OVERWINTERING SITE SELECTION AND DISPERSAL STRATEGIES OF JUVENILE COHO SALMON IN THE BIG LAKE WATERSHED, ALASKA

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By

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THESIS

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ABSTRACT

The amount and quality of in-stream rearing habitat can influence the survival and growth of juvenile Pacific salmon. While seasonal habitat use of juvenile Coho salmon (*Oncorhynchus kisutch*) in freshwater environments has been examined in open-water environments during summer or in salmon systems at lower latitudes, understanding of overwinter habitat use in ice-bearing systems remains nascent. Juvenile Coho Salmon (JCS) remain in their natal streams for 1 - 4 years before smolting and demonstrate seasonal changes in habitat occupancy. Generally, fish occupy higher-flow main stem habitats in the summer and move to lower-flow off channel habitats in the winter. To date, there has been a lack of work focused on the habitat use and overwinter seasonal dispersal strategies of this species in regions with prolonged periods of freezing temperatures and persistent ice cover. In this study, passive integrated transponder (PIT) tags were used to track the seasonal movement of 3,305 JCS in two sub-drainages (Meadow Creek and Fish Creek) within the Big Lake watershed, located in Southcentral Alaska. The fish were tagged in 26 main-stem locations (13 Meadow Creek, 13 Fish Creek), 13 tributary locations (9 Meadow Creek, 4 Fish Creek), and nine lake locations (8 Meadow Creek, 1 Fish Creek) during the summers of 2011 and 2012, and were detected occupying seven off-channel overwintering areas for the duration of ice cover; the majority of which were lakes. The importance of distance from the estuary, dispersal direction, and fish length on overwintering area choice was examined using a classification tree framework owing to its flexibility in assessing the relationship between predictor variables and dispersal pathways in predicting overwinter area choices of tagged fish. Final fitted models were successful at describing overwinter location selection, producing low misclassification rates ranging from 9 - 13%. Dispersal direction was the most important predictor of overwintering area choice for fish

tagged in the Meadow Creek sub-drainage for both years, and distance from the estuary was the most important for the Fish Creek sub-drainage. The consistency of model results across years and drainages demonstrated that overwinter redistribution behavior of JCS was regular and predictable, emphasizing lakes as strongly preferred overwinter habitat as well as indicating that fish generally found their way to the nearest overwinter habitat proximal to their summer rearing locations. The observed seasonal migration patterns from summer rearing locations to off-channel overwintering areas such as lakes is consistent with previous published findings; however, this is the first known study to track the individual-level movements of JCS using PIT tag technology in a high latitude, seasonally ice-covered watershed.

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INTRODUCTION

Relative to all their life phases, Pacific salmon (*Oncoryhynchus spp.*) survival rates are lowest during juvenile freshwater residency. Bradford (1995) found a 36% survival rate within all freshwater life stages of juvenile Pacific salmon (egg-smolt). Juvenile Coho Salmon (*O. kisutch*, hereinafter JCS) are thought to maximize survival and growth rates by seasonally migrating (Quinn and Peterson 1996; Kocik and Ferreri 1998), but the relative importance of seasonal habitats on the population structure of JCS is poorly understood. Anthropogenic impacts to freshwater ecosystems may further reduce survival rates during juvenile residency by preventing migrations between seasonal habitats, especially if there is a loss of habitat connectivity (Beamish and Bouillon 1993; Beechie et al. 1994; Gibson et al. 2005). The production of juvenile salmon in freshwater habitats is dependent upon habitat connectivity, as juvenile salmon production potential for a watershed is limited by the amount of available and exploitable habitat (Marshall and Britton 1990).

Barriers which prevent seasonal migrations between habitats and cause habitat connectivity loss come in many forms, both natural (e.g. waterfalls, high gradient, and beaver dams) and anthropogenic (e.g. culverts and dams). Culvert surveys have been ongoing in the Matanuska-Susitna valley (Mat-Su), in Southcentral Alaska since 1999, and 60% of the approximately 500 surveyed culverts were found to be barriers to juvenile salmon migration at certain flows (Mat-Su Basin Salmon Habitat Partnership 2011; Dekker and Rice 2016). Restoration efforts over the last 18 years on barrier culverts have restored habitat connectivity, yet no studies have investigated if restored habitats are subsequently used by juvenile salmon. An understanding of seasonal movements, seasonal habitat preferences, and dispersal strategies between seasonally used habitats for all life stages and species of salmon is critical for successful management (Cunjak 1996), especially when managing for habitat restoration efforts such as fish passage improvement. This thesis addresses a poorly understood component of juvenile salmon freshwater habitat use in high latitude systems and examines the overwinter seasonal distribution and habitat use of JCS in a region with prolonged periods of freezing temperatures and persistent ice cover.

