Fish Abundance, Habitat, and Habitat Use at Two Stabilized Banks in the Hoh River, Washington:

Preliminary Data to Evaluate the Influence of Engineered Logjams

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The State of Washington
Department of Transportation
Paula J. Hammond, Secretary

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Abstract

Engineered logjams (ELJs) have become popular as an alternative to riprap for bank stabilization due to their perceived ecological benefits, which could potentially limit mitigation requirements for project proponents. This, along with the fact that many riprap bank stabilization projects have failed, led the Washington State Department of Transportation (WSDOT) to use ELJs to stabilize chronically eroding banks of the Hoh River near milepost 174.4 of Highway 101 (ELJ site). WSDOT also proposes to use ELJs to stabilize Hoh River banks near milepost 175.9 (RR site), where riprap has chronically failed. Although ELJs are expected to provide ecological benefits, they have not been thoroughly evaluated. The Hoh River sites offer an opportunity to use a before-after-control-impact design to evaluate the ecological benefits of ELJs. The study objectives were to 1) collect baseline data that would allow future comparisons of habitat diversity, fish species diversity, fish abundance, growth, and survival in areas stabilized using riprap and ELJs, and 2) to evaluate fish habitat use and movement at the ELJ site. We collected pre-project data for fish habitat and fish abundance at both sites during the summer of 2009 and 2010, and fish abundance data during the winter of 2011. There were more channels (i.e., main, braid, side) and primary (i.e., pools, glides) habitats at the RR site than the ELJ site; however, these differences were likely related to larger scale geomorphic factors than the bank stabilization. In contrast, there were more secondary habitats, which are smaller distinct units within primary habitat, at the ELJ site, which contained much more eddy habitat. Species diversity at the RR and ELJ site was variable. Chinook salmon, coho salmon, steelhead, mountain whitefish, and sculpin were the most common species or genus collected at both sites. Differences in fish abundance, size or growth at the two sites were quite variable. Apparent survival of PIT-tagged coho salmon (*Oncorhynchus kisutch*) was greater at the ELJ site than the RR site; however, the results could not be compared statistically since only one ELJ and RR site were sampled. Acoustic tracking data showed that steelhead parr (*O. mykiss*) and juvenile Chinook salmon (*O. tshawytscha*) used a large portion of the study area, often within a 24-hr period. The acoustic tracking system provided quality tracking data for just over 50 percent of the time the fish were expected to be present in the array. Steelhead parr selected primary pools and secondary eddy habitats. They generally selected areas that were intermediate in depth (~0.6 to 3.5 m) and distances (~4-8 m) from the river bank. They generally did not use areas directly under the ELJs, which we hypothesize was related to the turbidity of the Hoh River. Turbidity likely provides cover thereby reducing the reliance on instream structures for protection from potential predators. The habitat and fish data collected will be useful for completing a before-after-control-impact assessment of the benefits of ELJs in the Hoh River. The movement data suggest that the reach scale may be the most appropriate spatial scale for monitoring ELJ projects, which is larger than the primary unit scale we used during this study. The habitat use results suggest that the ELJs will provide better habitat for juvenile steelhead, which preferred eddy habitats which were more abundant at the ELJ site than the RR site.

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Introduction

Large angular rock (riprap) is often used to stabilize eroding river banks, especially when infrastructure is threatened. However, several reports suggest that stabilizing banks using rock revetments negatively impacts habitat complexity and aquatic communities (e.g., Beamer and Henderson; 1998; Schmetterling et al. 2001; but see Dardeau et al. 1995). In addition, several reports suggest that wood is an important ecological component of streams and rivers (e.g., Coe et al. 2009; Pess et al. 2012). As a result, large wood complexes, such as engineered logjams (ELJs) have been used as alternative bank stabilization and for stream restoration in general (Abbe et al. 2002; McHenry et al. 2007). ELJs may be favored over riprap due to their perceived ecological benefits, which could potentially limit mitigation requirements for project proponents.

The Hoh River has continually eroded riprap stabilized banks to threaten Highway 101 (HWY 101) near milepost (MP) 174.4 and MP 175.9. In response to this chronic erosion at MP 174.4, the Washington State Department of Transportation (WSDOT) built 10 ELJs in the Hoh River in 2004 to protect the highway from further erosion. The success of this project has led WSDOT to propose building several more ELJs in the Hoh River at HWY 101, MP 175.9 (Hoh II) to protect the highway from chronic erosion at that location. Although ELJs are commonly used for habitat restoration, their benefits have not been fully evaluated. For this reason, WSDOT wants to evaluate the physical habitat and biological response of this reach of the Hoh River to the placement of ELJs, and to test the hypothesis that ELJs provide better fish habitat than the original riprap stabilized reach. This report describes results from pre-project data collected between August 2009 and March 2011 to evaluate the influence of the proposed ELJs at MP 175.9.

The goal of the proposed ELJ projects is to protect WSDOT infrastructure using a perceived ecologically beneficial method. Aquatic communities often occur in greater densities and diversity at locations associated with wood (Coe et al. 2009). This information suggests that removing a rock revetment and replacing it with ELJs should be beneficial to river ecosystems. However, this has rarely been examined and this project offers an opportunity to compare biological communities at rock revetments and stabilized wood sites in the same river. In addition, this project provides an opportunity to evaluate the relative change in the aquatic communities at a site before and after the rock revetment is replaced with ELJs. We hypothesized that removing the rock revetment and replacing it with ELJs would benefit the river ecosystems by increasing the abundance of juvenile salmonids rearing at this location.

The objective of this work was to 1) collect baseline data that would allow for future comparisons of habitat diversity, fish species diversity, fish abundance, growth, and survival in areas associated with riprap and ELJ stabilized banks, and 2) evaluate fish habitat use and movement at the ELJ site. This report summarizes results from two years of pre-project evaluation, which addressed these objectives using habitat surveys, fish catch-per-unit-effort (CPUE) estimates (2009), mark-recapture population estimates, survival estimates and habitat use as determined by acoustic tracking at the site scale (e.g., 1,000 m^2 to 5,000 m^2) (Figure 1)

Study Area

This project was completed at approximately river kilometer (rkm) 18.5 and 20.1 of the Hoh River (Figure 1). The Hoh River, located on the west side of the Olympic Mountains drains a watershed area of 894 km^2 (Brenkman et al. 2007). The Hoh River originates from the ice-fields of Mount Olympus and flows west for approximately 91 km from an elevation of 1,216 m to sea-level where it enters the Pacific Ocean. The gradient is initially steep (approximately 68 m/km for approximately the first 13 km) but becomes more moderate for the last 77 km (approximately 3.7 m/km) (Heusser 1974). The Hoh River watershed has a maritime climate with moderate temperatures and heavy rainfall, which delivers between 305 cm and 508 cm of rain annually (Hatten 1991). This precipitation falls predominately from November through March as rainfall below an elevation of 500 m; with snow common above 900 m (Hatten 1991). The mean annual discharge is 72 m^3/s (2,544 ft^3/s), with a record discharge of 1,758.5 m^3/s (62,100 ft^3/s) in October 2003 and mean annual low flow discharge of 31.9 m^3/s (1,125 ft^3/s) during late summer (USGS 2009).

The study reach lies in an area with a wide alluvial valley with a meandering river pattern. Channel gradient in the study area is approximately 0.23% (Herrera Environmental Consultants 2008). Bankfull width in the study reach is approximately 137 m with an additional 450 m active gravel bars bordering the river channel, although the floodplain at the riprap site is much narrower than at the ELJ site (Herrera Environmental Consultants 2008). Substrate consists of medium to large cobbles with interspersed gravels and sand.

The Hoh River has populations of coho salmon (*Oncorhynchus kisutch*), fall Chinook salmon (*O. tshawytscha*), spring/summer Chinook salmon, chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), winter and summer steelhead (*O. mykiss*), cutthroat trout (*O. clarkii*) and bull trout (*Salvelinus confluentus*). Coho salmon are the most abundant species in the basin; however, their populations have declined since 1992 (Smith 2000). The Chinook salmon stocks have shown slight declines. Steelhead populations have been classified as stable, but have been declining since the early 1980’s (Smith 2000). Bull trout, chum salmon, pink salmon and summer steelhead likely have the smallest salmonid populations in the system. Other fish species present in the Hoh River include mountain whitefish (*Prosopium williamsoni*), shorthead sculpin (*Cottus confusus*), torrent sculpin (*C. rhotheus*), reticulate sculpin (*C. perplexus*), prickly sculpin (*C. asper*), coastrange sculpin (*C. aleuticus*), riffle sculpin (*C. gulosus*), longnose dace (*Rhinichthys cataractae*), threespine stickleback (*Gasterosteus aculeatus*), Pacific lamprey (*Lamretra tridentada*), and western brook lamprey (*L. richardsoni*) (Mongillo and Hallock 1997).

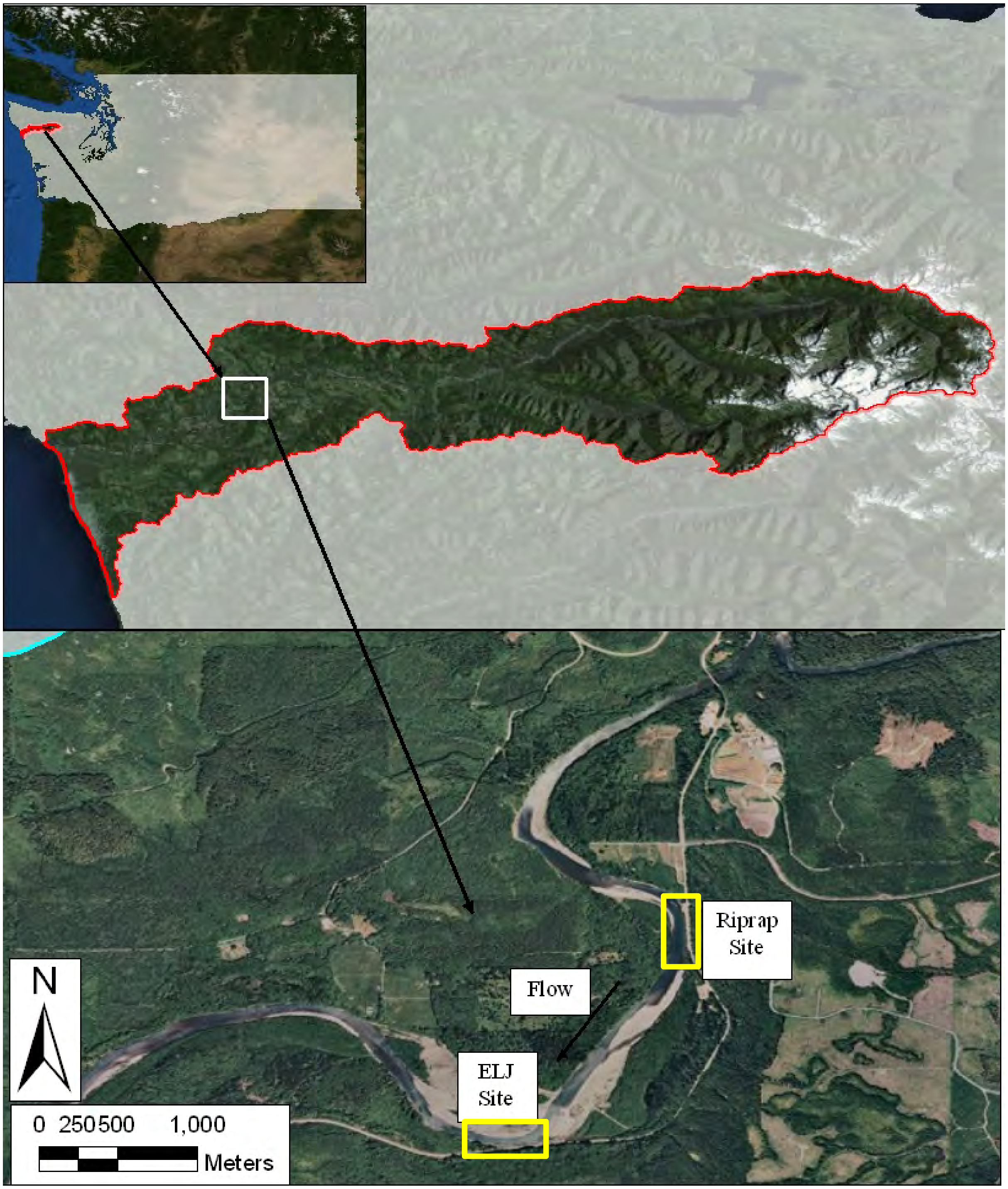

Figure 1. Engineered logjam (ELJ) and riprap study sites on the Hoh River.

Methods

Study Design

The influence of ELJs on habitat diversity and biologic communities will be assessed using a before-after-control-impact design (BACI) (e.g., Smith et al. 1993; Underwood 1996; Smith 2002) at the site scale, which is defined as the stabilized bank including the entire wetted channel (Figure 2). The existing ELJ site (Hoh I) is serving as the control, while the current riprap site which is proposed to be stabilized using ELJs (Hoh II) will serve as the treatment. Monitoring is proposed to occur at both sites before and after the riprap at the Hoh II site is replaced by ELJs. This report presents data collected prior to the riprap site being converted to ELJs (i.e., pre-project data).

Field Methods

Habitat Assessment

We used a hierarchical habitat classification system to classify channels, primary habitat units (i.e., pool, riffle), and secondary habitat units (sub units within primary habitat units) at each site. This system is based on modifications (Peters et al. *in prep*.) of the habitat classification system described by Hawkins et al. (1993). First we classified the channel type as defined in Table 1.

Second, we classified primary habitat units, which encompassed the entire wetted channel width (e.g., pools, riffles). Finally, we classified secondary units within the primary habitat units. Secondary units had to be 20% of the wetted channel width wide and/or long to be considered a secondary habitat unit. Primary habitat units are classified by comparing their physical features to previously defined terms that are increasingly more detailed (Table 2). In the first step, the depth of habitat unit is simply classified as shallow (riffle), average (run, glide), or deep (pool). Step 2 further divides these classes as turbulent or non-turbulent for shallow and average depth habitats, and scour pool or dammed pool for deep water habitats. Step 3, further differentiates the shallow, deep, turbulent, non-turbulent grouping. Shallow, turbulent areas are classified as falls, cascades, riffle, or chute, while scour pools are classified as eddy, lateral, mid-channel, trench, convergence, or plunge. Step 3 classifications are used to describe secondary habitat units. It is possible to have shallow-water secondary habitats within deep-water primary habitats. For example, glides are generally associated with average or shallow water primary habitats units; however, a secondary glide habitat can be present in a deep-water primary habitat unit (see Figure 3).

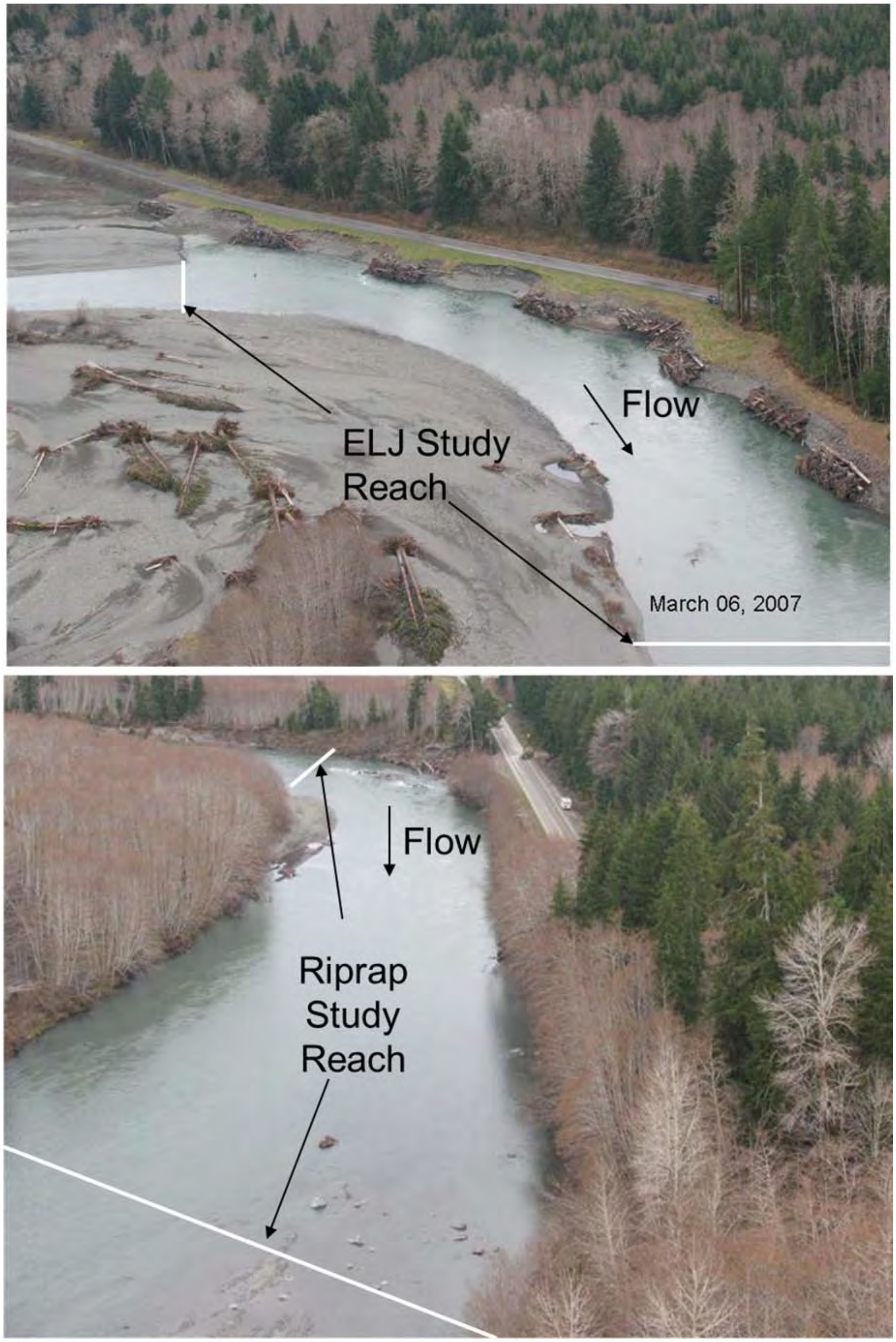

Figure 2. ELJ and RR study reaches in the Hoh River. The study reaches included the entire wetted width of the river.

Table 1. Channel type classifications used in the hierarchical habitat classification system.

Channel Type	Description
Main channel	Primary channel containing a majority of the stream discharge.
Braided main channel	Two or more channels in the active channel separated by a gravel bar lacking vegetation or having only sparse and young (< 2 yrs.) vegetation, such as immature trees and/or brush.
Side channel	Channel separated from the main channel by well-vegetated riparian woodlands.
Overflow channel	Small channels that inter-connect a side channel to the main channel.
Tributary mouth	Mouth of a tributary stream entering the main channel.
Backwater	An abandoned channel formed when sediment and organic debris blocks the head of a braid or branch of a main channel (very slow water velocity).

