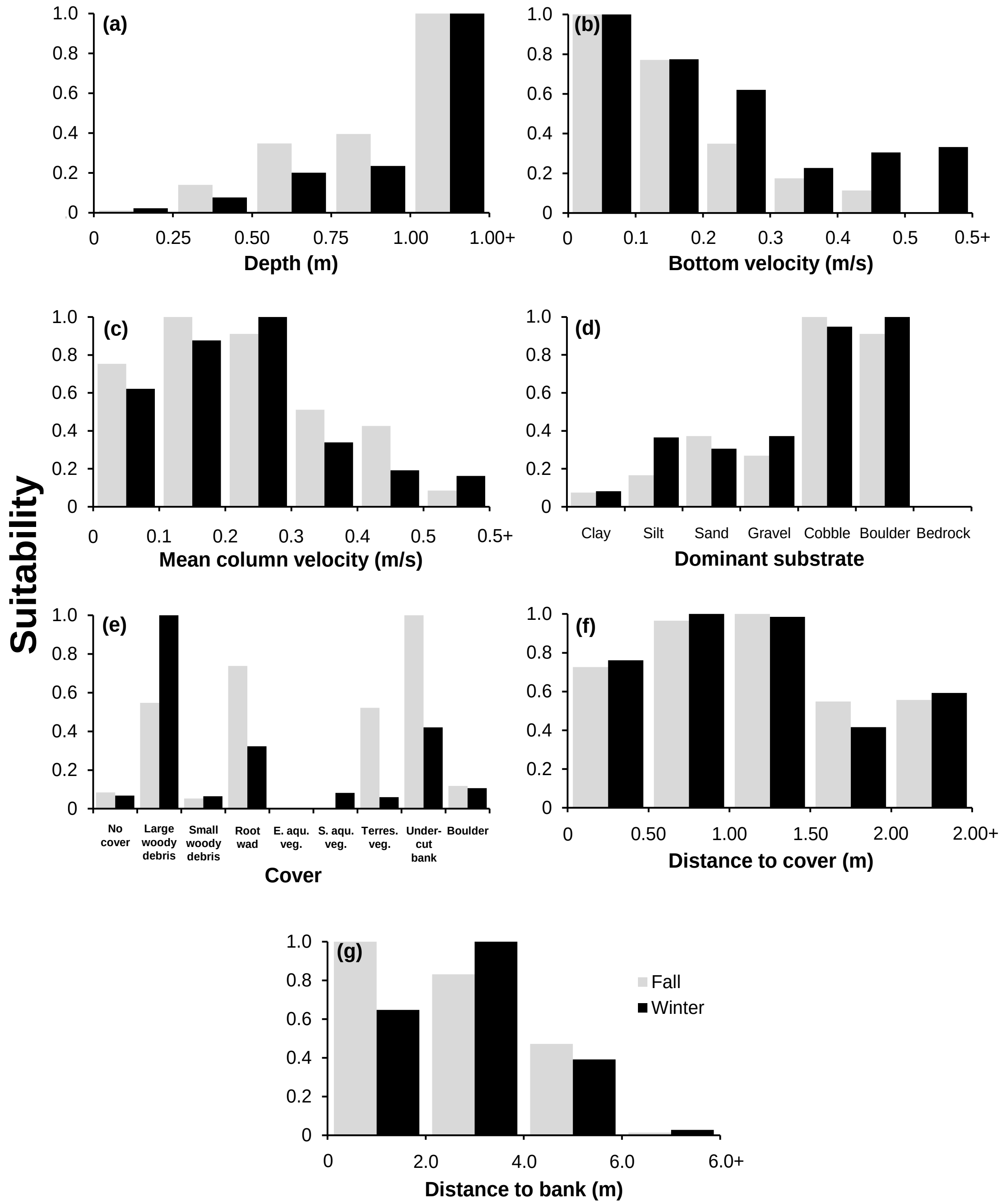

Figure 19. Catherine Creek spring Chinook salmon moderate gradient microhabitat suitability indexes for variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank during fall and winter.