Among their freshwater residency life stages, winter conditions are believed to strongly influence the survival and population dynamics of juvenile salmon, yet the overwintering ecology of these species is not well studied (Reynolds 1997; Huusko et al. 2007). This data gap in overwintering ecology is presumably associated with the difficulty of sampling aquatic habitats with extensive ice cover during winter months. In Southcentral Alaska, average low air temperatures are at or below freezing for seven months of the year (October - April), resulting in long periods of ice cover in freshwater aquatic systems. Previous overwintering studies involving stream salmonids were carried out in areas where air and water temperatures rarely reach freezing and ice cover is absent (Swales et al. 1986; Swales and Levings 1989; Quinn and Peterson 1996); however, advancements in fish-tracking technology such as passive integrated transponders (PIT) tags and in-stream antenna arrays, have improved the ability to track fish year round, as tag deployment can be done during the ice-free summer months (May -September) coupled with passive tracking of tagged fish using in-stream antenna arrays during periods of ice cover (Greenberg and Giller 2000; Roussel et al. 2004; Gerken and Sethi 2013).

In Southcentral Alaska, three species of Pacific Salmon generally reside for at least one year in freshwater before migrating to the ocean as smolts; there are some documented cases of three to four years of freshwater residency (Sandercock 1991). Coho Salmon, Chinook Salmon (*O. tshawytscha*), and Sockeye Salmon (*O. nerka*) all contribute to commercial, subsistence, sport, and personal use fisheries. Huusko et al. (2007) proposed that extended freshwater residency (e.g. more winters) exposes juvenile salmon to multiple overwintering “bottlenecks”, defined as a critical period during which juvenile salmon population density is reduced by mortality resulting from either density-dependent or density-independent processes. In watersheds with reduced habitat connectivity due to barriers like culverts, extended freshwater residency may result in higher winter mortality and a loss in the production potential as suitable winter habitats become limiting.

Juvenile salmon which overwinter in freshwater have been shown to exhibit redistribution between summer rearing habitats and overwintering habitats, generally during late summer and early autumn (Bustard and Narver 1975; Cunjak 1996; Renyolds 1997; Bramblet et al. 2002). Seasonal habitat redistributions have been documented for JCS in the Pacific Northwest, where juveniles disperse from main channel summer rearing locations to off-channel habitats such as backwater sloughs, wetland complexes, and beaver ponds. This is thought to be an avoidance response to unfavorable winter conditions in summer rearing areas (Swales et al. 1986; Heggenes and Dokk 2001). Off-channel ice-free lakes were also found to support populations of overwintering JCS in British Columbia (Swales et al. 1988). Sethi and Benolkin (2013) found JCS migrated to shallow lakes in late summer and fall in Southcentral Alaska, presumably to overwinter. To date, seasonal habitat use studies have yet to focus on the overwintering ecology and preferred overwintering habitats of JCS in areas of prolonged winter and significant ice cover, such as in Southcentral Alaska.

This thesis aims to identify freshwater habitats that are occupied by JCS during ice-covered winter months, and to explore the dispersal patterns of individual fish from summer rearing habitats to winter rearing habitats in the Big Lake watershed in Southcentral Alaska. Passive integrated transponder tags were implanted into JCS during the ice-free summer months, and the fish were subsequently tracked using recapture trapping and in-stream PIT tag antenna array sites. The primary objectives of this thesis are: 1) to identify locations that support successful overwintering of JCS within the Big Lake watershed; 2) to estimate the proportional occupancy of tagged JCS within identified overwintering areas; and 3) to classify individual level dispersal behaviors in relation to overwintering area selection by tagged JCS. In addition to addressing current information gaps regarding the overwinter ecology of juvenile salmon in high latitude systems, results from this thesis will also directly inform prioritization efforts for ongoing watershed connectivity restoration activities designed to address freshwater life stage needs for Pacific salmon.