Table 2. Steps and definitions used describe primary and secondary habitats (modified from Hawkins et al. 1993)

Step 1	Step 2	Step 3	Description
Shallow Water			Riffles; rapid, shallow stream sections with steep water surface gradient (McMahon et al. 1996).
	Turbulent		Channel units having swift current, high channel roughness (large substrate), steep gradient, and non-laminar flow and characterized by surface turbulence.
		Riffle	Shallow, lower-gradient channel units with moderate current velocity and some partially exposed substrate (usually cobble).
	Non-Turbulent		Channel units having low channel roughness, moderate gradient, laminar flow, and lack of surface turbulence.
		Sheet	Shallow water flowing over smooth bedrock
		Glide	Shallow water flowing over a variety of substrates
Average Water Depth			
	Turbulent		
		Rapid	Deeper stream section with considerable surface agitation and swift current; large boulders and standing waves often present.
		Run	Fast flowing water that is relatively deep and mildly turbulent. Usually found at the head of pools or in areas that result in limited scour.
	Non-turbulent		
		Glide	Shallow water flowing over a variety of different substrates
Deep Water			
	Scour Pool		Formed by scouring action of current
		Eddy	Formed by circular current pattern created by bank obstruction, usually occur along the bank
		Trench	Formed by scouring of bedrock. Usually located in the main channel
		Mid-Channel	Form in the main channel by channel constriction at the head of the pool
		Convergence	Form in the main channel by converging streams
		Lateral	Formed in the main channel where flow is deflected by a partial channel obstruction (stream bank, rootwad, log, or boulder); for example at the outside bends in the channel of meandering streams, deeper on one side than the other and form as a result of a deflector at the head of the pool

Table 2.-Continued

Step 1	Step 2	Step 3	Description
		Plunge	Form in the main channel, deeper upstream, and are formed by water dropping vertically over a channel obstruction
		Deposition	Depositional area within a scour pool. Usually along the point bar of a lateral scour pool.
	Dammed Pool		Water impounded by channel blockage
		Debris	Formed by rootwad and logs
		Beaver	Formed by beaver dam
		Landslide	Formed by large boulders
		Backwater	Formed by obstructions along banks
		Abandoned Channel	Formed alongside main channel, usually associated with gravel bars

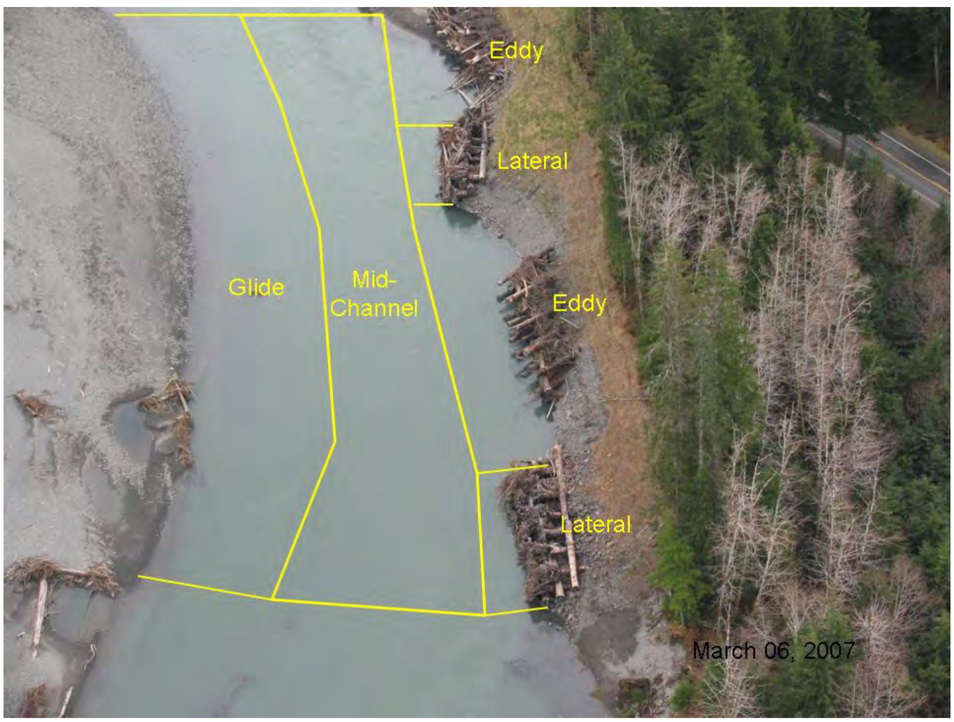

Figure 3. Example of secondary habitat units at the ELJ (Hoh I) site. The primary habitat type would be classified as a main channel. The three step classification of the primary unit would result in classifications of deep water, scour pool, and lateral scour pool, respectively. Secondary habitat unit classifications are shown on the figure.

Habitat surveys were conducted prior to biological community sampling to identify the distribution of habitat types within each reach. For each secondary habitat unit, we measured length and width, mean water column velocity, depth, bank slope, in-stream cover, riparian cover, and overhanging vegetative cover. Substrate data was not collected due to water turbidity which limited our ability to see the river bottom.

Unit lengths and widths were measured using laser range finders (TruPulse 200B) (nearest 0.1 m). This information was used to calculate surface area for each secondary unit. Surface areas for primary units and the reach were calculated by summing the values for secondary units lying within their boundaries. Mean water column velocity was measured at a location that appeared to represent the average velocity in the secondary unit using a Marsh McBirney Flow-Mate Model 2000 flow meter. Depth (0.1m) was measured using a stadia rod. The maximum depth was measured after searching the unit for the deepest location. Average depth was calculated based on the maximum depth and twelve other depth measurements made in a grid throughout the unit. Depth was measured at 20%, 40%, 60%, and 80% of the distance across the unit at transects spaced at 25%, 50%, and 75% longitudinally along the unit. The distance from these depth measurements to the shore were also measured using a stadia rod. Bank angle was calculated using the distance to shore and depth data collected at the 80% transect distance. In-stream cover was classified according to Table 3. The length and width of each cover element was measured using either a stadia rod or laser range finder.

Riparian and overhanging vegetative cover was estimated visually. Riparian cover was estimated as the percent of the total habitat unit with riparian vegetation overhanging the banks of each unit. Overhanging vegetative cover was estimated as the percent of the habitat length covered by overhanging vegetation that was within 0.3 m of the water’s surface.

Table 3. Cover types classified and measured to assess fish cover.

Cover Type	Description
Rock	Alluvial or placed rock that is cobble size or larger
Boulder (BL)	Rock ≥256 mm
Cobble (CB)	Rounded rocks 64-256 mm
Riprap (RR)	Angular boulder-sized rock placed for bank protection
Rubble (RU)	Angular cobble-sized rock placed for bank protection
Deep water (DW)	Water depths >1m (other cover takes precedence)
Vegetation (VG)	Live, terrestrial or aquatic vegetation
Undercut banks (UB)	Submerged area underneath an overhanging bank
OHV	Overhanging Veg. within 30 cm of water surface.
Wood	Woody debris of various types
Anchored brush (AB)	Branches of non-tree woody plants hanging in the water
Branch (BH)	Woody debris < 20 cm in diameter, not accumulated in debris piles
Bank roots (BR)	Roots of live trees and shrubs in the water
Debris piles (DP) Sm/Lg	Numerous or single types of wood cover accumulated in a pile or jam
Single log (SL)	Woody debris > 20 cm diameter, not accumulated in debris piles
Rootwad (RW)	Roots and lower trunk of non-growing trees
Rootwad/SL (RWSL)	Roots and lower truck of non-growing trees and tree trunk, branches, etc.
Hydraulic	Slow water areas of various type
Eddy (ED)	Back eddies
Shelf (SH)	Shelf habitat
Deposition (DE)	Depositional area that still has some current velocity
Deadwater (DD)	Depositional area with no current.
No Cover (NC)	Substrate is < cobble size, depth is < 1.0 m, and none of the above present.

Fish Abundance

Fish abundance was estimated using catch-per-unit-effort (CPUE) for every survey (2009, 2010, and 2011) and mark-recapture methods for the summer 2010 and winter 2011 surveys. CPUE was assessed at the ELJ and RR using beach seining during late summer (September) 2009 and 2010, and winter (March) 2011. Multiple sites were seined at both study sites during each survey. Seining was completed at night to prevent our sampling efforts from interfering with sport fishing that was occurring in the river during these periods and to take advantage of movements of fish to slower current areas at night (R.J. Peters, unpublished data). Seining was limited to areas where the seine could be fished without hanging up on debris or large boulders. These conditions were most common on point bars across from the stabilized banks and between the ELJs at the ELJ site. Thus, this sampling assumes that fish would move across the river channel within our sampling period (i.e., population would mix). During 2009, multiple passes were completed at each seining location to ensure that the location had been sampled adequately. However, during 2010 and 2011, only one set was made at each location, since mark-recapture estimates were also being used to assess abundance (see below). CPUE was only calculated for the mark survey during the mark-recapture estimates. Sets where hang-ups occurred or that were poorly executed were not included in the CPUE estimates. All fish were identified, weighed (nearest 0.1 g), measured for fork length (nearest mm) and scanned for PIT tags (see survival and habitat use section below). CPUE for each site (i.e., ELJ and RR) was calculated by dividing the total catch from all sets by the total number of sets for the site and were calculated for each species separately and all species combined.

All fish were identified to species when possible. Steelhead and resident rainbow could not be distinguished and are referred here jointly as steelhead. In addition, steelhead and cutthroat fry could not be identified to species and are referred to collectively as trout fry. Riffle and reticulate sculpin are both known to occur in the Hoh River but are difficult to separate. For this reason, we refer to them collectively as riffle sculpin. Although lamprey adults can be readily classified to species, it is difficult to distinguish lamprey ammocoetes to species, so we simply classified them collectively as lamprey.

Fish abundance was estimated using mark-recapture methods during the summer of 2010 and winter of 2011, since it was apparent from the first year of sampling (2009) that sampling efficiency varied substantially among the two sites (easier at the RR site). This method also relies on the assumption that fish would move across the river (i.e., mix). Fish were captured using seining as described above. All fish were marked using Bismark Brown. The fish were then released back to the habitat from which they had been removed. During September 2010, fish were marked one night and recaptured on the next night. We completed the mark and recapture surveys at the ELJ site first, since it was downstream of the RR site; reducing the likelihood that fish would move (upstream) from this site to the RR site during our mark-recapture assessment. During March 2011, fish at both sites were marked the same night and recaptured on the next night, due to forecasted freshets the following day (which occurred).

Population estimates and 95% confidence intervals were calculated for each site following the Chapman modification of the Petersen mark-recapture estimate (Ricker 1975) using:

$$\text{Equation 1,}\quad N = ((m+1)*(c+1))/(r+1)$$

where, *N* is the estimated population size, *m* is the number of fish marked during the marking survey, *c* is the catch during the recapture survey, and *r* is the number of marked fish caught during the recapture survey. Confidence intervals (95%) were calculated as:

$$\text{Equation 2,}\ \ CI = N \pm 1.96 * SE$$

Where *SE* equals the standard error of the variance (*V(N)*) which was calculated as:

$$\text{Equation 3,}\ \ SE = V(N)^{1/2} = (((N^2(c-r))/((c+1)*(r+2)))^{1/2}$$

Survival and Habitat Use

We used two different tagging techniques to assess survival and habitat use. PIT tags were used to assess survival, while acoustic tags were used to assess habitat use. PIT tags were more appropriate to assess survival since the tags aren't limited by battery life and are cheaper than acoustic tags, which allow many more fish to be tagged. Acoustic tags are more appropriate for determining habitat use, since specific locations used by fish can be determined without impacting fish behavior or preferred habitat use with snorkelers and/or boaters, which would be required if PIT tags were used to assess habitat use.

We used PIT tagging methods to assess survival at both the ELJ and RR sites. We collected fish at both sites during early- to mid-August (ELJ: August 11, 12, 17-18, 2009; August 3-4, 2010; RR: August 18, 2009, August 11-12, 2010) 2009 and 2010 using beach seining, as described above. All fish were identified to species, weighed and measured for fork length. Fish greater than 60 mm in fork length were tagged by placing a PIT tag into their body cavity using a modified 12-gauge hypodermic needle (Prentice et al. 1990). All fish were released back into the habitat from which they were removed.

We attempted to relocate PIT tagged fish during the CPUE beach seine sampling and by using mobile PIT tag surveys. Mobile PIT surveys were completed by snorkeling and wading using mobile (hand held) PIT transceivers developed using Alflex PIT readers (OEM PNL PIT Interrogation unit (840029-001)) fitted with octagon antennas with approximately 23-cm sides. Snorkelers surveyed deep (>1 m) areas, while shallow (< 1 m) areas along the point bars were surveyed while wading. Surveys were completed while moving upstream and two passes were made in each reach, one during the day and one at night. We surveyed as much of the channel as possible during each survey. Larger antennas, measuring approximately 1 m high by 2.4 m long were used conjunction with the Alflex PIT readers in 2010 to sample for PIT tagged fish. The antennas were moved through the reach by wading the shallow areas and were towed using a raft through the deep water units.

We used a fine-scale acoustic tracking system developed by Hydroacoustic Technology, Inc. (HTI), Seattle, Washington to examine movement patterns and habitat use by fish. This system uses acoustic tag transmitters implanted within the study fish, and a fixed array of omnidirectional hydrophones (Model 590-330) to track fish movements in a specific study area. Tag transmitters are programmed to periodically emit a signal or ping of a specific length of time, called the ping rate. Each fish was given a unique ping rate so that movements of individual fish could be tracked. When a tagged fish moves through or near a hydrophone array, each ping is detected by the hydrophones at slightly different times depending on how far the fish is from each hydrophone. The system then uses these time differentials to triangulate a position for the origin of each ping. Calculated positions are estimated to be within 0.5 m of the true location in the horizontal plane for fish within the perimeter of the hydrophone array. Accuracy declines outside the array perimeter, but has been estimated to be within 3 m of the true location in the horizontal plane at a distance of one array width from the array perimeter.

Our tracking system consisted of two parts: 1) hydrophone array – used for fine-scale fish tracking, and 2) supplemental hydrophones – used for coarse-scale fish movements outside the main tracking area. All the hydrophones of the fine-scale tracking array were cabled to a HTI Model 290 receiver. The receiver was connected to a personal computer that continuously logged the acoustic data. Sixteen hydrophones were deployed which enabled us to track fish over a 197-m long stretch of the river from bank to bank (width, 34 to 57 m) (Figure 4). Hydrophone arrangement allowed for optimal two-dimensional tracking and tagged fish to be continuously tracked inside the array coverage area. We mounted a temperature logger (StowAway Tidbit) on two hydrophones (one in shallow water and one in deep water) to collect temperature data which was used in tracking calculations (Appendix A). Most hydrophones were mounted to a weighted pipe (steel pipe filled with cement) and placed on the riverbed. A few hydrophones were bolted to large wood. Lead line or weighted bags (filled with rocks) were attached to the cables to keep them on the bottom. Prior to fish tagging, snorkelers swam through the array with acoustic tags to make sure all the equipment was functioning properly.

The supplemental part of the tracking system consisted of two hydrophones; one placed 350 m upstream of the tracking array and the other placed 400 m downstream of the tracking array (Figure 4). Information collected at these hydrophones provided presence/absence data for tagged fish moving upstream or downstream outside of the fine-scale tracking array. These hydrophones were placed far enough away from the coverage area of the fine-scale tracking system to ensure all detections were outside of the coverage area of the fine-scale array. Both hydrophones were cabled to a HTI Model 291 receiver, which was connected to a personal computer that continuously logged the data.

Acoustic tagging of fish occurred only at the ELJ site during 2009 in conjunction with the PIT tagging (August 11th, 12th, 17th). No acoustic tracking was completed at the riprap site. Fish were surgically implanted with HTI Model 795m acoustic tags. These tags weighed 0.75 g in air, and measured 6.8 mm in diameter and 16.5 mm in length. Each tag was programmed with a unique ping rate, which allowed us to track movements of specific fish. Ping rates ranged from 4.8 to 5.6 s. Tag life varies with water temperature, pulse width and ping rate. For this study, the 795m tags were expected to last 10-14 d. In general, we maintained a tag weight to fish weight ratio of $\leq$ 7% (mean 2.08%). Studies on the effects of tagging on fish behavior suggest that this is an appropriate ratio (Adams et al. 1998; Brown et al. 1999; Anglea et al. 2004).

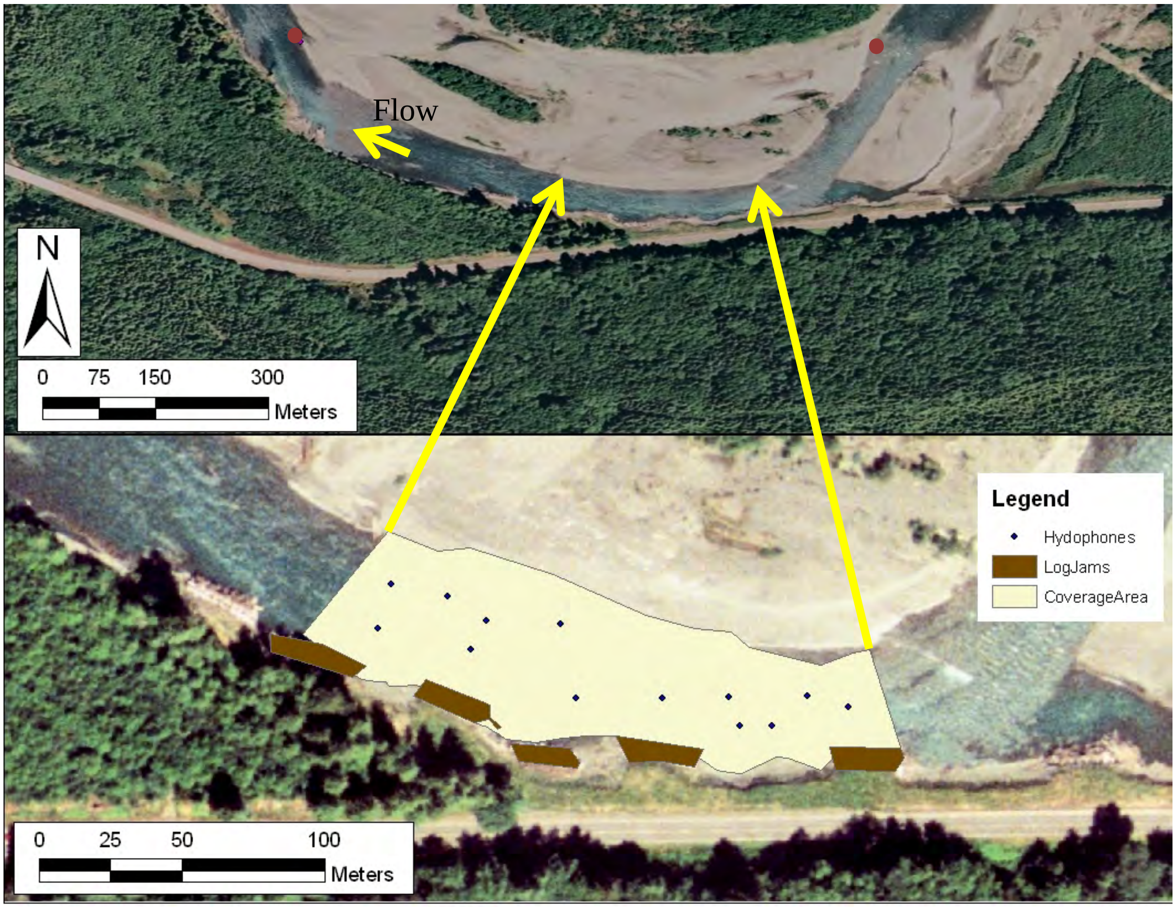

Figure 4. Location of hydrophones in the acoustic tracking array (bottom panel) and data loggers upstream and downstream of the array (top panel).

All surgical instruments and tags used during surgical implanting of acoustic tags were sterilized in a solution of distilled water and 2-5% Nolvasan ® disinfectant. Instruments and tags were allowed to soak for at least 5 minutes and were then rinsed in a 5-10% saline bath. Each fish was anesthetized in a solution of tricaine methane sulphonate (MS-222) buffered with sodium bicarbonate. Most fish were adequately anesthetized within 3 min. The anesthetized fish was removed from the MS-222 solution and washed with cool fresh water. It was then placed on a customized surgical platform consisting of a piece of foam with a depression scored in the center. This was soaked in cold water prior to tagging. The foam surgical platform held the fish in a suitable and stable position, and helped keep it cool during the surgery. Fish were placed in the platform's depression with the ventral side exposed. During the surgery, a pipette was used to irrigate the gills with MS-222 solution at 30 s intervals. An incision approximately 8-12 mm long was made between the pectoral and pelvic fins. The tag was then inserted into the peritoneal cavity through the incision. Two or three sutures of 6-0 coated Vicryl® braided suture material were used to close the incision. Fish were then placed in a recovery tank of cool fresh water. The entire operation was usually completed in 2-6 min. Fish were allowed to recover before being released at their approximate capture location (same habitat unit).

Data Analysis

Habitat

Habitat data was summarized at the secondary habitat, primary habitat, and reach (channel) scale. For the secondary habitat scale analysis, each similar secondary habitat type was combined using their unit areas to provide a weighted average condition for each of the habitat parameters measured: average current velocity, average depth (m), average bank slope, average percent of the unit with either rock, vegetative, or hydraulic cover, and average percent riparian cover, vegetative overhang, and LWD cover. Bank slope for each individual unit was calculated by averaging the rise over run data from the three (25%, 50%, and 75% of the unit length) points 80% of the way across the unit. The ELJ site had two max depths, and the RR site had one, that were estimated based on approximate measurement because conditions prohibited direct measurement.

Summaries of the primary habitat unit data were performed in a similar manner to the secondary habitat unit scale. The secondary habitat units within each primary habitat unit were again weighted based on their unit area. Reach scale summaries were also calculated with the same weighted approach, and then compared based on the same parameters.

Fish Size and Growth

The lengths and weights of fish captured at the ELJ and RR sites (during both the population estimate and PIT-tagging surveys) were compared using a Mann-Whitney U test separately for each species. Growth rates, calculated as mm/day and g/day were also compared using the Mann-Whitney U test. We used the Mann-Whitney U test since the data were not normally distributed.

Habitat Use – Acoustic tracking

Raw acoustic data files were manually processed through HTI MarkTags software to identify fish signals and isolate them from background noise. We searched for each fish that could possibly be present (based on release date and tag battery life) in each raw data file and any observed tag signals were highlighted. Isolated tag signals were then processed through HTI AcousticTag software, which performs the triangulation calculations and provides a database of point locations for each fish. For the remainder of this report, we refer to these calculated point locations simply as “data points.” The “track” for an individual fish is the temporally sequenced collection of all its data points.

Fish location point data output from the AcousticTag software was imported into ArcMap 9.2 Geographic Information System (GIS) software. Fish tracks were graphically represented and analyzed by overlaying them on a map of the site with bathymetry contours. Each fish track was evaluated for signs of mortality which included one or more of the following: 1) no sign of fish movement in the fish track; 2) no sign of fish movement in the raw hydrophone data; and, 3) extraordinarily unusual characteristics in the fish track. If a fish showed signs of mortality, it was removed from the data set, and no part of the fish track was used for analysis. Data points for the first 24 h after release were not used to allow time for the fish to recover and start to behave naturally. Tracking data were separated into dawn, day, dusk, and night time periods to examine diel behavior. These time periods were defined as:

Dawn - the period one hour before and after sunrise.

Day - the period from one hour after sunrise until one hour before sunset.

Dusk - the period from one hour before sunset until one hour after sunset.