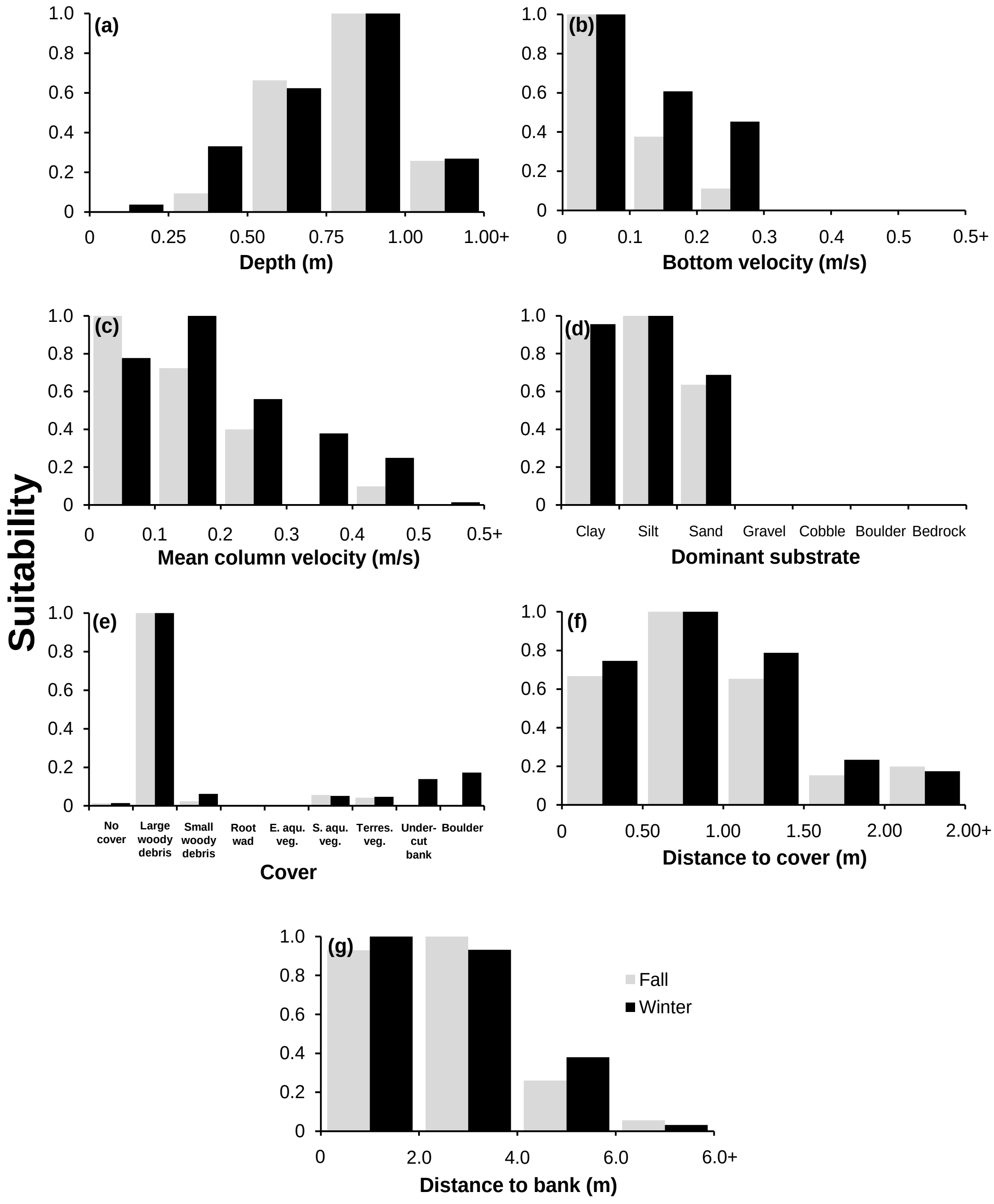

Figure 20. Catherine Creek spring Chinook salmon low gradient microhabitat suitability indexes for variables (a) depth, (b) bottom velocity, (c) mean column velocity, (d) dominant substrate, (e) cover, (f) distance to cover, and (g) distance to bank during fall and winter.