STUDY AREA

The Big Lake watershed, located west of the city of Wasilla, is in one of Alaska's most rapidly developing areas (US Census Data Bureau 2010 Census). The Mat-Su Basin Salmon Habitat Partnership (2009) rated both the *biological value* and *vulnerability to development* of this system as "extremely high." The watershed is approximately 300 km^2 and composed of two sub-drainages: Meadow Creek and Fish Creek, with Big Lake proper separating the two (Jokela et al. 1991; Hogan 1995; Figure 1). The Meadow Creek sub-drainage is the most extensive (drains 176 km^2) and is composed of numerous lakes and small tributaries. Meadow Creek is a low gradient, 29 km long, meandering wetland/ peatland system, surface flow characteristics are primarily composed of glides, with abundant in-stream vegetation. In-stream sediments are dominated by sand, clay, and organic materials; gravel and cobble sediments occur, but are patchy and located in areas with groundwater exchange or with higher in-stream gradients. Off-channel habitats include beaver ponds, lakes, and narrow entrenched tributary channels (Curran and Rice 2009).

Fish Creek, the only outflow from Big Lake, meanders 23 km south and terminates in the Knik Arm of Upper Cook Inlet. The Fish Creek sub-drainage is much smaller than the Meadow Creek sub-drainage (draining 81 km^2). Similar to Meadow Creek, Fish Creek is a low gradient, meandering wetland system, but is primarily composed of riffle and pool tail-out surface flows with patchy in-stream vegetation. In-stream sediments are dominated by gravels and cobbles, with occasional boulder patches. Fine sediments are present but restricted to the edges of main channels and a few areas with low gradient run habitat. Off-channel habitats are similar to those of Meadow Creek but are less abundant. Threemile Creek is a major tributary connecting Fish Creek to Threemile Lake. Several other small tributaries and groundwater exchange points contribute to the Fish Creek surface flow, but are difficult to identify because they lack well defined channels with visible surface flow.

Big Lake proper, separating the Meadow and Fish Creek sub-drainages, is one of the largest lakes in the Mat-Su valley, with a surface area of 12.6 km^2 and an average depth of 9.1 m. Big Lake is composed of two major basins; the west basin is a deep, oligotrophic basin, with a maximum depth of approximately 27 m, and the east basin is shallower with a maximum depth of 15m and is classified as mesotrophic (Woods 1985). The west basin is the larger of the two, making up 53.7% of the lake's 12.6 km^2 surface area; however, both Meadow and Fish Creek sub-drainages are located within the east basin (Woods 1992). Big Lake contains 22 islands and has a shoreline length of 27.1km exclusive of the islands.

The Big Lake watershed supports spawning populations of Sockeye Salmon, Coho Salmon, Pink Salmon (*O. gorbuscha*), and, to a lesser extent, Chum Salmon (*O. keta*). Several resident species are also found in the Big Lake watershed, including: rainbow trout (*Oncorhynchus mykiss*), arctic char (*Salvelinus alpinus*), burbot (*Lota lota*), whitefish (*Coregonus spp*), three-spine stickleback (*Gasterosteus aculeatus*), sculpin (*Cottus spp*), longnose sucker (*Catostomus catostomus*), and Pacific lamprey (*Entosphenus tridentatus*). Invasive northern pike (*Esox lucius*) and Alaska blackfish (*Dallia pectoralis*) were documented for the first time in the watershed, in 2006 and 2015, respectively.

METHODS

Sampling Site Selection

Minnow traps were used to collect JCS for tagging in three general habitat types: main-stem, tributary, and lakes. Main-stem habitats were defined as the main channels of both Meadow and Fish Creeks, lake habitats were standing bodies of water, and tributary habitats connected lakes to the main-stem. Collecting and tagging fish in these three habitat types allowed the tracking of tagged fish across general habitat categories within both sub-drainages (e.g. Ebersole et al. 2006). All three habitats are present in both the Meadow and Fish Creek sub-drainages within the Big Lake watershed.