Night - the period from one hour after sunset until one hour before sunrise.

This tracking system requires that each hydrophone has line-of-sight to a tag to detect its signal. Thus, gaps in the fish tracks occur when the fish are no longer in line of sight of at least four hydrophones. These gaps can occur when fish leave the coverage area or move to areas where they could not be detected, including areas within the ELJs, areas in close proximity to the substrate, and potentially in the deep pool at the upstream part of the jam. If unaccounted for, these gaps could potentially result in significant bias in the results. For example, if a fish was detected 50% of the time and was located outside the jam during these detections, the home range and habitat use analysis would suggest that the ELJs were not important. However, if under further examination it is shown that the fish always disappears into the ELJ and then reappears out of the ELJ and this represent the other 50% of the tracking data, the results would be seriously biased.

We examined the data for all data gaps and determined if the fish had left the coverage area or if it had disappeared and reappeared within the array. We defined accurate fish tracks as those which occurred within 15 s of each other since the ping-rate of our tags was approximately 5 s. Thus, this definition would allow us to miss only two consecutive pings. We assumed the fish would likely not move large distance within 15 s. Gaps were defined as those periods when no fish track was recorded for greater than 15 s. The plot of gaps for every fish were examined to determine if there were any consistent patterns in where the gaps occurred (i.e., within the ELJs) and or if they were generally small (i.e., less than 2 min).

Fixed-kernel home range polygons for each fish were calculated using the Fixed-Kernel Density Estimator in the Hawth’s Tools extension for ArcMap 9.2 (Beyer 2004) for each of the four diel time periods described above. The Percent Volume Contour was used to create the 95% lines, which were then converted to polygons. The contour area was calculated using the spatial statistics tools in ArcMap 9.2. Home range polygons were projected on maps of the study area to visually assess the extent of habitat use. The size of wild and hatchery steelhead home ranges during the four different diel periods were compared using a two-way ANOVA.

We evaluated population-level habitat and depth selection for each fish species with sufficient sample size. For habitat selection, each site was segregated into discrete habitat units. Depth selection was based on the depth of the entire water column, not the position of the fish in the water column. For depth selection, the tracking area was segregated into water column depths at 0.2 m intervals (i.e., 0-0.2 m, 0.2-0.4 m, etc.). The total horizontal area of each habitat and depth category contained within the tracking area was considered that category’s availability. For each fish, the proportion of time estimated within each habitat or depth category was determined by multiplying the number of points by 5 seconds, the approximate period between pings. The estimated time that fish spent in the different habitat and depth categories was determined using standard tools in ArcMap 9.2. To determine habitat availability, survey data were put into ArcMap 9.2 GIS software to develop maps of the survey area and divide the coverage area into various habitat and depth categories. In GIS, a spline tool was used to convert points to polygons.

Manly's selection ratio (Manly et al. 2002) was used to determine selectivity of a particular habitat or depth category. The selection ratio for the j^{th} fish and the i^{th} habitat or depth category was calculated as:

$$\text{Equation 4,} \quad \hat{w}_{ij} = (u_{ij} / u_{+j}) / \pi_i$$

where u_{ij} is the amount of time spent in habitat type or depth category i by fish j, u_{+j} is the amount of time fish j was tracked across all habitat types or depth categories, and π_i is the proportion of available habitat or depth in category i relative to all available habitats or depths at the study site. The mean population-level selection ratio for each habitat or depth category was calculated as:

$$\text{Equation 5,} \quad \hat{w}_i^{'} = \sum_{j=1}^{n} \hat{w}_{ij} / n$$

where n is the number of fish tracked across all habitat types or depth categories.

To determine if there was significant selection for a particular habitat type or depth category, simultaneous Bonferroni 90% confidence intervals were calculated as:

$$\text{Equation 6,} \quad \hat{w}_i^{'} \pm z_{\alpha(2I)} SE(\hat{w}_i^{'})$$

where I is the number of habitat types or depth categories, and

$$\text{Equation 7,} \quad SE(\hat{w}_i^{'}) = \sqrt{\frac{1}{n(n-1)} \sum_{j=1}^{n} \left(\hat{w}_{ij} - \hat{w}_i^{'}\right)^2}$$

Selection for a habitat or depth occurs if the lower confidence interval is greater than 1. Selection against a habitat or depth occurs if the upper confidence interval is less than 1. Confidence intervals that include 1 indicate proportional distribution across that habitat type or depth category. That is, the habitat type or depth category is neither selected for nor selected against, but rather is used in proportion to its availability.

The methods used to evaluate habitat and depth selection avoid the problem of pseudoreplication by taking each animal as the experimental unit (e.g., Garton et al. 2001; Manly et al. 2002; Rogers and White 2007). Also, by evaluating each animal's proportional habitat and depth use, serial correlation between an individual's data points does not present a problem (Aebischer et al. 1993; Rogers and White 2007). The high frequency of location sampling achieved with the HTI system provides a concomitantly high level of detail with regard to habitat use. Such detail, according to Aebischer et al. (1993), provides more precise estimates of habitat use, and the associated high degree of serial correlation is rendered a non-issue as long as proportional habitat use of individuals is the basis for analysis.

Results

Habitat

The length and surface areas of the study reaches varied between 2009 and 2010. The reach length was shorter (~40%) at both the ELJ and RR site in 2009 compared to 2010. This was due to the fact that the reach length was set by the area we could cover with the acoustic tracking array in 2009 and our desire to match our habitat and fish abundance study reach to this array in 2009. We kept the RR reach a similar length to the ELJ reach in 2009 for comparison purposes. Since the array was not set up in 2010, we extended both the ELJ and RR reach to encompass the entire treated bank (Figure 1).

Habitat conditions varied at the two study reaches and between years at all three spatial scales investigated (Table 4 and Table 5). The ELJ site consisted of a single channel during both 2009 and 2010, while the RR site consisted of two different channels during 2009 and four channels during 2010. In addition to the main channel, the RR site had one braided channel in 2009 and three braided channels in 2010. These braided channels made up 8.6% and 20.7% of the channel habitat during the two years, respectively (Table 4).

The proportion of primary habitats also varied among sites and years (Table 4). The ELJ site had a greater proportion of glide habitat during both years. Glide habitats made up more than 76% of the ELJ reach in 2009, but only 56% in 2010. In contrast, glide habitats made up only 43% and 0% of the RR reach during 2009 and 2010, respectively. A majority of the habitat at the RR site in 2010 was composed of lateral scour pools (~82%).

The proportion of secondary habitat also varied among sites and years (Table 4). Eddy habitats were absent from the RR reach, but made up approximately 15% and 9% of the habitat in the ELJ reach during 2009 and 2010, respectively. Glide secondary habitats were much more abundant in the ELJ reach during 2009, but not in 2010, when they were nearly equal. There was also more run secondary habitat at the RR site in 2009, but not in 2010.

Slight difference existed in the number and diversity of primary and secondary habitats at the ELJ and RR sites and among years (Table 5). The RR site had more primary units than the ELJ site and generally had a greater diversity of primary habitat types. In addition, the overall number of primary habitat units was greater in 2010 than 2009. In contrast, secondary habitat unit diversity was approximately 30% to 44% greater at the ELJ site than the RR site in both years. The number of secondary units increased at the ELJ site from 2009 to 2010, but decreased at the RR site (Table 5).

The reach scale physical parameters also varied among the sites and in some cases by season (Table 5). Average water velocity was between 36% greater at the RR site in 2009, but was 26% less in 2010 (Table 5). Average depth was slightly greater during both years at the ELJ site, while banks were steeper at the RR site in 2009 but not 2010. Average riparian cover was relatively low at both sites, but was greater at the RR site than the ELJ site during both years. Average overhanging vegetation cover was extremely low at both sites, but was greater at the RR site during 2009, but not 2010. The cover types available at each site varied considerably (Figure 5). There was more wood cover at the ELJ site and more rock cover at the RR site during both years. Hydraulic cover was more abundant at the ELJ site than the RR site in 2009, but not 2010.

Fish Abundance and Diversity

The number of fish species/groups present varied slightly among sites and by survey (Table 6). Species diversity was slightly greater at the RR site during the 2009 CPUE survey and the 2010 PIT tagging survey, but was slightly greater at the ELJ site than the RR site during the 2010 and winter 2011 mark-recapture surveys. Chinook salmon, coho salmon, steelhead, mountain whitefish, and sculpin were the most common species or genus collected at both sites during each survey. Lamprey ammocoetes, riffle sculpin, and torrent sculpin were the next most common fish collected, (six of eight site/survey combinations). Cutthroat trout, unidentified trout fry, and longnose dace were the next most common types of fish observed. Prickly sculpin were observed at both sites during only one survey.

CPUE varied by site, survey (year and season), and species; however, these data could not be compared statistically since only single replicates exist for the ELJ and RR sites (Table 7). CPUE was generally greater at the RR site than the ELJ site and was greater for Chinook salmon, mountain whitefish, sculpin, and longnose dace during all three surveys. Cutthroat trout and lamprey ammoecetes were the only species with consistently greater CPUE at the ELJ site. Coho salmon CPUE was greater at the ELJ site in two of the three surveys. CPUE was generally greater during the September surveys than the March survey. In addition, CPUE was generally much greater during the September 2010 survey than the September 2009 survey. The single exception to this was the similar CPUE observed for steelhead at the RR site during the two surveys. Salmonid CPUE was also much greater than that for non-salmonids during each survey.

Population estimates for all fish species combined, Chinook salmon, coho salmon, and sculpin at the ELJ and RR sites varied by species, season, and year (Table 8). Population estimates for all fish species combined were greater at the RR site than the ELJ site during both mark-recapture surveys (Table 8). However, the difference was likely significant only for the summer 2010 survey, for which the 95% confidence intervals for the population estimates did not overlap. The mean population estimate for Chinook salmon during the summer of 2010 was slightly greater at the ELJ site; however, the 95% confidence intervals overlapped. The population estimate for coho salmon was greater at the ELJ site than the RR site during September 2010 and the 95% confidence intervals did not overlap, suggesting that the difference is significant. We estimated that 279 juvenile coho salmon were residing at the RR site, about half of what was estimated to be at the site during September. Based on the 95% confidence intervals, the sculpin population sizes did not differ between the ELJ and RR sites.

Table 4. Percent channel types, primary habitat unit types, and secondary habitat unit types at the ELJ and riprap (RR) sites during the summer of 2009 and 2010. MC = main channel, BC = braided channel, GL = glide, LT = lateral scour, RI = riffle, RN = run, RP = rapid, BW = backwater, DE = deposition, ED = eddy, PP = plunge pool.

		% Channel Type		% Primary Habitat					% Secondary Habitat								
Site	Year	MC	BC	GL	LT	RI	RN	RP	BW	DE	ED	GL	LT	PP	RI	RN	RP
ELJ	2009	100.0	0.0	76.6	23.4	0.0	0.0	0.0	0.0	0.0	15.1	62.8	21.1	0.0	1.1	0.0	0.0
RR	2009	91.4	8.6	43.1	8.6	0.0	48.4	0.0	11.7	2.7	0.0	12.2	2.4	2.6	22.1	46.3	0.0
ELJ	2010	100.0	0.0	56.8	20.6	0.0	22.6	0.0	1.3	5.0	8.9	48.8	24.1	0.0	0.0	11.9	0.0
RR	2010	79.3	20.7	0.0	81.9	11.6	5.8	0.7	0.0	18.1	0.0	48.9	14.8	0.0	7.1	10.3	0.7

Table 5. Summary of weighted reach level habitat conditions at the ELJ and riprap (RR) sites during the summer of 2009 and 2010. Ave. Vel. = average current velocity; Ave. Slope = average bank slope; Ave. Rip. = average riparian cover; Ave. OHV = average overhanging vegetation.

		# of Habitat Units (Types)								
Site	Year	Channels	Primary	Secondary	Total Area	Ave. Vel. (cm/s)	Ave. Max. Depth (m)	Ave. Slope	Ave. Rip. (%)	Ave. OHV (%)
ELJ	2009	1 (1)	2 (2)	13 (4)	7,643	49.9	1.44	11.7	0.63	0.51
RR	2009	2 (2)	3 (3)	10 (7)	7,967	67.9	1.15	14.1	10.59	3.05
ELJ	2010	1 (1)	3 (3)	16 (6)	15,592	75.2	1.79	13.1	0.21	0.21
RR	2010	4 (2)	5 (4)	9 (6)	19,619	55.5	1.71	11.4	6.95	0.25

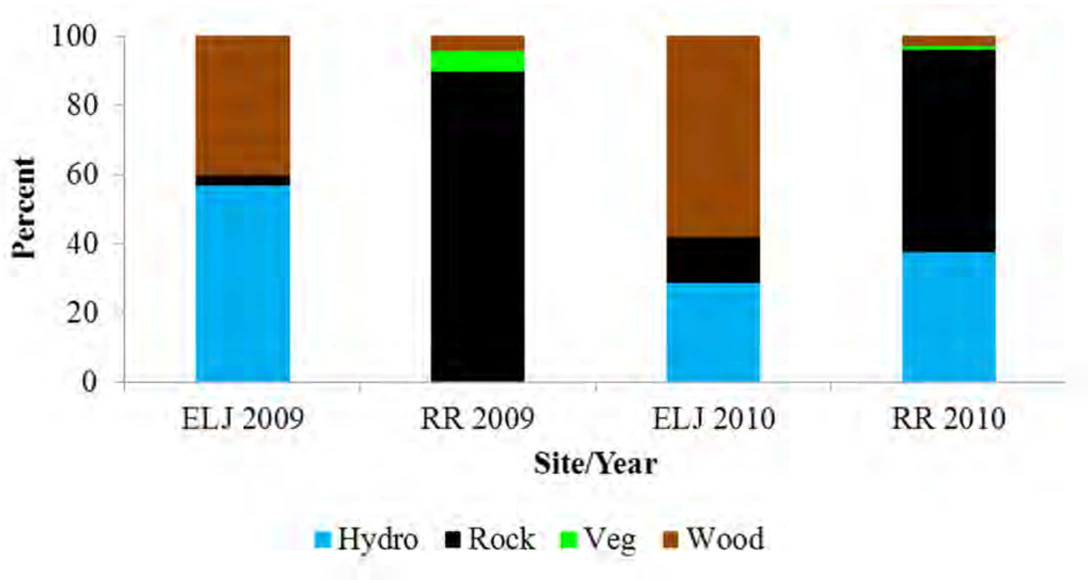

Figure 5. Percent of hydraulic (Hydro), rock, vegetative (Veg), and wood cover at the ELJ and riprap site in 2009 and 2010 in the Hoh River.

Table 6. Number of different fish species observed at the ELJ and RR site during PIT tag, catch-per-unit-effort (CPUE), and mark-recapture (M-R) surveys in the Hoh River during the summer of 2009, 2010, and winter 2011. PIT tagging surveys from 2009 were not included, because only fish actually tagged were recorded. P = present, N = not present.

	CPUE 9/09		PIT 8/10		M-R 9/10		M-R 3/11		# Surveys Observed
Species	ELJ	RR	ELJ	RR	ELJ	RR	ELJ	RR	
Salmonids									
Chinook salmon	P	P	P	P	P	P	P	P	8 of 8
Coho salmon	P	P	P	P	P	P	P	P	8 of 8
Cutthroat trout	N	N	P	P	P	P	P	N	5 of 8
Steelhead	P	P	P	P	P	P	P	P	8 of 8
Trout fry	N	N	P	P	P	P	N	P	5 of 8
Mountain whitefish	P	P	P	P	P	P	P	P	8 of 8
Other Fish									
Longnose dace	N	P	N	P	P	P	P	N	5 of 8
Lamprey	N	P	P	P	P	N	P	P	6 of 8
Prickly sculpin	N	N	N	N	P	P	N	N	2 of 8
Riffle sculpin	N	N	P	P	P	P	P	P	6 of 8
Torrent sculpin	N	N	P	P	P	P	P	P	6 of 8
Unid. sculpin	P	P	P	P	P	P	P	P	8 of 8
Number of Species	5	7	8	9	11	9	9	7	

Table 7. Catch-per-unit-effort (CPUE) (fish/set) by species for fish sampled at the ELJ and RR sites on the Hoh River, September 2009 and 2010, and March 2011.

Species group	Sept. 2009		Sept. 2010		March 2011	
Species	ELJ	RR	ELJ	RR	ELJ	RR
Salmonids						
Chinook salmon	1.86	4.45	3.28	3.44	0.25	1.22
Coho salmon	1.07	0.64	19.94	16.00	1.75	6.78
Steelhead	0.43	1.00	1.39	1.00	0.50	0.78
Cutthroat trout	0	0	0.61	0.19	0.06	0
Trout fry	0	0	1.56	4.19	0	0.11
Mountain whitefish	0.36	0.64	0.83	3.81	0.56	2.00
Other Fish						
Lamprey	0	0	0.11	0	0.06	0
Longnose dace	0.00	1.73	0.06	2.19	0	0
Sculpin	0.79	3.45	9.72	12.94	1.13	5.11

Table 8. Population estimates (95% lower and upper confidence interval) for all fish species combined (All Fish), juvenile Chinook, Coho and all sculpin at the ELJ and RR site in September 2010 and March 2011.

Species	Sept. 2010		Mar. 2011	
	ELJ	RR	ELJ	RR
All Fish	2,372 (2,062 - 2,603)	3,398 (2,851 - 3,787)	1,274 (607 - 3,080)	1,305 (830 - 2,239)
Chinook	399[a] (150 - 691)	370[a] (126 - 656)	---[b]	---[b]
Coho	804 (701 - 879)	570 (474 - 634)	---[b]	279 (182 - 496)
Sculpin	1,919 (843 - 4,646)	1,534 (821 - 3,216)	285[a] (100 - 503)	658[a] (232 - 1,157)

[a]Estimate is biased due to low number of recaptures (1).
[b]Insufficient number of recaptures to calculate a population estimate.

Recovery of PIT Tagged Fish

Similar numbers of fish were PIT tagged at the ELJ and RR sites during both August 2009 and 2010; however nearly three times as many fish were tagged at the two sites during 2010 than 2009 (Table 9). The species composition for fish tagged varied by year and site. Chinook salmon were the most common species tagged in 2009, while coho salmon were the most numerous fish tagged in 2010. Although more coho salmon were tagged in 2010, more Chinook salmon were tagged at the RR site than the ELJ site.

Recovery rates (i.e., percent) of PIT tagged fish varied by site, year and species (Table 9). Recovery rates were greater at the ELJ (ELJ: 2009 - 10.7%, 2010 - 10.6%; RR: 2009 - 6.9%, 2010 - 4.8%) site during both years. Results for Chinook and coho salmon were variable; greater at the ELJ site one year, but similar between the sites the other year. Overall recovery rate of PIT tagged Chinook salmon at the two sites in 2010 was substantially less than that of 2009, while overall recovery rates were similar during both years for coho salmon. With the exception of steelhead in 2009 (6 recoveries), recovery of other PIT-tagged species were very low or zero. No fish PIT tagged at the ELJ site were later recovered at the RR site; however, one Chinook PIT tagged at the RR site was recovered at the ELJ site. Only one fish PIT tagged during August 2010 was recaptured during the March 2011 survey, a coho from the ELJ site that was recovered at that site.

Although the number and percentage of PIT-tagged fish recovered at the two sites were similar in 2010, estimated numbers of PIT-tagged fish remaining at each reach based on mark-recapture estimates of PIT-tagged fish was greater at the ELJ site for both coho salmon and all PIT-tagged fish combined (Table 10). Estimated numbers of PIT tagged fish remaining at the ELJ site were more than four times greater than those estimated to be remaining at the RR site. The percent of all PIT tagged fish remaining at the ELJ site was two to four times greater than that of the RR site.

Fish Size and Growth

We compared only the fish size (fork length and weight) data from the September CPUE survey in 2009 and 2010, since the PIT tag surveys at the ELJ and RR sites were separated by a week during both years. The size data for CPUE surveys and mark-recapture surveys for the summer 2010 survey and winter 2011 survey were separated by no more than 2 days.

There were few differences in fish size between the ELJ and RR site, and the differences were not consistent (Figure 6). Chinook salmon fork lengths were significantly greater at the RR site than the ELJ site during the September 2009 survey (Mann-Whitney U test: P=0.017), but significantly less during the September 2010 survey (Mann-Whitney U test: P=0.007). No differences between sites were observed during the March 2011 survey (Mann-Whitney U test: P=0.75). Juvenile Chinook salmon at the RR site weighed more than those at the ELJ during the September 2009 survey (Mann-Whitney U test: P=0.008); weighed more at the ELJ site during the September 2010 survey (Mann-Whitney U test: P=0.022), while no difference was observed during the March 2011 survey (Mann-Whitney U test: P=0.43).

Results for fish size based on length and weights of coho salmon were also inconsistent (Figure 6). Coho salmon fork length was greater at the RR site than the ELJ site in August 2010 (Mann-Whitney *U* test: $P = 0.0003$). In contrast, coho salmon fork length was greater at the ELJ site during March 2011 (Mann-Whitney *U* test: $P = 0.006$). No differences were observed for the September 2009 or September 2010 surveys (Mann-Whitney *U* test: $P = 0.46$-0.59). Coho salmon weights varied significantly in three of the four comparisons. There was no significant differences observed for the September 2009 survey (Mann-Whitney *U* test: $P = 0.22$). Juvenile coho salmon weighed more at the ELJ site than the RR site during the September 2010 (Mann-Whitney *U* test: $P = 0.002$) and March 2011 surveys (Mann-Whitney *U* test: $P = 0.002$). However, juvenile coho weighed more at the RR site than the ELJ site during the August 2010 survey (Mann-Whitney *U* test: $P = 0.0004$).