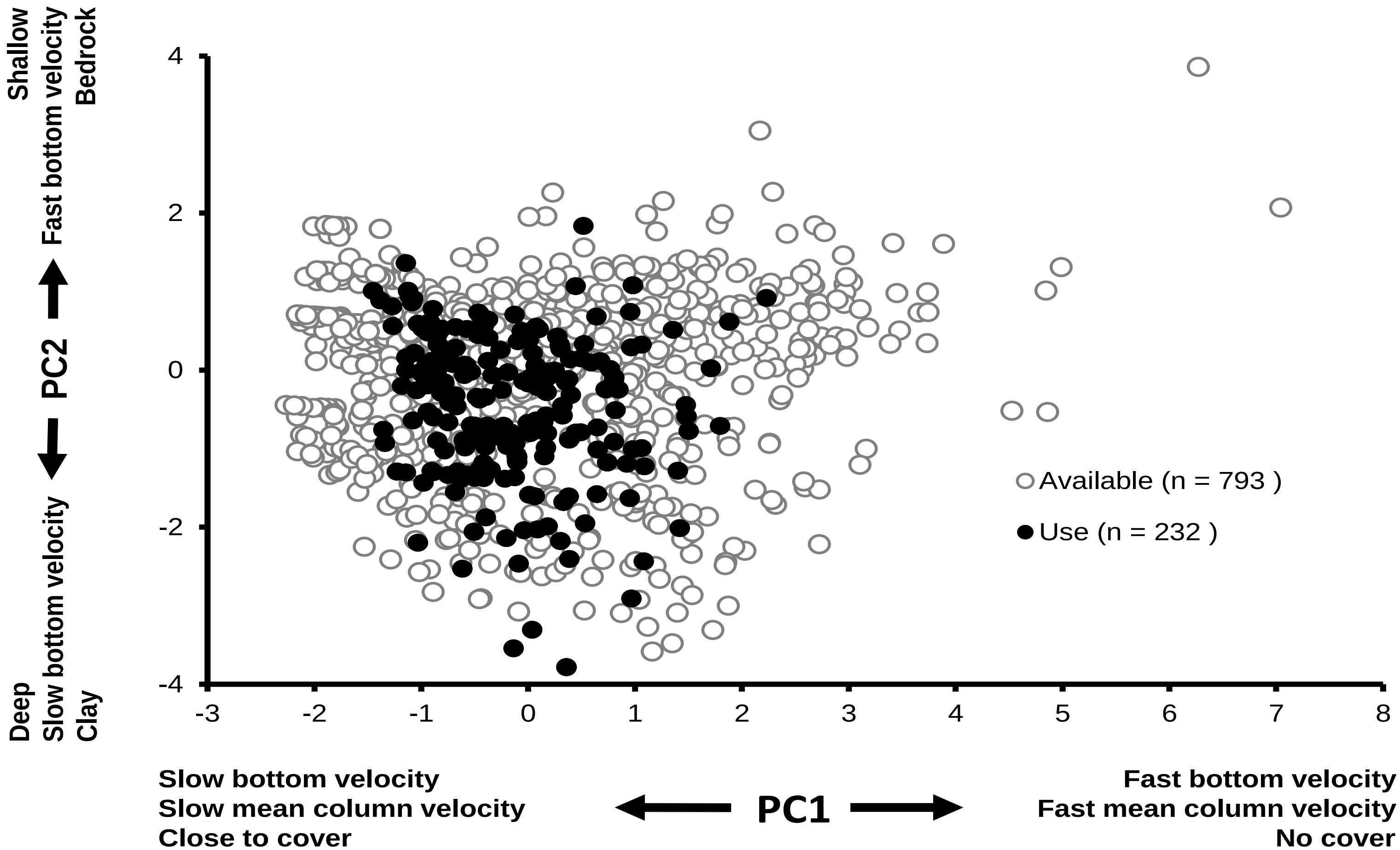

Figure 21. Plot of fall migrant spring Chinook salmon parr moderate gradient microhabitat use and availability principal component scores describing microhabitat variable combinations for principal components 1 and 2 that are most important in defining fall migration and rearing mesohabitat.