There were no significant differences in the fork length or weight of steelhead and mountain whitefish at the ELJ and RR sites during this study (Figure 6). However, the sample size for many of these comparisons was relatively small in some cases, where relatively large size differences were observed. For instance, steelhead at the RR site (n=12) were nearly three times heavier than those at the ELJ site (n=6) during September 2009. The small sample size and relatively large variation in weight resulted in very low power (Power = 0.122).

Growth rates of individual PIT tagged fish recaptured during the CPUE and mark-recapture surveys did not vary between the ELJ and RR sites. Few PIT tagged fish were recovered and handled in 2009. Three fish from the RR site (all Chinook salmon), and two from the ELJ site (one coho salmon and one a steelhead) were recovered. The low recapture rate precluded comparisons of growth rates. Of the fish that were recaptured, Chinook salmon from the RR site averaged 7.80 (mg/g fish)/day; coho salmon at the ELJ site grew at a rate of 8.94 (mg/g fish)/day; and steelhead from the ELJ site had a negative growth rate of -0.29 (mg/g fish)/day.

More PIT-tagged fish were recovered during 2010; however, growth rates of individual PIT-tagged fish later recovered at the same site could only be compared for coho salmon. There were no differences in the length of PIT-tagged juvenile coho salmon at the ELJ and RR sites at the time of tagging (August: Mann-Whitney *U* test: $P = 0.49$) or during recapture (September: Mann-Whitney *U* test: $P = 0.82$). There was also no difference in the weight of PIT tagged juvenile coho salmon at the ELJ and RR sites during recapture (Mann-Whitney *U* test: $P = 0.912$). Although the growth rate of PIT-tagged juvenile coho salmon based on fork length was somewhat greater at the RR than the ELJ site, this difference was not statistically significant (Mann-Whitney *U* test: $P = 0.087$) (Figure 8).

Growth rates for one cutthroat trout, one Chinook salmon, and one steelhead could also be calculated. The cutthroat trout tagged and recaptured at the ELJ site grew 16 mm and 15.4 g in 41 days, a rate of 0.39 mm/day and 0.376 g/day. The Chinook salmon initially tagged at RR site and recovered at ELJ site grew 17 mm and 5.6 g in 34 days, a rate of 0.5 mm/day and 0.167 g/day. Finally the steelhead tagged and recovered at the RR site grew 10 mm and 6.7 g in 34 days, a rate of 0.294 mm/day and 0.197 g/day.

Table 9. Number of fish by species PIT-tagged at the ELJ and RR site, and the number (percent) of PIT tagged fish by species recovered at each site during 2009 and 2010. Ch = Chinook, Co = coho, Cutt = cutthroat, Sth = Steelhead, Trout = trout fry, Wf = whitefish.

Site	Date	Survey	Ch	Co	Cutt	Sth	Trout	Wf	Total
					2009				
ELJ	Aug. 11, 17-18	Tagging	57	30	0	43	5	5	140
RR	Aug. 18	Tagging	123	30	0	2	0	4	159
ELJ	Sep. 1-2	Recovery	5 (8.8)	4 (13.3)	-	6 (14.0)	0 (0)	0 (0)	15 (10.7%)
RR	Sep. 1-2	Recovery	11 (8.9)	0 (0)	-	0 (0)	-	0 (0)	11 (6.9%)
					2010				
ELJ	Aug. 3-5	Tagging	52	419	3	7	0	1	482
RR	Aug. 11-12	Tagging	220[a]	181[a]	5	27	2	16	451
ELJ	Sep. 13-14	Recovery	1 (1.9)	50 (11.9)	1 (33.3)	0 (0)	-	0 (0)	52 (10.8%)
RR	Sep. 15	Recovery	1 (0.005)	19 (10.7)	0 (0)	1 (3.7)	0 (0)	0 (0)	21 (4.7%)

[a]Includes morts, 9 Chinook salmon and 4 coho salmon, so the number released alive was 211 Chinook salmon and 177 coho salmon.

Table 10. Population estimate, 95% confidence interval, and percent of the original number PIT tagged coho salmon and all PIT tagged fish (all fish regardless of species) combined, at the ELJ and RR sites during 2010.

	Population Estimate (95% CI)		Percent	
Species	ELJ	RR	ELJ	RR
Coho Salmon	96 (67-126)	18 (13-23)	22.9	10.2
All Fish	104 (72-136)	22 (16-28)	21.6	5.0

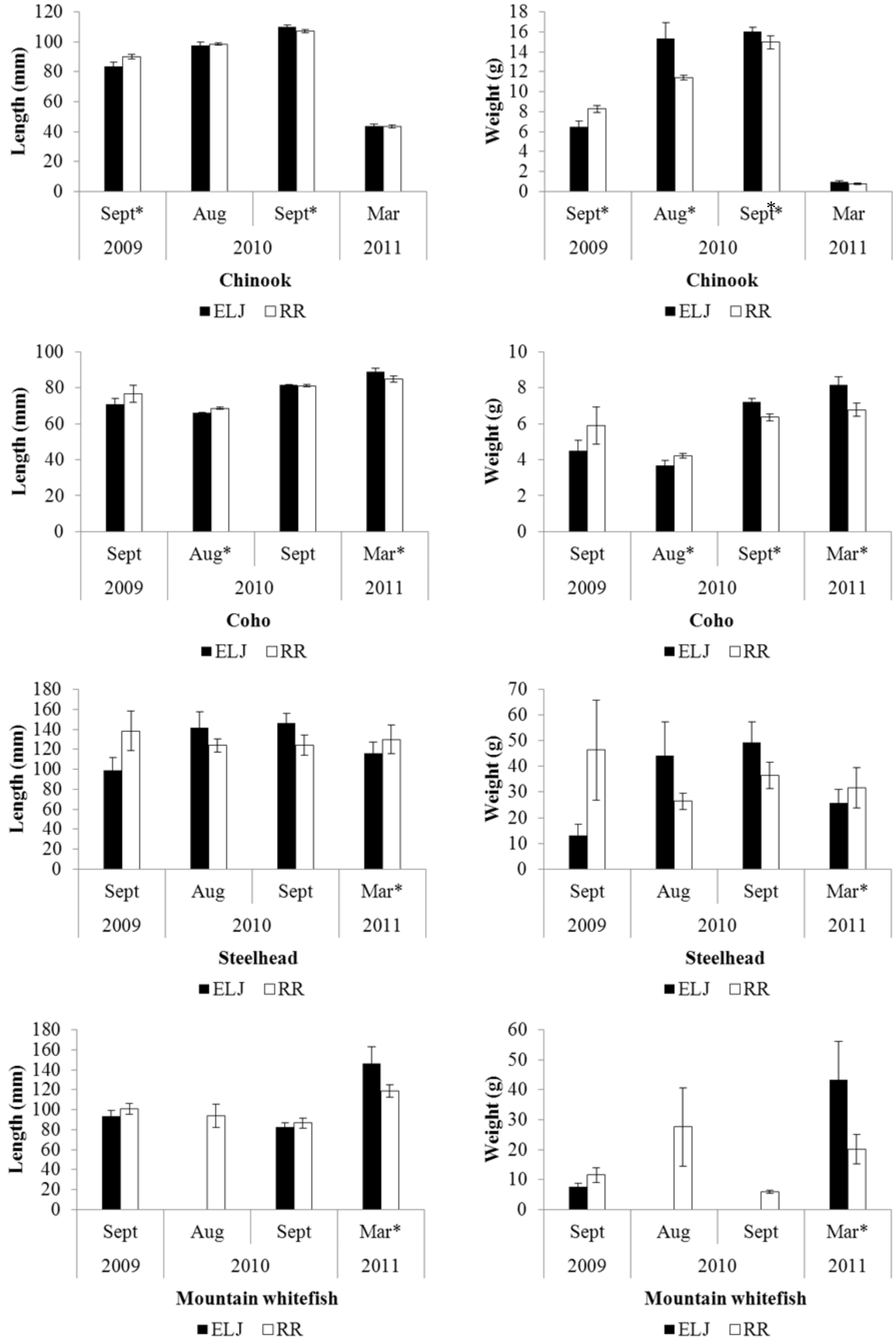

Figure 6. Mean fork length and weight (+/- SE) of Chinook salmon, coho salmon, steelhead, mountain whitefish, and sculpin sampled at the Hoh ELJ and RR sites during September 2009, August and September 2010, and March 2011 surveys. Numbers above the bars are the number of fish sampled. Significant differences (α <0.05, Mann-Whitney U test) existed for those test where an asterisk (*) is next to the year on the x-axis. Note that the y-axis scales vary among the different charts.

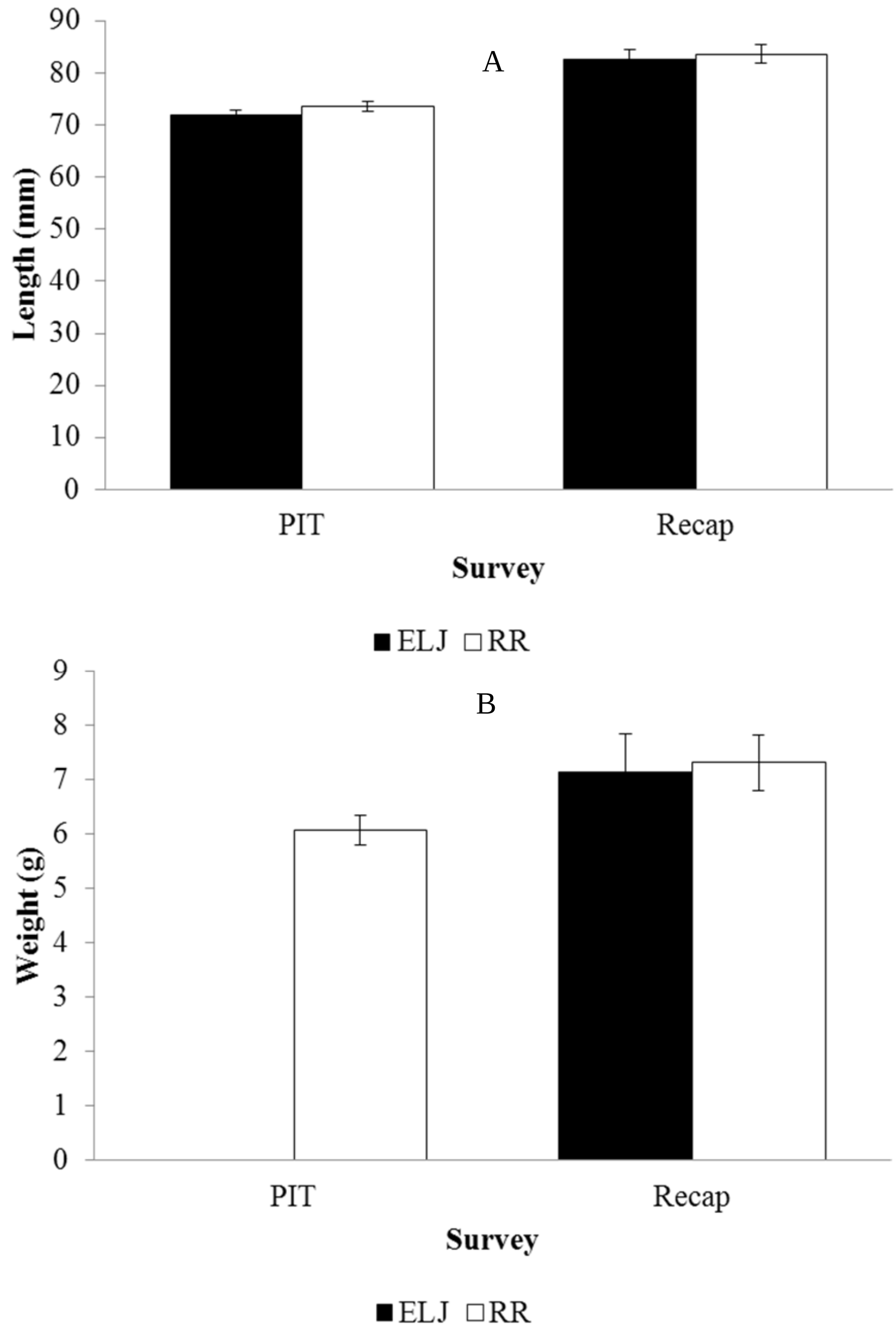

Figure 7. Mean ±SE) length (A) and weight (B) of coho salmon PIT tagged during August 2010 and recaptured during September 2010 at the ELJ (n = 50) and RR sites (n = 20). Fish were not weighed during PIT tagging at the ELJ site due to a scale malfunction. Sample sizes were, ELJ = 50; RR = 20.

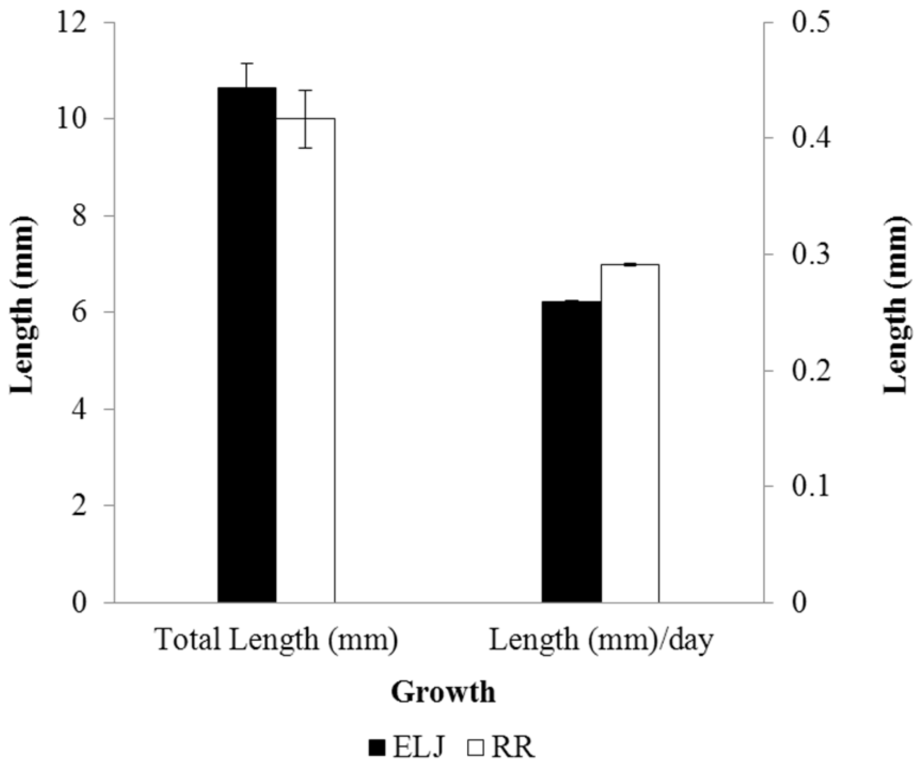

Figure 8. Mean (±SE) increase in coho salmon fork length (total length (mm)) and the mean increase in fork length per day (length (mm)/day) (second Y-axis) between PIT-tagging (8/2010) and recapture (9/2010), at the ELJ and RR site. Sample sizes were, ELJ = 50; RR = 20.

Behavior and Habitat Use (Acoustic Tracking)

Forty-two fish were successfully tagged and released into the array during this study (Table 11). Sixteen fish, seven wild steelhead, seven Chinook salmon, and two mountain whitefish died during surgeries. These mortalities were likely due to relatively warm air temperatures (~20-24^{o}C) during tagging, since water temperatures in the holding tank were similar to background temperatures and mortalities were significantly reduced when we began tagging at night. Chinook salmon were the smallest fish tagged and hatchery steelhead were larger than their wild counterparts (Table 12).

Thirty-one of the 42 fish released back into the Hoh River provided useful tracks, including 3 Chinook salmon, 1 cutthroat trout, 26 steelhead (17 wild, 9 hatchery), and 1 unidentified sculpin (tagged with an old tag). Six fish moved downstream and were detected by the downstream data logger prior to initiating tracking (4 wild steelhead, 1 hatchery steelhead, and 1 white fish). The whitefish was detected at the downstream data logger for a total of 3.5 days. The minimum tracking time for fish remaining the array ranged from 0.1 to 16.7 days, and averaged 11.8 days (Table 13). Data from two wild steelhead were not included in the analysis since they were tracked for such short periods (<0.3 days). This reduced our overall sample size to 29 fish, including 3 Chinook salmon, 1 cutthroat trout, 15 wild steelhead, 9 hatchery steelhead, and 1 sculpin. Due to the small sample sizes for the other species, we focused our analysis on steelhead.

Tagged fish considered collectively used nearly the entire area covered by the tracking array at one time or another (Figure 9), and also used areas outside the array. Two fish, one wild steelhead (tag code 4820) and one juvenile Chinook (tag code 5240) left the array at the downstream end and were detected at the downstream data logger for a very short time (< 4 hrs). One wild steelhead (tag code 5420), moved upstream out of the array and was detected at the upstream data logger located approximately 250 meters upstream of the upper extent of the array at 2200 on August 19, 2009. This fish then moved back downstream into the array and was tracked through 0650 August 30, 2009.

Individual fish also used relatively large areas considering their relatively small. The surface area of individual fish home ranges ranged from approximately 17 m^2 to over 1,000 m^2 (<1% to > 11% of the array coverage area; see Appendix B), with the total areas used covering more than double this area (Appendix B). Figure 10 and Figure 11 provide examples of tracks from individual fish for a 24-h period starting at the beginning of the dawn time period; with the tracks for the remaining fish shown in Appendix B. In the example provided in Figure 10 (wild steelhead 184 mm FL; 67.6 g), the fish spent the dawn period on the left bank of the river and moved downstream about 40 m during this period. During the day period, the fish moved upstream, crossed to the right bank, moved to the upstream extent of the array, crossed back to the left bank, and then moved downstream. The behavior displayed during dusk was similar to that during the dawn; however, the fish was located more than 100 m upstream. The fish remained on the left bank for the entire night period, but also moved from the upstream extent of the array to the downstream extent. The juvenile Chinook (109 mm FL, 15.7 g), showed a similar behavior pattern. Although the juvenile Chinook didn’t move to the extent of the steelhead described above, it still crossed the Hoh River during the day period.

The quality of the tracking data for individual fish varied substantially (Figure 12). On average, the gaps between tag detections for each fish enabled us to accurately track the fishes movement 52%of the time (range - 15 to 81%). On average the greatest loss of tracking time occurred during individual, long duration gaps (> 3,600 s). The loss of tracking time from gaps of 15 to 30 s, 30-60 s, and 60-300 s varied little (average 7-9%), and accounted for approximately 24% of the lost tracking time combined. Although the distance between the last tracked point prior to a gap and the first tracked point after the gap was generally short, there were instances where the gaps were relatively large (Figure 13). The gaps also appeared to occur randomly within our array rather than clumped in one location that would indicate a systematic error in our tracking array (i.e., blind spots). Due to the uncertainty of where the fish were located during these gaps and the relatively large change in habitat conditions (i.e., depth, distance from shore, etc.) that could occur over these gaps, the home range and habitat use results for this tracking information should be viewed cautiously.

Table 11. Summary of acoustic tagging including tag date, tag code, species, hatchery/wild, fork length, start and end of tracking, the number of days tracked and fate of fish not tracked if known. Species include steelhead (Sth), Chinook (CH), cutthroat (Cutt), Sculpin (sculp) and whitefish (WF).

Tag Date	Tag Code	Species	Hatchery /Wild	Fork Length mm	Weight g	Start Track	End Track	Track Days	Fate/Comments
8/17/09	4780	Sth	Wild	178	56.22	8/18/09 11:33 PM	8/26/09 5:57 AM	7.3	Tracked
8/17/09	4790	Sth	Hatchery	163	42.01	8/19/09 12:00 AM	8/28/09 9:56 PM	9.9	Tracked
8/17/09	4800	Sth	Wild	125	21.45	Not Tracked	Not Tracked		Moved Downstream ?
8/17/09	4810	Sth	Wild	175	51.65	8/18/09 11:32 PM	8/29/09 2:00 AM	10.1	Tracked
8/17/09	4820	Sth	Wild	184	67.55	8/18/09 11:32 PM	8/22/09 1:28 AM	3.1	Tracked Moved Downstream?
8/17/09	4830	Sth	Hatchery	149	38.13	Not Tracked	Not Tracked		Moved Downstream ?
8/17/09	4840	Sth	Hatchery	177	64.49	8/19/09 12:21 AM	9/1/09 8:51 AM	13.4	Tracked
8/17/09	4850	Sth	Hatchery	224	118.1	8/18/09 11:37 PM	8/29/09 9:09 PM	10.9	Tracked
8/17/09	4860	Sth	Wild	176	60.09	Not Tracked	Not Tracked		Moved Downstream ?
8/17/09	4870	Sth	Hatchery	173	53.97	8/18/09 11:37 PM	8/30/09 10:59 PM	12.0	Tracked
8/17/09	4880	Sth	Wild	176	62.34	8/18/09 11:37 PM	8/30/09 6:59 AM	11.3	Tracked
8/17/09	4890	Sth	Hatchery	165	50.5	8/18/09 11:37 PM	8/29/09 10:28 AM	10.5	Tracked
8/17/09	4900	Sth	Hatchery	175	54.56	8/18/09 11:37 PM	9/1/09 6:36 AM	13.3	Tracked
8/18/09	4910	Cutt	Wild	209	94.01	8/19/09 9:52 AM	9/1/09 8:56 AM	13.0	Tracked
8/18/09	4920	Sth	Hatchery	179	48.47	8/19/09 10:13 AM	9/1/09 8:49 AM	12.9	Tracked
8/18/09	4930	Sth	Wild	143	30.38	8/19/09 10:13 AM	9/1/09 6:16 AM	12.8	Tracked
8/18/09	4940	Sth	Wild	147	35.87	8/19/09 10:21 AM	8/19/09 12:14 PM	0.1	Data not included
8/11/09	5050	Sculp	Wild	106	13.74	8/13/09 10:00 PM	8/19/09 1:59 PM	5.7	Tracked
8/11/09	5060	WF	Wild	268	244.7	Not Tracked	Not Tracked		Unknown
8/11/09	5120	WF	Wild	185	67.01	Not Tracked	Not Tracked		Moved Downstream ?
8/11/09	5180	Sth	Wild	138	28.94	Not Tracked	Not Tracked		Moved Downstream ?
8/11/09	5190	Sth	Hatchery	182	58.6	Not Tracked	Not Tracked		Unknown
8/11/09	5240	Ch	Wild	96	10.78	8/13/09 12:00 PM	8/25/09 2:20 AM	11.6	Tracked, Moved Downstream ?

Table 11. Continued

Tag Date	Tag Code	Species	Hatchery /Wild	Fork Length mm	Weight g	End Track	Start Track	Track Days	Fate/Comments
8/11/09	5260	Ch	Wild	110	16.77	8/13/09 12:00 PM	8/27/09 10:40 PM	14.4	Tracked
8/11/09	5270	Ch	Wild	98	11.9	Not Tracked	Not Tracked		Unknown
8/11/09	5280	Sth	Wild	136	26.7	8/13/09 12:00 PM	8/28/09 6:39 AM	14.8	Tracked
8/12/09	5300	Sth	Wild	143	34.33	8/13/09 12:06 PM	8/28/09 11:51 PM	15.5	Tracked
8/12/09	5310	Sth	Hatchery	200	91.03	8/13/09 12:00 PM	8/28/09 8:39 AM	14.9	Tracked
8/12/09	5320	Sth	Wild	131	24.48	Not Tracked	Not Tracked		Unknown
8/12/09	5330	Sth	Wild	148	32.07	8/14/09 8:00 AM	8/21/09 11:40 PM	7.7	Tracked
8/12/09	5340	Sth	Wild	175	61.94	8/14/09 3:29 PM	8/30/09 1:50 PM	15.9	Tracked
8/12/09	5350	Sth	Wild	144	27.86	8/14/09 6:00 PM	8/30/09 7:59 AM	15.6	Tracked
8/12/09	5360	Sth	Hatchery	206	101.5	8/15/09 8:52 PM	8/28/09 7:58 PM	13.0	Tracked
8/12/09	5370	Sth	Wild	205	86.61	8/14/09 11:01 AM	8/29/09 10:30 PM	15.5	Tracked
8/12/09	5380	Sth	Wild	186	68.69	8/14/09 6:00 PM	8/29/09 10:59 PM	15.2	Tracked
8/12/09	5390	Sth	Wild	186	60.23	8/14/09 12:09 PM	8/14/09 8:03 PM	0.3	Data not included
8/12/09	5400	Sth	Wild	181	60.16	Not Tracked	Not Tracked		Moved Downstream ?
8/12/09	5410	Sth	Wild	169	54.32	8/14/09 8:00 AM	8/29/09 1:59 PM	15.2	Tracked
8/12/09	5420	Sth	Wild	168	45.36	8/14/09 11:00 AM	8/30/09 6:50 AM	15.8	Tracked, Moved upstream and then back downstream into the array again
8/12/09	5430	Sth	Wild	140	29.31	8/14/09 8:00 AM	8/30/09 6:59 PM	16.5	Tracked
8/12/09	5440	Sth	Wild	168	48.16	Not Tracked	Not Tracked		Unknown
8/12/09	5450	Ch	Wild	109	15.69	8/14/09 8:00 AM	8/30/09 11:59 PM	16.7	Tracked

Table 12. Number (n), mean fork length (mm), weight (g) and standard error for the different fish species tagged with acoustic tags and released into the Hoh River acoustic array during August 2009.

	Chinook	Cutthroat	Sculpin	Steelhead Wild	Steelhead Hatchery	Whitefish
n	4	1	1	23	11	2
Mean Length	103.3	209.0	106.0	161.8	181.2	226.5
SE	3.64	N/A	N/A	4.55	6.44	41.50
Mean Weight	13.8	94.0	13.7	46.7	65.6	155.8
SE	1.45	N/A	N/A	3.71	7.88	88.83

Table 13. Minimum, average, and maximum number of days that tagged fish were tracked within the Hoh River tracking array at the ELJ site in 2009.

	All Species	Chinook	Cutthroat	Wild Steelhead	Hatchery Steelhead	Sculpin
Minimum	0.1	11.6	13.0	0.1	9.9	5.7
Average	11.8	14.2	13.0	11.3	12.3	5.7
Maximum	16.7	16.7	13.0	16.5	14.9	5.7

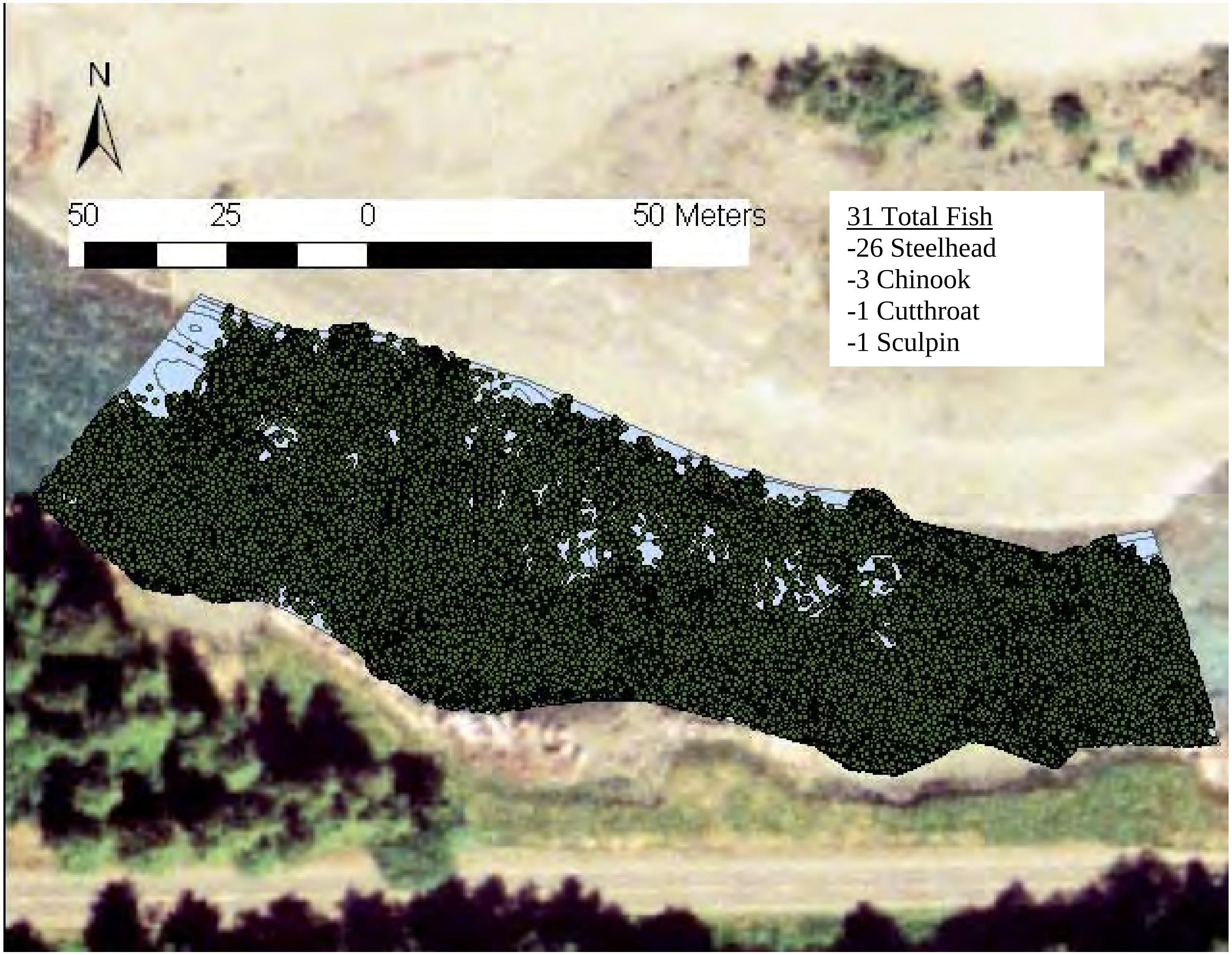

Figure 9. Plot showing each detection for all fish tracked in the Hoh River array during 2009.

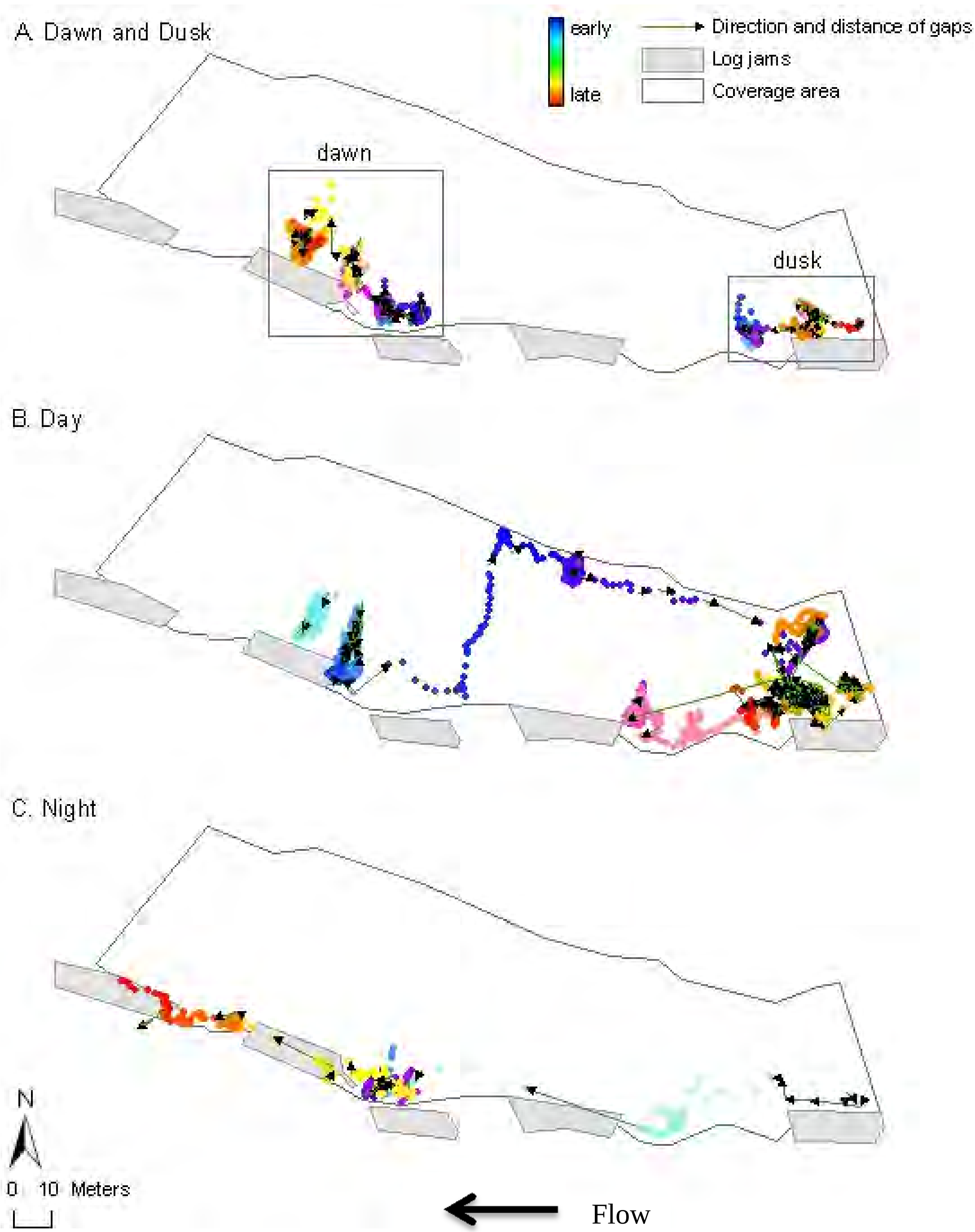

Figure 10. Example of movements by a steelhead (tag 4820) within the Hoh River array during four distinct time periods, dawn, day, dusk, and night from dawn (05:22) August 21, 2009 until dawn (05:23) on August 22, 2009. The line and arrow connect the last tracked point before the gap and the first tracked point after the gap.

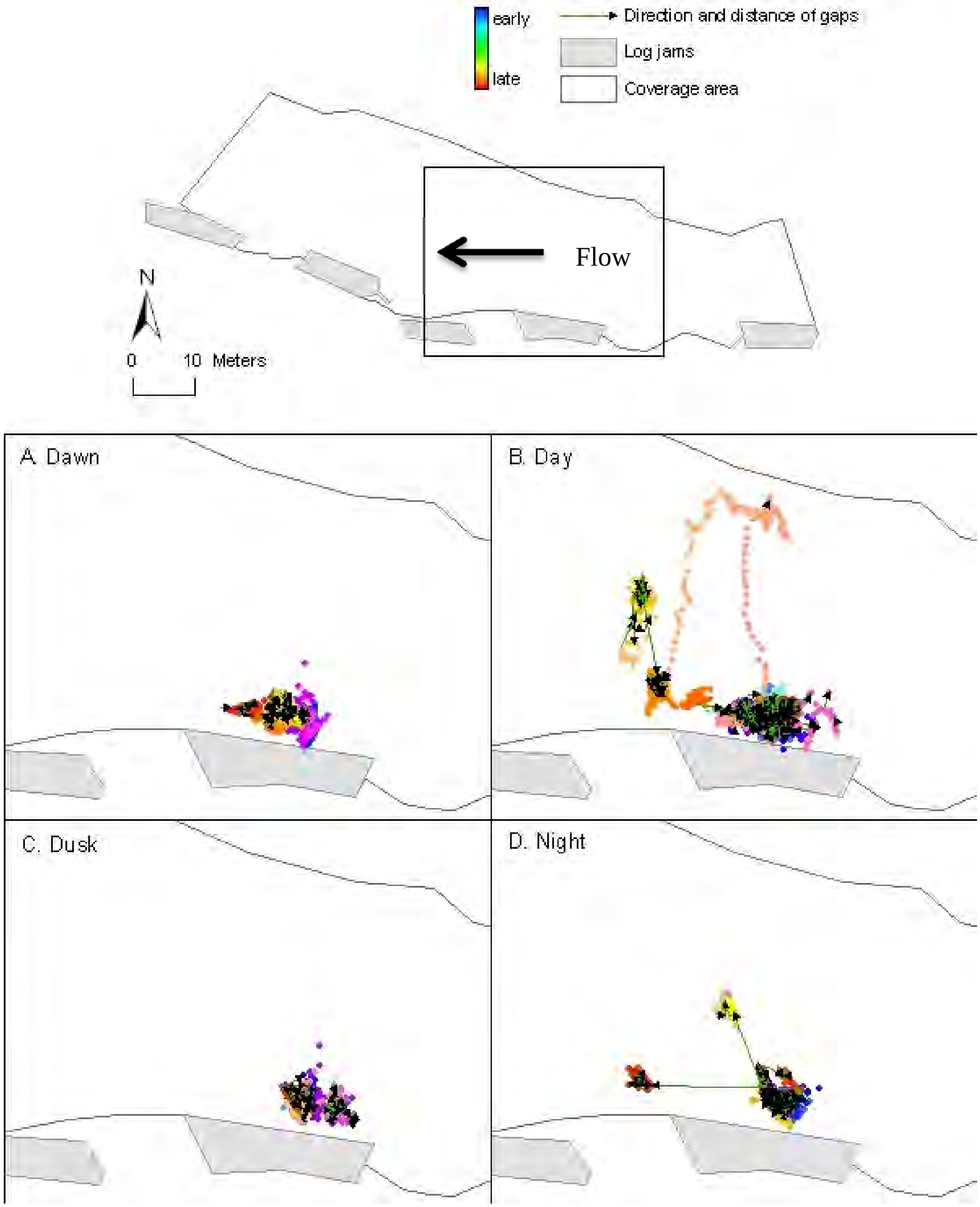

Figure 11. Example of movements by a juvenile Chinook salmon (tag 5450) within the Hoh River array during four distinct time periods, dawn, day, dusk, and night from dawn (05:15) August 16, 2009 until dawn (05:16) on August 17, 2009. The line and arrow connect the last tracked point before the gap and the first tracked point after the gap.

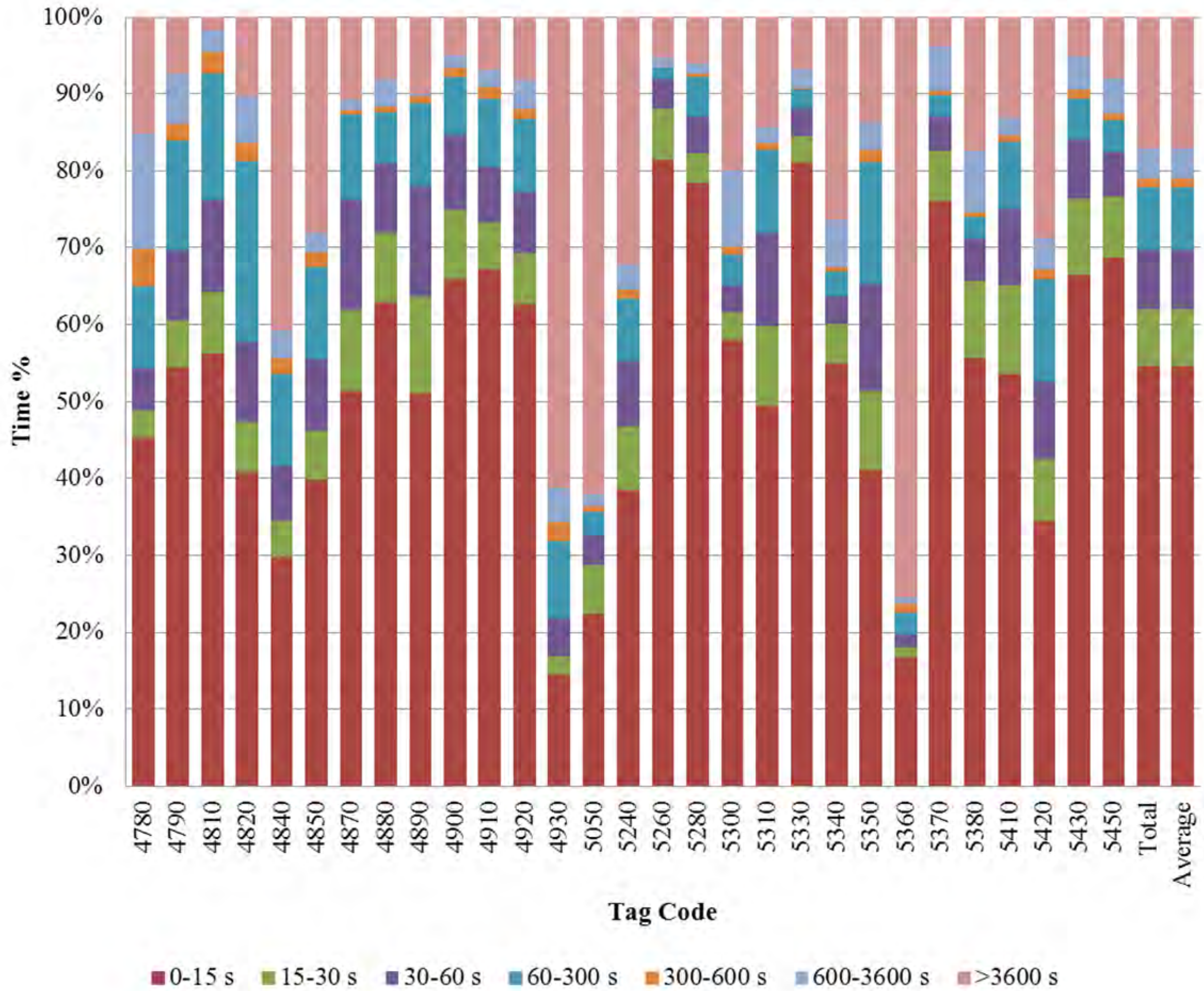

Figure 12. Time (%) that each fish (i.e., represented by Tag Cod) were accurately tracked (0-15 s time interval) and for which gaps (> 15 s time interval) of different size (e.g., time intervals in seconds (s)) occurred during tracking. The average of all fish combined is also presented (far right).