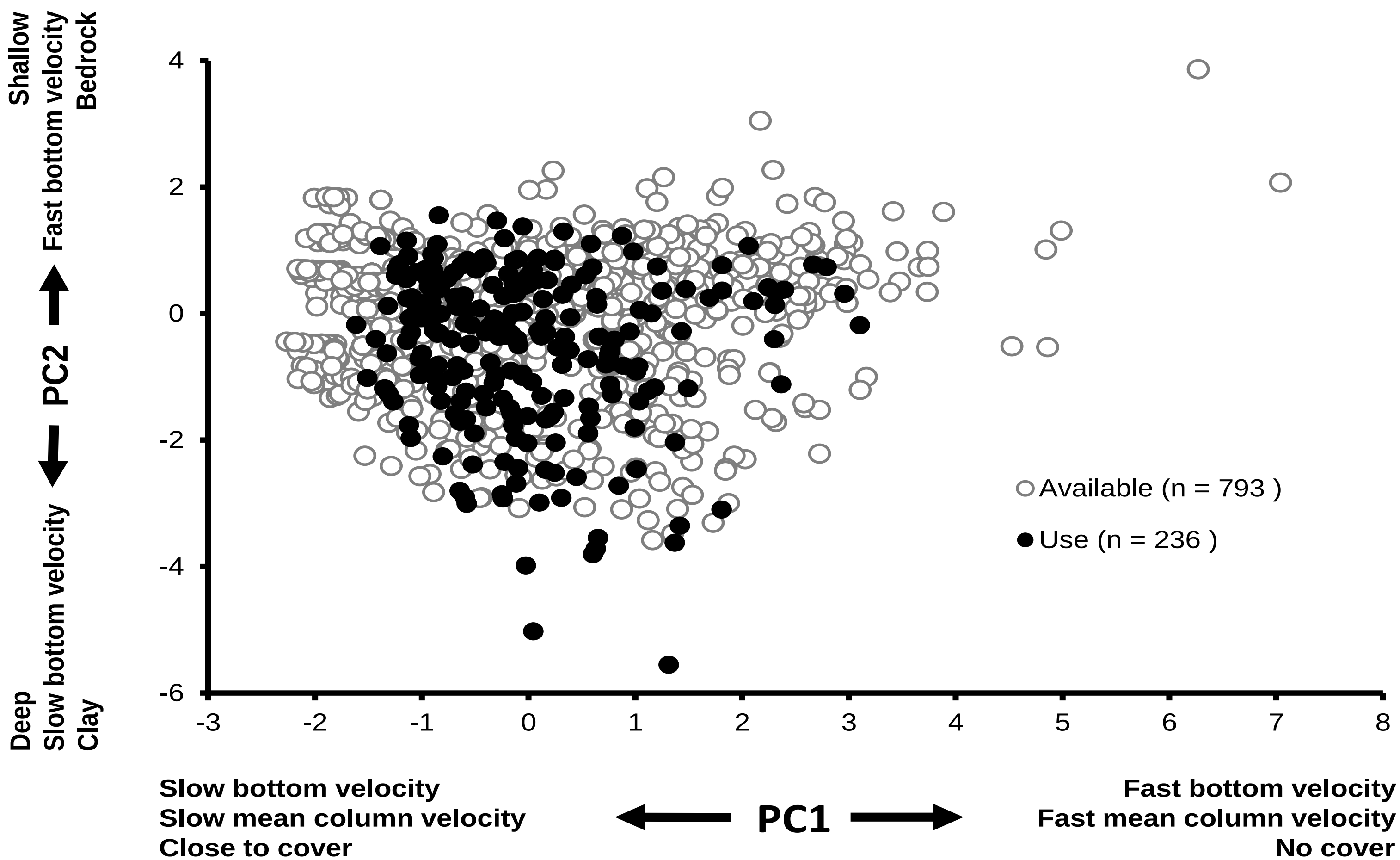

Figure 22. Plot of fall migrant spring Chinook salmon parr moderate gradient microhabitat use and availability principal component scores describing microhabitat variable combinations for principal components 1 and 2 that are most important in defining overwintering mesohabitat associated with free-flowing and surface ice stream conditions.