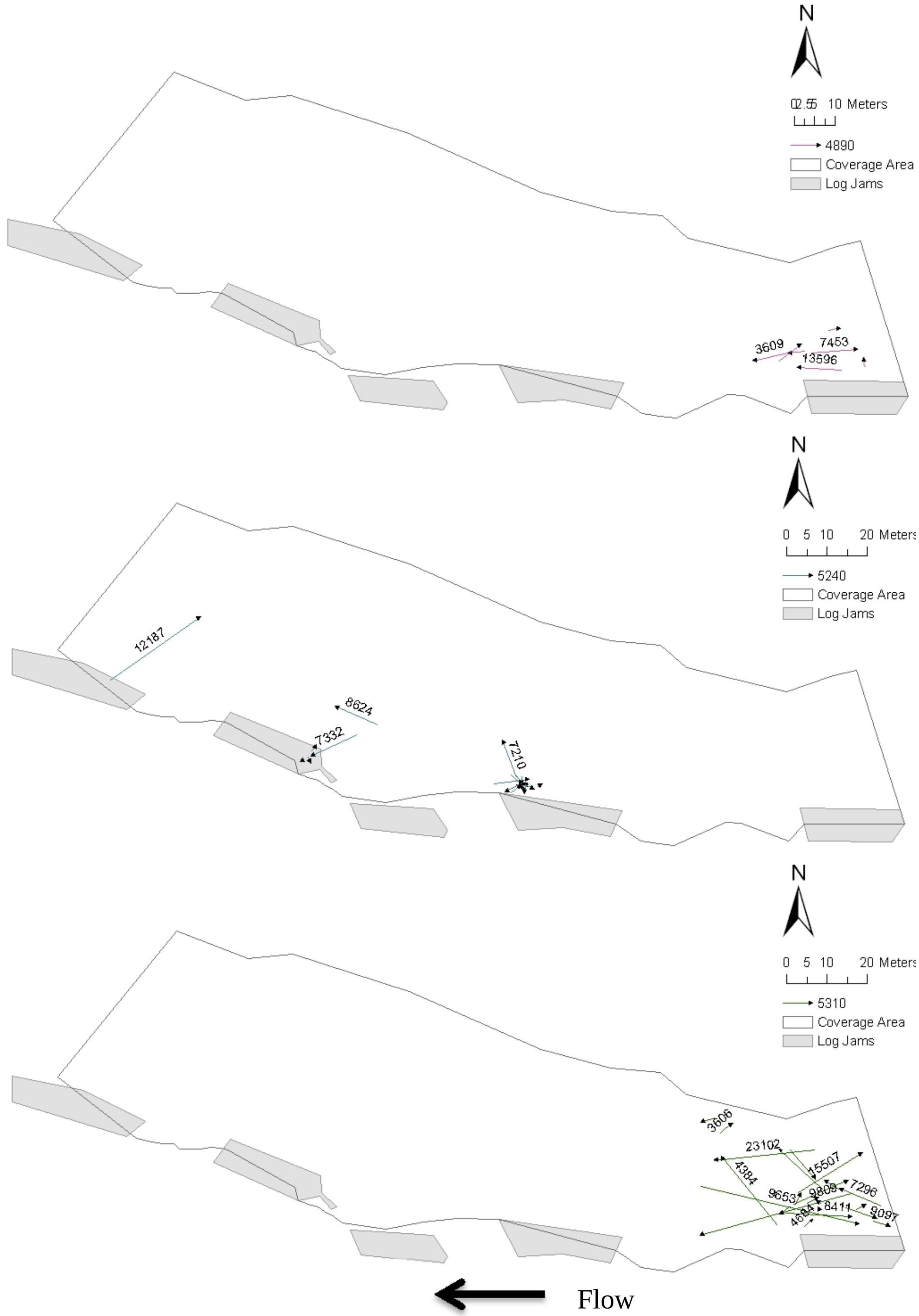

Figure 13. Examples of tracking gaps greater than 3,600 s for three tag code: 4890 (hatchery steelhead), 5240 (Chinook), and 5310 Hatchery Steelhead. The lines represent the gaps, the arrow at the end of the line shows the first tracked point after the gap, and the text displays the gap time (seconds).

The size and location of steehead home ranges varied substantially amongst the different fish tracked during this study (Figure 14 - Figure 15; Appendix B figures). A majority (10) of the home ranges were in the upper third of the array, with fewer found in the middle (5) and downstream (2) third of the array. A majority of the home ranges were also found throughout the river cross section (9), with a majority of the remaining home ranges found on the left (ELJ) bank (7) compared to the right bank (3).

In general, the size and location of home ranges used during the different diel periods did not vary substantially (Figure 14, Figure 15, Appendix B figures). Home ranges from the four diel periods (dawn, day, dusk, night) generally overlapped (Figure 14 and Figure 15, Appendix B figures). Home ranges varied from about 17 m^2 to about 1,060 m^2, representing approximately 0.4% to 11.5% of the total area covered by the array. There were no significant differences in the size of steelhead home ranges for the four different diel periods (Two-way ANOVA: P = 0.09), although nighttime home ranges were the smallest of the four time periods (Figure 16). There also were no differences in the size of hatchery and wild steelhead home ranges (Two-way ANOVA: P = 0.676).

Juvenile steelhead used different habitat types differently, which was also influence at times by diel period (Figure 17 - Figure 21) Juvenile steelhead used secondary glide habitats less than expected based on the availability of this habitat type during all four time periods (Figure 17). They used riffle secondary habitats less than expected based on availability during three (dawn, day, and night) of the four time periods, only using secondary riffle habitat during dusk. Secondary eddy habitats were selected for during three of the four time periods, while deposition habitats were selected during only one time period - the day. Secondary lateral scour pools were not selected or avoided during the study (Figure 17).

Juvenile steelhead showed a strong selection for some types of primary habitats (Figure 17). They selected primary pool habitats, but used primary glide habitats less than expected based on availability during all four time periods.

Juvenile steelhead showed preferences for different depth categories examined and these differences varied somewhat by time period (Figure 19). Juvenile steelhead displayed greater selectivity for depth during the dawn and day time periods. Juvenile steelhead used depths less than 0.6 m and greater than 3.5 m less than expected based on their availability during dawn and day, and depths of 0.2-0.4 m during dusk. The also showed a preference for depths of 1 to 1.5 m during the day. Juvenile steelhead used depths of 0.2 to 0.4 m and 2 to 2.5 m less than expected based on availability at dusk, but showed no preference at night.

Juvenile steelhead in the Hoh River appeared to prefer locations that were an intermediate distance from the bank and their selection varied somewhat among the four time periods examined (Figure 20). They used near-bank areas (0-0.5 m) less than expected and used areas 4 to 8 m from the bank more than expected based on availability during all four time periods. They also used areas 0.5 to 1 m from the bank and areas greater than 16 m from the bank less than expected during the day and at dusk.

Juvenile steelhead tended to use areas directly under the ELJs less than expected based on availability, while using areas further from the ELJs greater than expected based on availability

(Figure 21). They used areas directly below ELJs less than expected during the day, dusk and night. No other distance category was either selected for or against based on this statistic.

Figure 14. Dawn, day, dusk, and night home ranges (90%) for the three Chinook salmon tracked during August 2009 at the Hoh ELJ site.

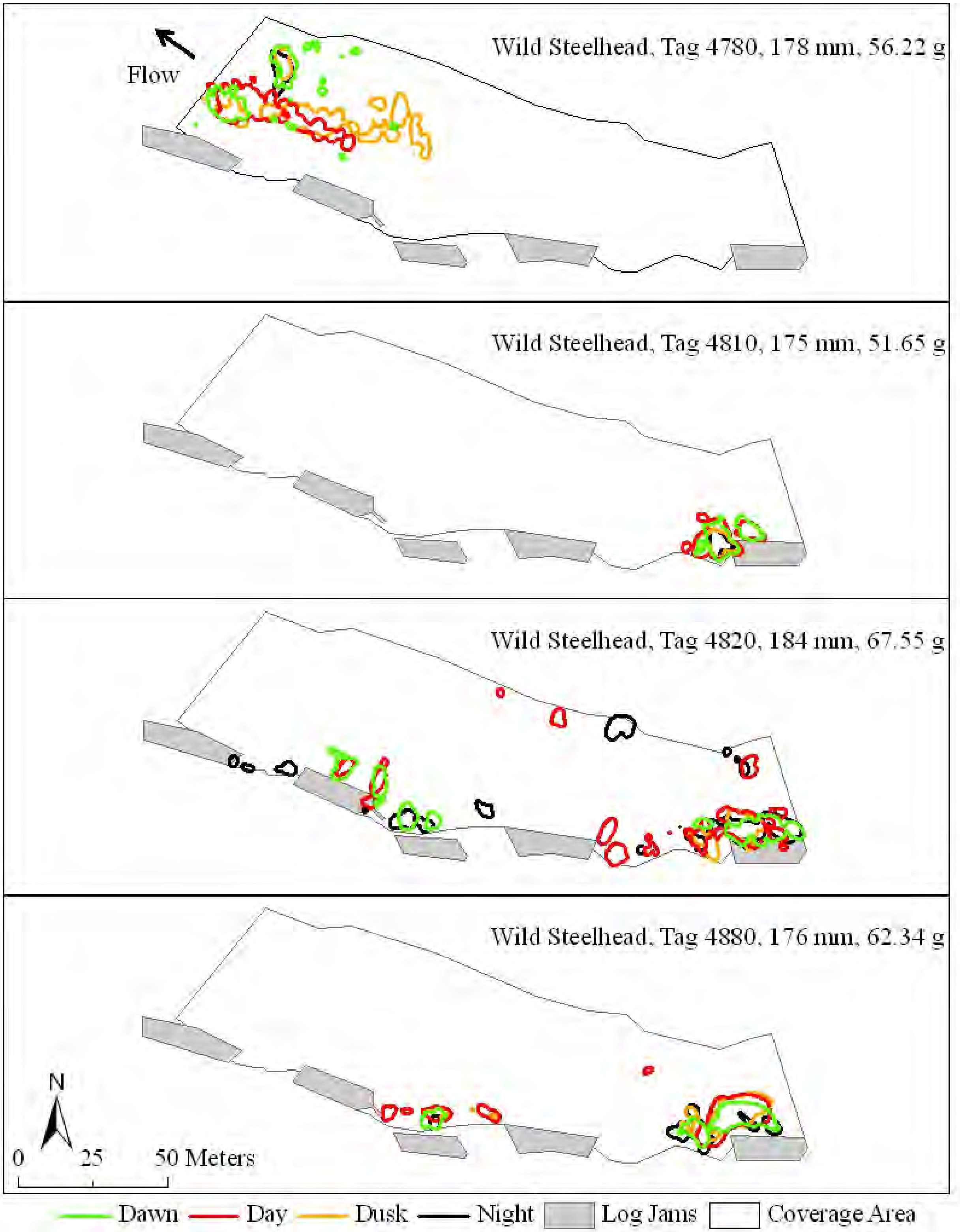

Figure 15. Dawn, day, dusk, and night home ranges (90%) for four wild steelhead tracked during August 2009 at the Hoh ELJ site.

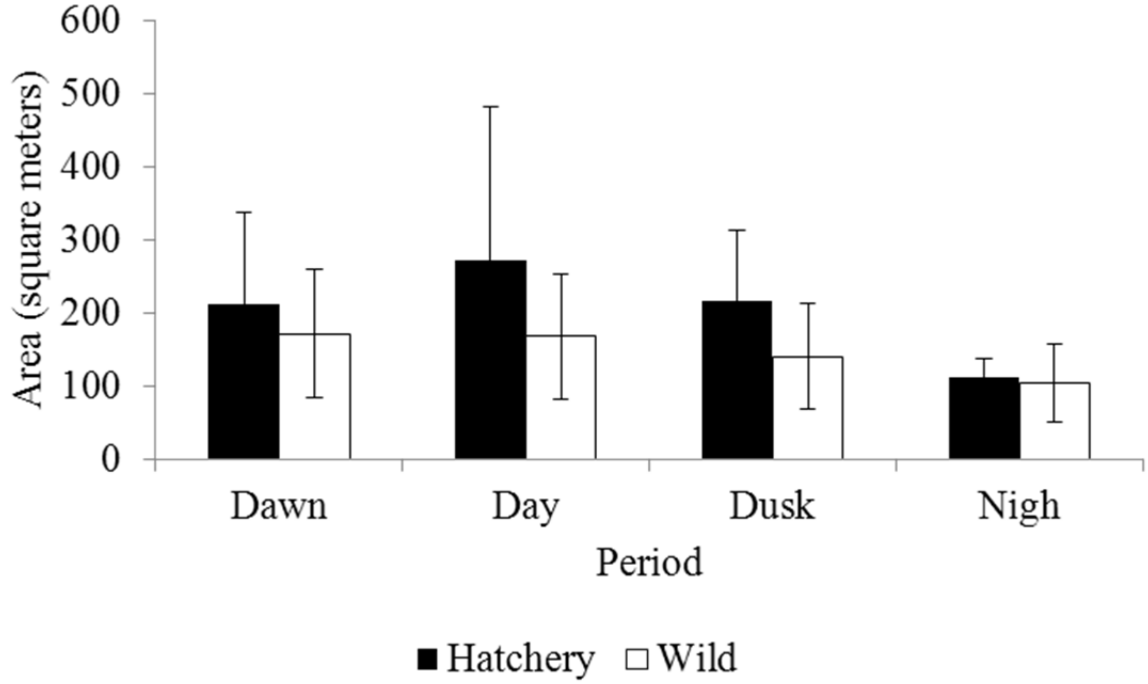

Figure 16. Mean (+/- 2 SE) home range areas (m^2) for hatchery and wild steelhead for the four diel periods examined.

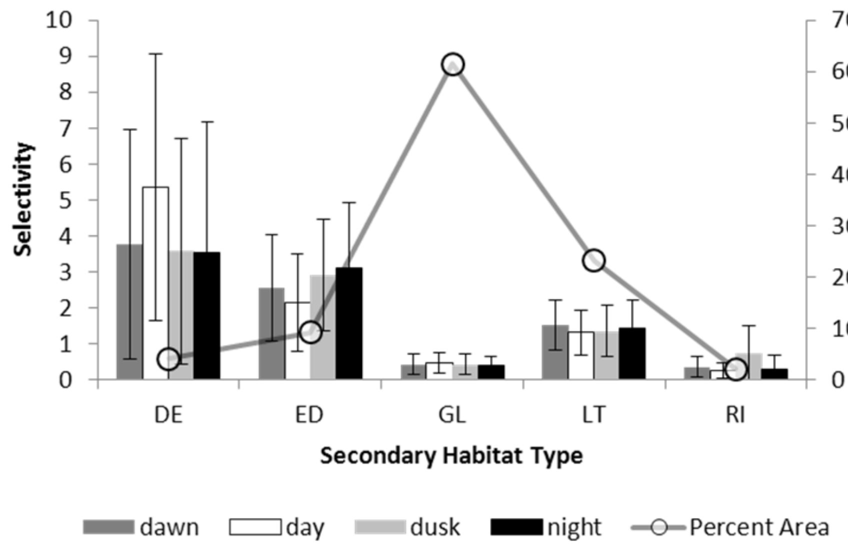

Figure 17. Manly's selection ratio (bars referencing the left y-axis:± 95% CI) for different secondary habitat types and the percent of the total habitat composed of that secondary habitat type (line referencing the right y-axis). DE = deep water; ED = eddy; GL = glide; LT = lateral scour; RI = riffle.

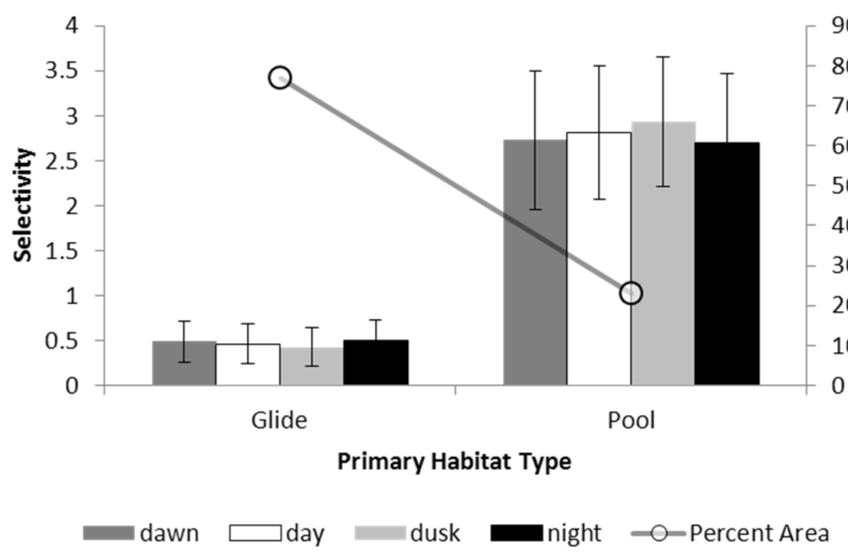

Figure 18. Manly's selection ratio (bars referencing the left y-axis; ± 95% CI) for different primary habitat types and the percent of the total habitat composed of that primary habitat type (line referencing the right y-axis).

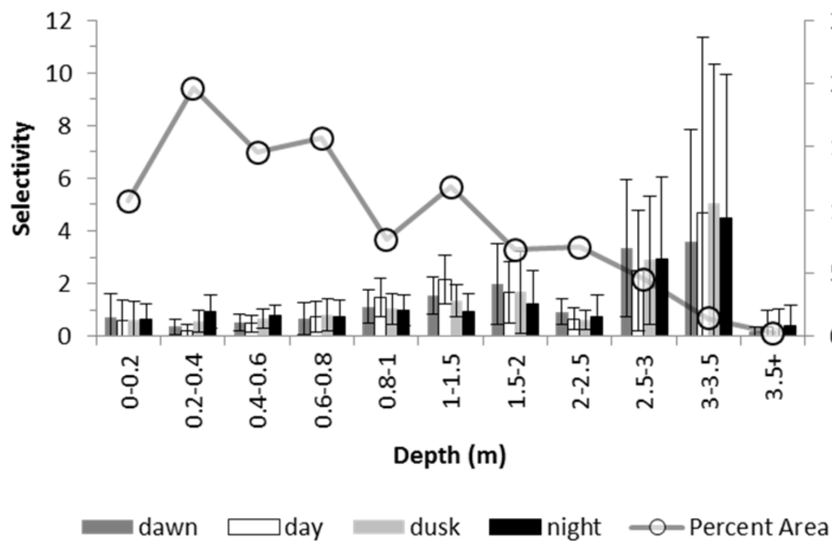

Figure 19. Manly's selection ratio (bars referencing the left y-axis; ± 95% CI) for different water depths and the percent of the total habitat composed of those depths (line referencing the right y-axis). .

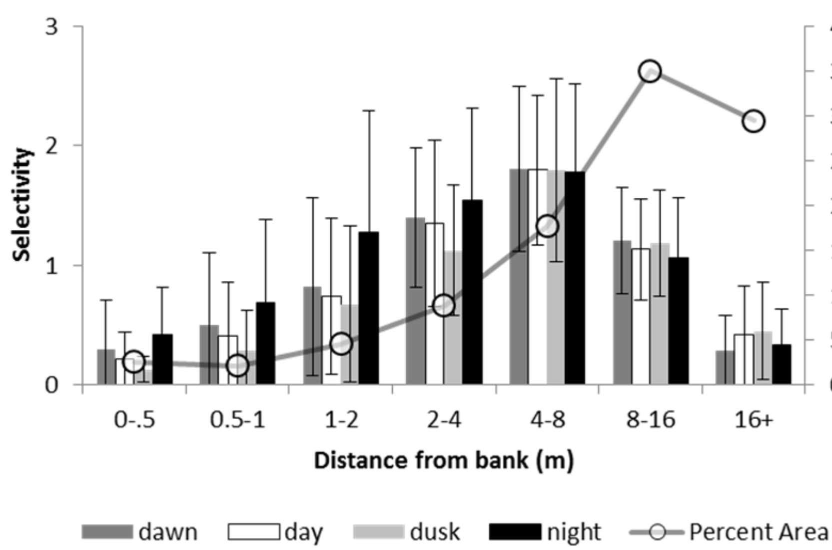

Figure 20. Manly's selection ratio (bars referencing the left y-axis; ± 95% CI) for different distances from the bank and the percent of the total habitat composed of those different distances from the bank (line referencing the right y-axis).

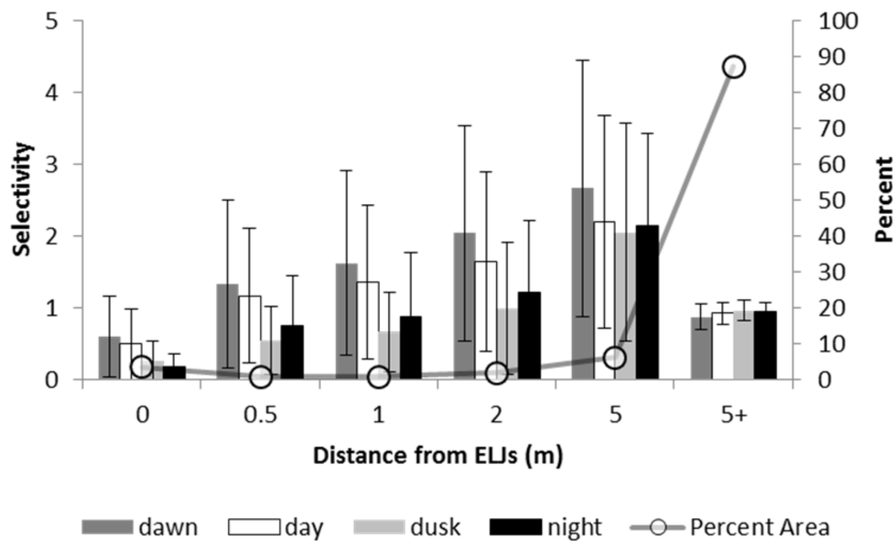

Figure 21. Manly's selection ratio (bars referencing the left y-axis; ± 95% CI) for different distances from the ELJs and the percent of the total habitat composed of those distances from the ELJs (line referencing the right y-axis).

Discussion

The overall goal of this project was to collect pre-project data for a before-after-control-impact study design to assess the influence of the second Hoh River ELJ project (milepost 175.9 on HWY 101) on fish habitat and fish populations. A second objective was to gain an understanding of how juvenile salmonids use habitat at the first Hoh ELJ site to inform future restoration projects and future monitoring activities. As such, statistical comparisons between the two sites for the current data set were expected to be limited and lack statistical power, since it represents a simple case study. We in fact observed few consistent differences in habitat, fish abundance, survival, size, and growth between the ELJ and RR site during this study. Movement patterns by juvenile steelhead tracked with an acoustic tracking system suggest that the spatial scale of the current study may be too small to encompass the extent of fish habitat use. Fish moved extensively throughout the area covered by the acoustic array, often within a single 24-h period. Several fish also moved out of the study area to habitats upstream or downstream of the acoustic array. Based on this, we believe a reach scale assessment of ELJs is required to account for fish movements.

The greater channel and primary habitat diversity observed at the RR site as compared to the ELJ site is likely due to historic failures of the RR bank stabilization. Although sites with riprap are generally criticized for having less diversity than either control or ELJ sites (Schmetterling et al. 2001), the presence of large boulders in the channel as a result of historic failures may have actually increased habitat diversity at the RR site. High winter discharges have dislodged several dozen large boulders over the years and deposited them in the river channel. These artificial structures, along with the near perpendicular channel alignment, may have increased deposition of sediments resulting in the creation of several additional channels and primary habitat units, resulting in more diverse habitat conditions than the ELJ site. Ironically, it appears as though the failing riprap increased in stream habitat diversity that may have been lacking had it not failed.

In contrast to channel and primary habitat diversity, secondary habitat diversity was greater at the ELJ site than the RR site. This was particularly true for eddy secondary habitats, which were generally associated with the ELJs. These differences were expected since riprap generally reduces bank roughness, thereby reducing the width of the boundary layer (i.e., separation bubble) at the edge of the river, while LWD in rivers commonly creates eddy habitat (Bisson et al. 1987). These findings are similar to those described by Peters et al. (1998) in a comparison of different bank stabilization methods employed in western Washington, where eddy habitats were more abundant along banks stabilized using LWD than those stabilized using riprap.

There were relatively few differences in any other habitat variables other than those that were likely related to the age of the projects and/or the primary bank stabilization techniques. There was more riparian and overhead cover at the RR site than the ELJ site. This was likely due to the differences in the age of the stabilization projects. The riprap project was relatively old and there were numerous relatively large alders growing in the riprap. These alder trees provided significant overhead cover at this site. In contrast, the ELJ site was only 5 years old at the time of this study. Thus, little riparian growth had occurred at this site. In general, riparian and overhead cover is greater at natural and or LWD stabilized banks than those stabilized using riprap (Peters et al. 1998, Schmetterling et al. 2001). Thus, one may expect riparian vegetation and overhead cover at the ELJ site to become equivalent to or greater than that at the RR site over time.

The availability of instream cover was the final habitat difference between the two sites. As expected, the ELJ site had more wood cover, while the RR site had more rock cover. This is an obvious difference based on the bank stabilization method used to stabilize the eroding banks and is common difference observed among these types of projects (Peters et al. 1998).

There were no consistent differences in fish abundance at the ELJ and RR sites. Although Chinook salmon, mountain whitefish and sculpin CPUE was greater at the RR site than the ELJ site during all three surveys, these differences were likely due to differences in sampling efficiency. The RR site had much smaller braided channels at the upstream end that were relatively easy to sample compared to the ELJ site. In addition, the current velocities on the point bar side of the channel were much less at the RR site than the ELJ, which also made sampling easier. We were unable to sample the riprap bank at the RR site due to swift currents, deep water, and the riprap which inhibited our ability to pull the beach seine to shore. In contrast, we sampled several areas along the ELJs at the ELJ site, which were extremely deep, which made pulling the seine slow and relatively difficult. This likely resulted in reduced CPUE at this site. These differences resulted in our decision to undertake mark-recapture surveys in 2010 and 2011.

Fish abundance based on mark-recapture was variable depending on the group of fish examined and season. The abundance of all fish species combined was greater at the RR site than the ELJ site during the summer but not the winter. In contrast, juvenile coho salmon abundance was greater at the ELJ site during the summer but not the winter. These results differed from the CPUE results and show the potential limitations of the CPUE method for this type of an assessment. The observed differences for all species combined, may have been the result of increased channel complexity at the RR site, which provided more edge habitat for fish. Edge habitat has been shown to be important for juvenile Chinook salmon and other fish species (Peters et al. *in prep*). Greater abundance of coho salmon at the ELJ site was likely due to the complex wood cover, which has been shown to be an important habitat feature for juvenile coho salmon in relatively large river channels (Pess et al, 2012, Peters 1996). Juvenile coho salmon densities at banks stabilized with LWD are generally greater than those stabilized using riprap in western Washington rivers (Peters et al. 1998).

The observation of similar, or even greater fish abundance at the RR site than the ELJ site contradict previous studies evaluating fish abundance at sites stabilized with RR and LWD. Peters et al. (1998) reported that juvenile salmonids densities were generally greater at sites stabilized with LWD than riprap. Based on a review of the literature, Schmetterling et al. (2001) reported that riprap banks generally supported fewer juvenile salmon. Differences observed in channel complexity, overhead cover, and the size of the riprap used to stabilize the RR site may have influenced the fish abundance results observed during the current study. The greater channel diversity provided more edge habitat which has been shown to be important to juvenile salmonids (Peters et al. *in prep*). There was also greater overhead cover at the RR site than the ELJ site. Peters et al. (*in prep*.) found that juvenile Chinook salmon abundance was related to overhead cover. In addition, overhead cover has been identified as an important habitat feature for fish (Helfman 1981). Finally, the riprap used to stabilize the RR site was relatively large, which has been show to support more juvenile salmonids than sites stabilized using smaller riprap or rubble (Lister et al. 1995).

Our CPUE and mark-recapture results may have been impacted by our sampling methods. We could only use a beach seine to sample a few specific locations within the study reaches. This resulted in much of the overall area in both study reaches not being sampled. Thus, our methods assume that fish would move substantially during the period between marking and recapture. Our PIT tagging and acoustic tracking data support this assumption. PIT-tagged fish tagged on one side of the river were later recaptured on the opposite bank. Acoustic-tagged steelhead also moved throughout the entire study reach on a daily basis, suggesting there would be adequate mixing of fish throughout the study area to allow fish not previously susceptible to our mark sampling effort to potentially be susceptible during the recapture sampling effort.

We attempted to assess survival at the two sites by PIT tagging fish as soon as they were large enough (early August) and then attempting to recapture these PIT-tagged fish through various methods (i.e., ‘mobile’ tracking, seining) to assess apparent survival. We consider this assessment to be apparent survival rather than true survival, since fish may have simply moved out of the study reach between the two surveys. Thus, we cannot differentiate between survival and emigration.

We recaptured similar numbers and percentages of fish PIT-tagged in early August during the early September survey at the ELJ and RR sites. However, mark-recapture population estimates for the number of PIT-tagged fish present at the two sites in September was greater at the ELJ site than the RR site. This provides more evidence that the CPUE surveys were likely biased, since CPUE for PIT-tagged fish was similar but mark-recapture estimate differed, results that were similar for the population assessments using CPUE and mark-recapture. Thus, apparent survival for juvenile coho salmon was greater at the ELJ site than the RR site. We found few reports where survival has been assessed in a river channel as large as the Hoh River; however, some reports were found for smaller streams and side channels. Giannico and Hinch (2007) found that the influence of instream wood in a side channel during the winter was influenced by the size of the fish at the start of the trial. Wood introductions had no impact on survival for trials with small fish and high rearing densities, but increased survival in treatments with larger fish and reduced densities. Water temperature has also been found to influence the impacts of wood on juvenile salmon survival. Giannico and Hinch (2003) found that juvenile coho salmon survival was increased with wood introductions in colder surface-fed side channels, but was slightly decreased in warmer ground water-fed channels.

Differences in size of fish at the ELJ and RR site were inconsistent, with fish being larger at one site during one survey and then smaller during the next survey. This result could be caused by differences in growth rates among the sites; however, we observed no differences in growth rate of recaptured PIT tagged fish at the two sites. Large wood has been shown to result in increased winter growth rates of juvenile coho salmon in side channel habitats (Giannico and Hinch 2003). However, Giannico and Hinch (2007) found no influence of wood treatments on growth rates of juvenile coho salmon in side-channel experimental units. As stated above, our inability to sample large sections of the study reaches could have contributed to this result, since we may have been more efficient at sampling one site relative to the other site. However, the observed fish movements suggest that many fish would have been equally susceptible to our sampling methods.

Acoustic tracking appeared to be an effective method of assessing general habitat use patterns of fish in the Hoh River. The tracking data showed that juvenile steelhead used nearly the entire study area within a 24-h period and moved extensively throughout the reach. In addition, several fish moved to adjacent habitats, some immediately after tagging, but others after holding in the array for several days. One fish was tracked for several days, moved upstream through a riffle/run habitat unit to the next pool upstream and then later moved back downstream into the array. Juvenile Chinook salmon did not move as much as the larger steelhead; however, they still used the entire river cross-section and made substantial upstream and downstream movements within the habitat unit.

Although stream rearing salmonids are generally thought to have limited movement (Gerking 1959; Rodriguez 2002), some authors have challenged this assertion (Gowan et al. 1994). Observations from this study would certainly challenge this limited movement 'paradigm' (so noted by Gowan et al. 1994). Much of the information related to fish movement has come from mark-recapture studies, which derives most of the information from recaptures, which bias the results toward limited movement behaviors (Gowan et al. 1994); although, movements greater than 200 m have also been observed during mark-recapture studies (Saunders and Gee 1964). This restricted movement paradigm may be the result of large scale movements followed by a return to a 'home site'. For example, Clapp et al. (1990) reported that a brown trout moved up to 1.5 km at night but then returned to the same home site the following morning. In addition, Diana et al. (2004) noted that a brown trout rested under cover during the day, moved away from cover at night and then generally returned to the same resting area the following morning. Mark-recapture experiments in these cases would conclude the fish were moving relatively small distances, when in fact the fish had moved extensively between 'observations'. The acoustic tracking system used during this study allowed us to monitor movement continuously to determine how fish were using habitat, which would have otherwise been very difficult in this turbid system. Our results, along with these other accounts of fish movement, suggest that the habitat unit may be too small of a spatial scale to assess the effectiveness of ELJs as a restoration and/or bank stabilization method since fish are using habitat at a larger spatial scale. Thus, we recommend that future assessments of ELJ's be conducted at a reach scale to more closely match habitat use patterns of juvenile salmonids.

Although the acoustic system used in this study provided useful data regarding the scale at which monitoring of ELJs should be completed, the usefulness for habitat use assessments should be viewed with caution. We obtained useful tracks for fish about 50% of the time that they apparently were in the array. This could result in biased conclusions regarding habitat use if the gaps occurred systematically within the array. For example, if fish used wood regularly during the course of the study, but they couldn't be detected when they were in the wood, an incorrect conclusion would be reached that wood wasn't important. We reviewed the gaps to determine if any systematic pattern appeared. There did not appear to be any systematic pattern in the gaps based on visual examination of the first and last point of each gap as well as comparisons of home ranges based on these points. Based on this we feel that our data is unbiased and although the fish were tracked only 50% of the time, the data provided a more accurate assessment of habitat use than simple point observations that are typically used (i.e., snorkeling or electrofishing surveys).

Although we believe habitat use patterns are unbiased, some of the habitat use data provided should be viewed cautiously. This is due to the accuracy of the tracking system (i.e., 0.5 m within the array to 3 m at a distance equal to one array width outside the array) and the change in habitat conditions in the Hoh River over these distances. Thus, habitat variables that change over short distances (i.e., <0.5 m) may be biased due to the accuracy of the system. For example, water depth at the site can change drastically (i.e., >100%) over a distance of 0.5 m in some cases. Thus, some point locations that are off by 0.5 m could result in depth changing by 100 percent or more. However, most of our habitat variables were relatively coarse and should provide unbiased results based on the accuracy of the system used.

At the secondary habitat scale, juvenile steelhead selected eddies, but generally used riffle and glide habitats less than expected based on availability. These results suggest that eddies (found only at the ELJ site) are an important habitat feature for juvenile steelhead. Juvenile steelhead also selected pool primary habitats during all four time periods. We could not find any reports of juvenile steelhead habitat use in relatively large rivers. However, our results are somewhat different than those provided by Roper et al. 1994 and Roni (2002). Roper et al. (1994) observed greater use of riffle habitat in the lower, wider (mean unit width ~14 m) of Jackson Cr., Oregon. Although our results vary from those reported by Roper et al. (1994), this could be due to differences in habitat availability since riffle habitats were not available in our study area. Roni (2002) assessed habitat use for streams in western Washington and western Oregon and reported that juvenile steelhead densities were greater in pools at night, but not during the day. Thus, our nighttime results are similar to that of Roni (2002), but the daytime results differ. These differences could be due to a variety of factors such as channel size, predator avoidance, and prey availability. It's important to note that the only primary habitats available during this study were a single pool and glide that was essentially a long pool tailout with relatively shallow and uniform depth.

Juvenile steelhead used intermediate depths during this study and the depths used were somewhat variable among the four time periods examined. Juvenile steelhead selected intermediate depths of 1-1.5 m and generally used the shallowest (<0.6m) and deepest (>3.5 m) areas less than expected based on their availability. Their selectivity was strongest during the dawn and daytime period. These results may be related to predator avoidance behavior. Schlosser (1987) and Power (1987) suggests that fish select habitats based on their size and related predation risk. Small fish are predicted to use shallow habitats to avoid piscivorous fishes, while the risk of predation from birds is relatively low due to their small size. They progressively move to deeper water as they grow because they are less vulnerable to piscivorous fishes but more vulnerable to birds. Selection of intermediate depths by steelhead parr in our study would fit this theoretical distribution. The size of juvenile steelhead tracked suggests they would be susceptible to predatory birds and would be safe from predation from all fish except bull trout. Large anadromous bull trout are known to inhabit the Hoh River (Brenkman et al. 2007) and would likely select the deepest habitats to avoid potential predators (i.e., otters, bears, humans). This would likely result in limited use of the deepest habitats by juvenile steelhead since bull trout, as an apex predator, would present a significant predator threat.

Juvenile steelhead generally used the area immediately adjacent to the banks less than expected and preferred areas an intermediate distance from the bank. This was likely partially due to their selection for intermediate water depths rather than their avoidance of the bank since water depth is generally shallow near the bank. Juvenile steelhead also appeared to select areas away from the bank when appropriate cover is available. Shirvell (1990) reports that steelhead parr preferred rootwad cover away from the shoreline. The apparent avoidance of shallow waters may be a similar predator avoidance response because areas near the shore would be more likely to contain some avian predators (i.e., blue heron (*Ardea herodias*)).

Juvenile steelhead generally used areas directly under the ELJs less than expected. This observation may be the result of balancing foraging efficiency and predator avoidance. Juvenile steelhead generally select areas with overhead cover (Shirvell 1990; Fausch 1993) with reduced light. These low light areas serve to obscure the fish from predators while improving their ability to see drifting prey originating from well-lit areas adjacent to the low light areas (Helfman 1981). However, selection for overhead areas with reduced light may not be as important in the turbid waters of the Hoh River which would limit light penetration. In fact, turbid waters may reduce feeding rates (Vinyard and Yuan 1996; Sweka and Hartman 2001) by reducing the visual abilities of fish (Berg and Northcote 1985; Gregory and Northcote 1993). It has also been suggested that juvenile salmonids select areas away from cover to improve their foraging efficiency (Wilzbach 1985), which would likely be even more important in turbid waters.

Instream wood is often thought to provide protection from predators (e.g., Dill and Fraser 1984; Abrahams and Healey 1993; Reinhardt and Healey 1997). The importance of instream cover may also be somewhat negated by turbidity, since turbid waters would provide cover for juvenile salmonids by inhibiting the visual abilities of potential predators. The other important function of instream LWD is to provide cover from fast current velocities (Bisson et al. 1987). The importance of this function at our ELJ site may have been somewhat negated by the fact that the project was completed in pool habitat with relatively slow current velocities. Finally, Peters (1996) found that at a fine scale, juvenile coho salmon were not located directly under cover, but their presence at large spatial scales were related to the presence of LWD. These fish would flee to LWD cover when attacked by predators. Steelhead parr in the Hoh River may be using the ELJs in a similar fashion; generally holding away from the ELJs until threatened by a predator.

In conclusion, the results of our studies and others indicate that ELJs can provide favorable habitat for juvenile salmonids. Regardless of how they are placed, they seem to offer significant hydraulic cover habitats, most notably deep pools and eddy habitats. The in stream cover they provide during summer low flows, however, is highly dependent on locating the ELJs as deep as possible to ensure much of the ELJ is submerged during the summer low–flow period. While the fish analysis section of our report was generally inconclusive, it did seem to indicate that coho salmon are the most favorably affected by the placement of ELJs.

Acoustic tracking data suggest that individual juvenile steelhead and juvenile Chinook salmon used the entire study area, often within a 24-h period. These observations suggest that ELJ monitoring for fish should be conducted at a reach scale to ensure the all the habitat used by the fish is included in the assessment. The acoustic system provided useful data for the scale at which ELJ monitoring should be completed. However, the system, although still useful, provides somewhat more limited data for habitat use. Juvenile steelhead tracked in this study selected secondary eddy habitats provided by the ELJs and selected the primary pool habitat. They used locations with intermediate depths and distance from the river bank. They also selected areas that were not directly associated with the ELJs. However, this may be due to the fact that ELJs were somewhat perched at summer low flow. Thus, they provided little complex instream wood cover relative to other ELJs we've monitored.

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Appendix A: Temperature

The following table summarizes the daily average temperatures as recorded by StowAway Tidbit temperature loggers attached to shallow and deep hydrophones.

	Temp C	
Date	Shallow	Deep
8/18/2009	21.8	15.7
8/19/2009	24.8	16.1
8/20/2009	19.8	15.1
8/21/2009	19.0	14.0
8/22/2009	20.0	14.1
8/23/2009	20.6	14.6
8/24/2009	19.6	14.7
8/25/2009	21.0	14.9
8/26/2009	20.8	14.3
8/27/2009	20.8	14.8
8/28/2009	17.7	14.1
8/29/2009	19.5	13.9
8/30/2009	19.4	15.0
8/31/2009	19.8	14.8
9/1/2009	17.7	15.5

Appendix B: Home Range

The figures below show the home range estimates (90%) for the remaining fish not shown in the body of the report.

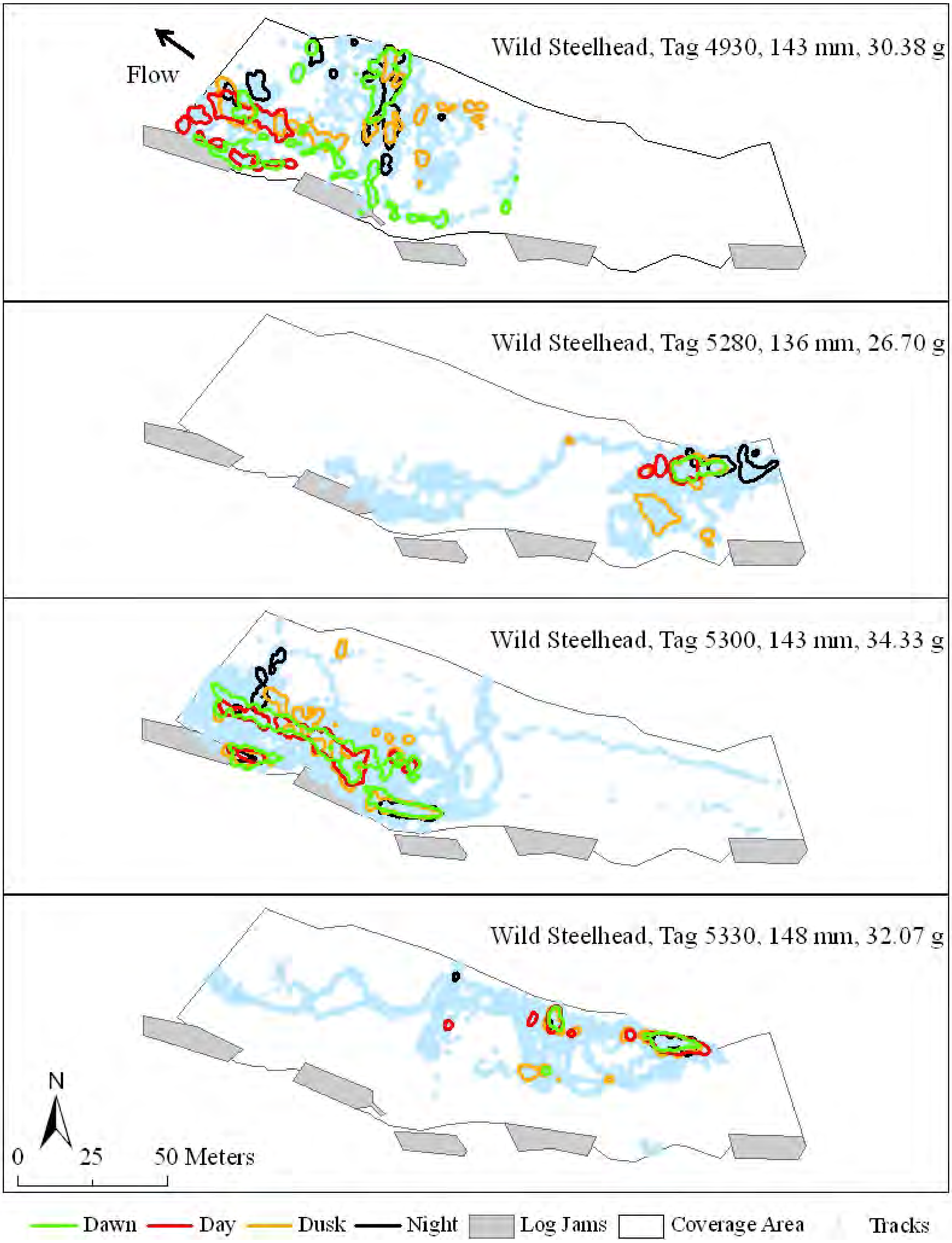

Figure B.1. Dawn, day, dusk, and night home ranges (90%) and all tracking points (Tracks) for four wild steelhead tracked during August 2009 at the Hoh ELJ site.