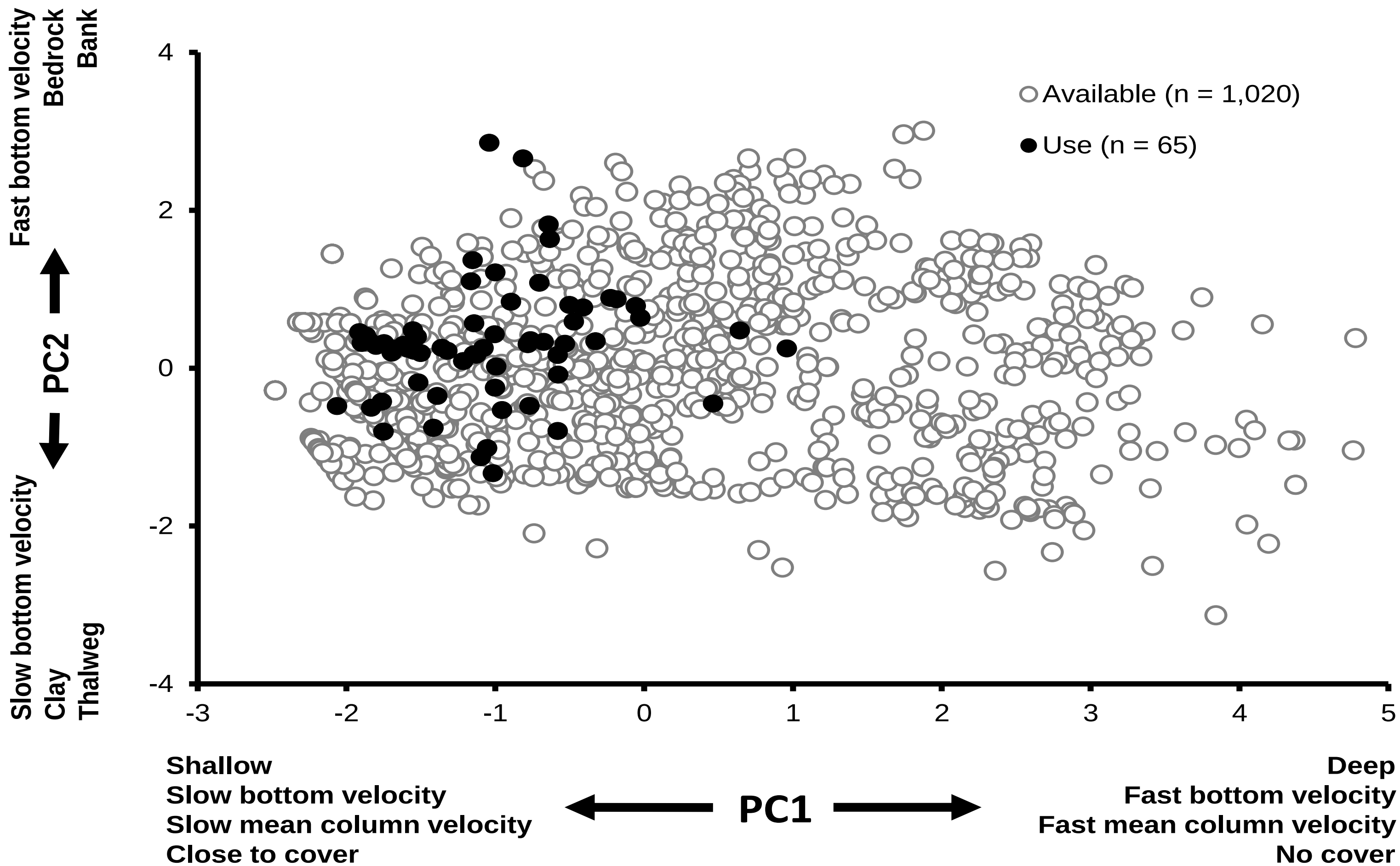

Figure 23. Plot of fall migrant spring Chinook salmon parr low gradient microhabitat use and availability principal component scores describing microhabitat variable combinations for principal components 1 and 2 that are most important in defining fall migration and rearing mesohabitat.