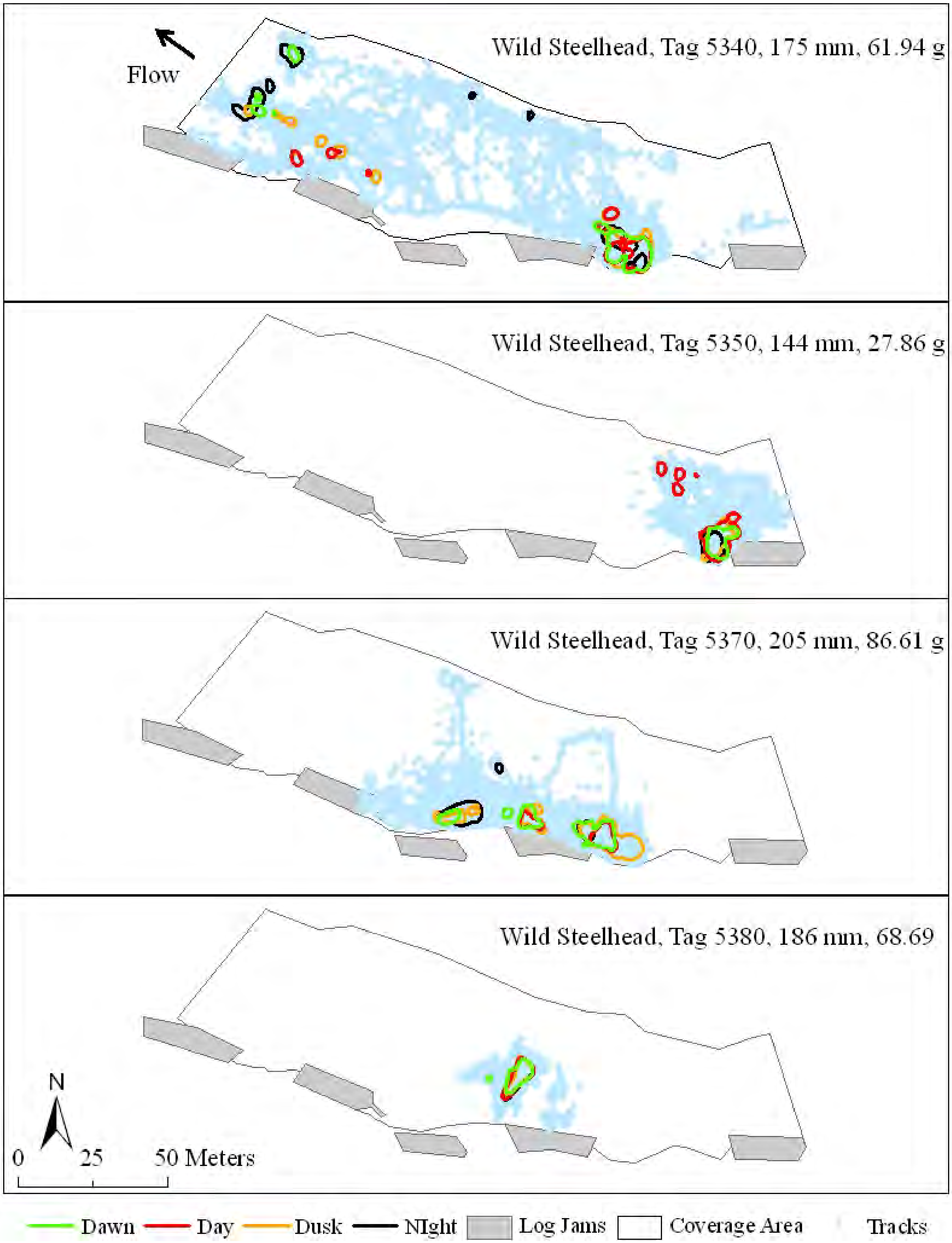

Figure B.2. Dawn, day, dusk, and night home ranges (90%) and all tracking points (Tracks) for four wild steelhead tracked during August 2009 at the Hoh ELJ site.

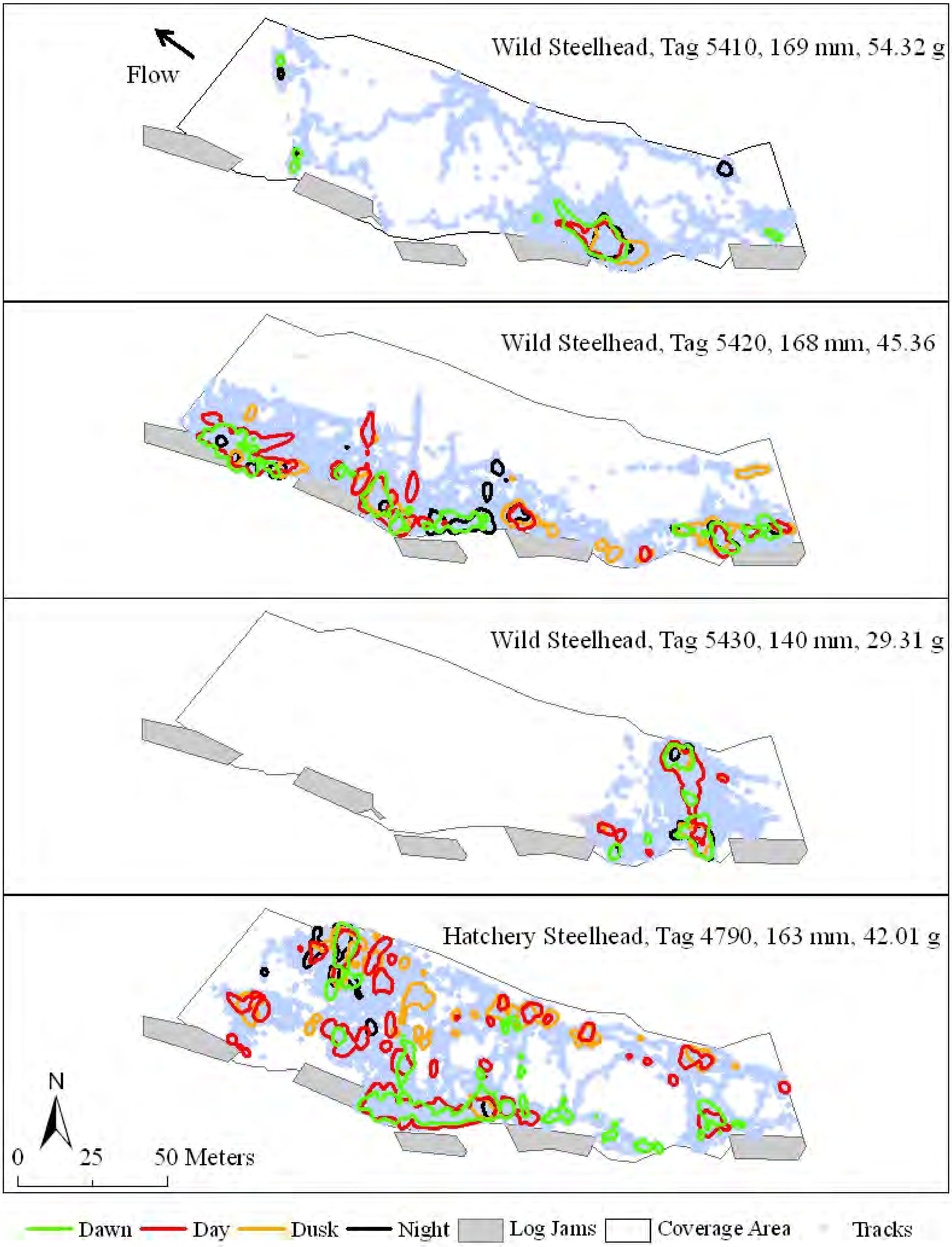

Figure B.3. Dawn, day, dusk, and night home ranges (90%) and all tracking points (Tracks) for three wild steelhead and one hatchery steelhead tracked during August 2009 at the Hoh ELJ site.

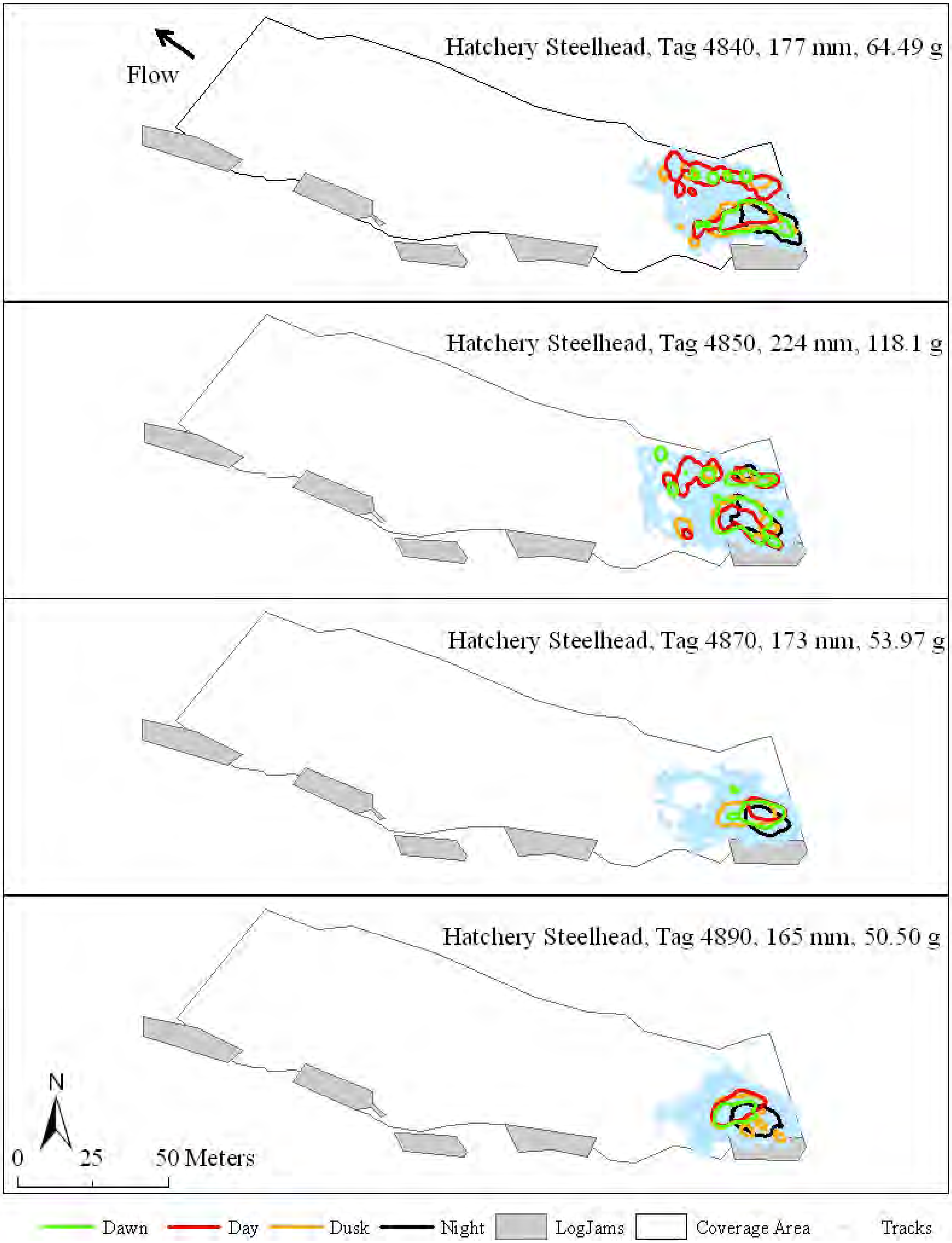

Figure B.4. Dawn, day, dusk, and night home ranges (90%) and all tracking points (Tracks) for four hatchery steelhead tracked during August 2009 at the Hoh ELJ site.

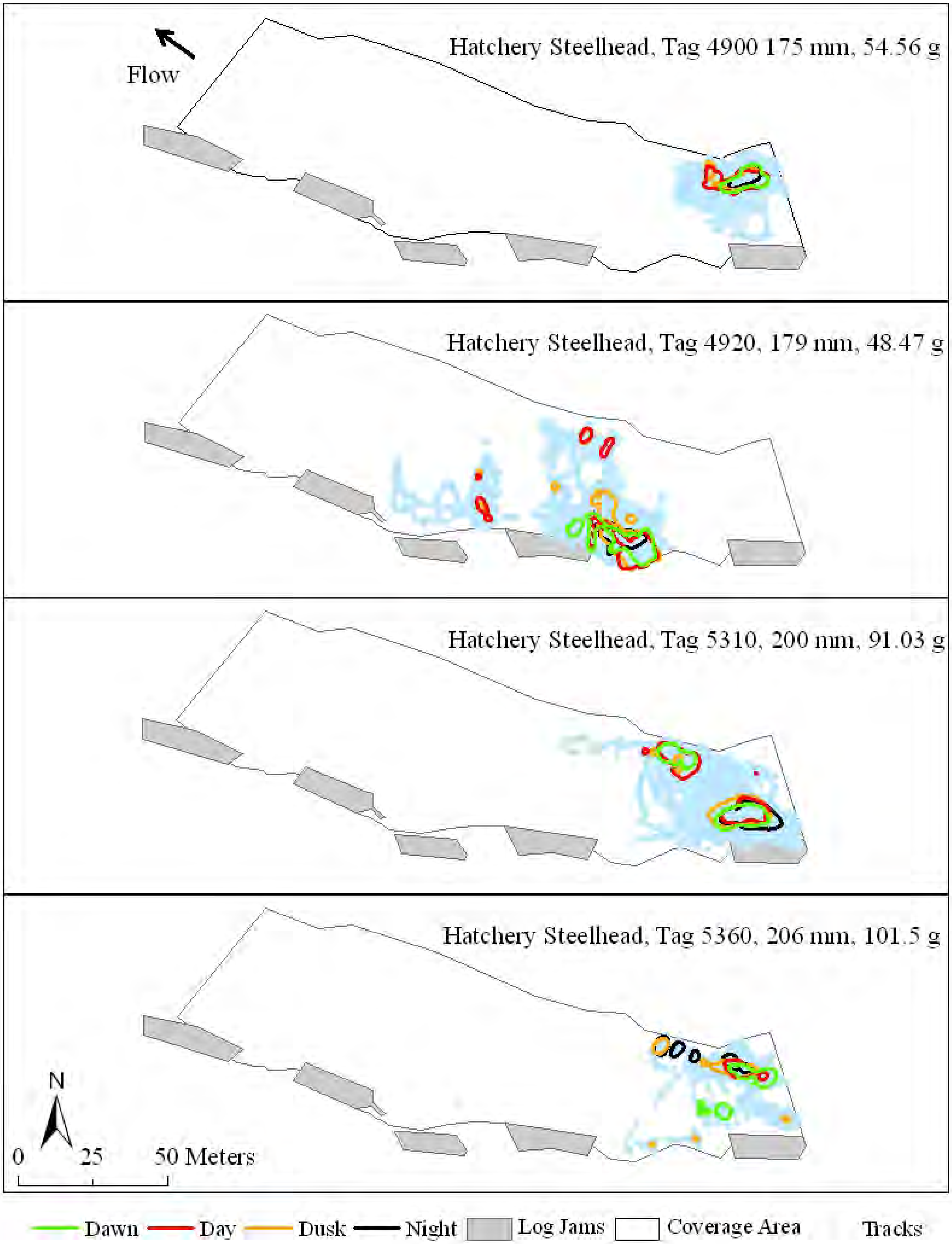

Figure B.5. Dawn, day, dusk, and night home ranges (90%) and all tracking points (Tracks) for four hatchery steelhead tracked during August 2009 at the Hoh ELJ site.

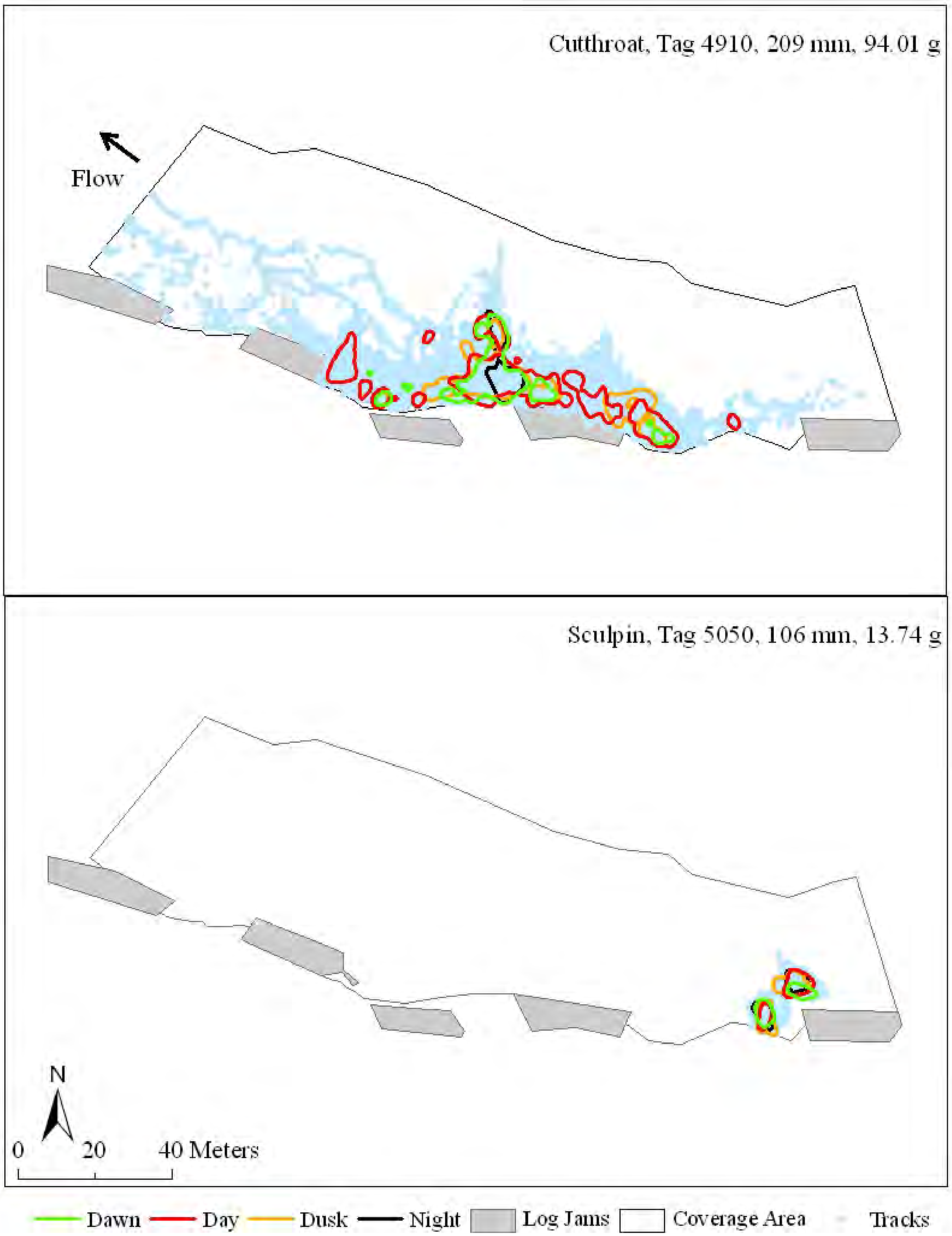

Figure B.6. Dawn, day, dusk, and night home ranges (90%) and all tracking points (Tracks) for a cutthroat trout and sculpin tracked during August 2009 at the Hoh ELJ site.