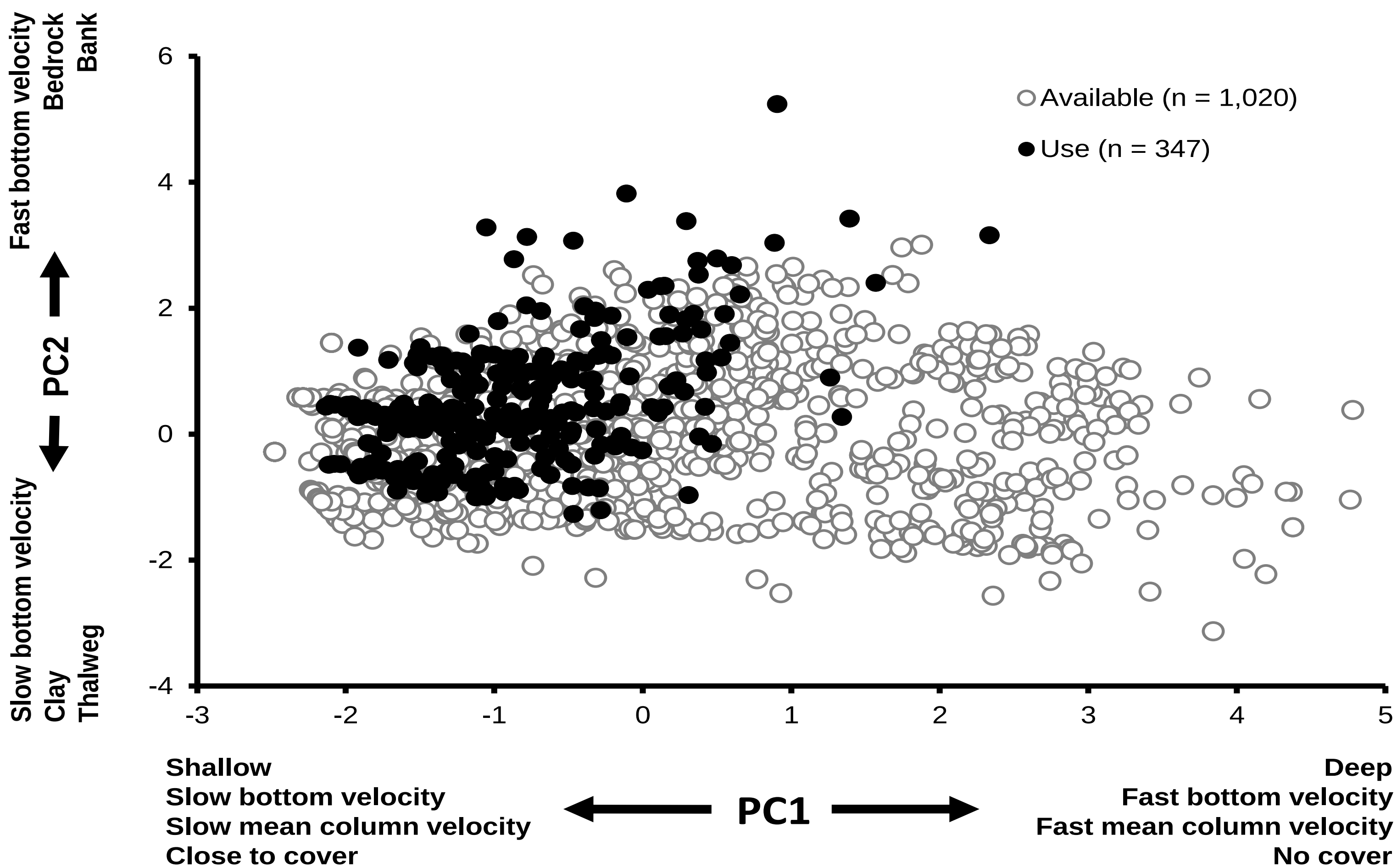

Figure 24. Plot of fall migrant spring Chinook salmon parr low gradient microhabitat use and availability principal component scores describing microhabitat variable combinations for principal components 1 and 2 that are most important in defining overwintering mesohabitat associated with free-flowing and surface ice stream conditions.