Trapping and tagging occurred within a 14 km stretch of main-stem Meadow Creek, four tributaries, and eight lakes in 2011 - 12. In 2012, the study was expanded to include the Fish Creek sub-drainage. Approximately 10 km of main-stem Fish Creek were sampled from the outflow of Big Lake to the Alaska Department of Fish and Game (ADFG) weir site, located approximately 1.4 km upstream of the confluence with Cook Inlet. Threemile Creek and Lake were also sampled within the Fish Creek sub-drainage. Sampling for JCS occurred in 26 main-stem habitat locations (13 Meadow Creek; 13 Fish Creek), 13 tributary habitat locations (nine Meadow Creek; four Fish Creek), and nine lake habitat locations (eight Meadow Creek; one Fish Creek; Figure 2). Fish were collected at each location on a bi-weekly sampling schedule, resulting in approximately two sampling events per location per month. Sampling locations within the Meadow and Fish Creek sub-drainages were randomly selected, although these areas were constrained to known Coho Salmon spawning areas identified during a spawning distribution radio telemetry study completed by the USFWS in 2009 and 2010 (Figure 2; USFWS, unpublished data). This constraint was used to ensure the capture of JCS emerging from known spawning locations.

The total area of each sampling habitat (main-stem, tributary, and lake) was not equal, so a proportional probability sampling design was used, setting the number of sampling events within habitats based upon the proportional contribution of each habitat within the study area (Hankin 1984). Each sampling location, regardless of habitat type, was parsed into equal-sized sub-sections, measuring approximately 250 m^2 of water surface area. To maintain consistency between main-stem and tributary habitats, average channel width was assumed to be 10 m for main-stem, and 3 m for tributary. As a result, each sub-section was 25 m long in main-stem habitats and 83 m long in tributary habitats. All main-stem habitat sampling locations consisted of 15 sub-sections with an overall length of 375 m. Tributary sampling locations consisted of five sub-sections with an overall length of 415 m. In lake habitats, each sampling location was randomly assigned 15 sampling sub-sections located in the littoral zone, each of which was approximately 250 m^2 of surface area.

Juvenile Coho Salmon Capture and Tagging

Fish trapping across all habitat types utilized 6 mm wire mesh minnow traps baited with salmon roe. Traps were soaked for a minimum of 60 minutes following field methods demonstrated to be the most effective and efficient for sampling JCS (see Swales 1987). Traps were baited with approximately 2 g of sodium sulfite-free salmon roe in perforated plastic canisters to prevent ingestion and unintended mortality (see Clements et al. 2011).

In main-stem and tributary habitats, two minnow traps were deployed per sampling sub-section, approximately 1 m upstream of areas with suspected JCS occupancy. Areas of suspected JCS occupancy in main-stem and tributary habitats was identified based upon the author’s field experience and from descriptions in published literature; for example, Bryant (2000) describes JCS habitat as characterized by large woody debris, undercut banks, rootwads, and deep pools.

Lake habitat trap deployment differed from the main-stem and tributary deployments. Sub-sections within lake habitats were each sampled with a five minnow trap cluster. Five-trap clusters, each consisting of a center trap plus four additional traps deployed in the four cardinal directions spaced no greater than 9 m from the cluster center, were deployed on the bottom of each lake subsection at randomly preselected sampling location points. The higher trapping intensity in lake subsections relative to main-stem and tributary habitats was to correct for potentially decreased minnow trap effectiveness in lake littoral zone (see Lapointe et al. 2006).

Trapped JCS were anesthetized in a 40 mg/l solution of tricane mesylate (MS-222) (Schoettger and Julin 1967), measured (fork length [FL], mm), and wet weighed (nearest .01 grams, 2012 only). All fish greater than 55 mm were injected with a 12.5 mm long, 2.1 mm diameter, full duplex PIT tag in the peritoneal cavity, using a Biomark MK-25 (Biomark, Inc., Boise, ID) implant gun with a pre-loaded 12-gauge needle. Adipose fins of tagged fish were also removed to aid in identification during recapture events. After tagging, fish were placed in a freshwater bath and monitored for 20 - 40 minutes during recovery before being released at their capture location. Non-target species (e.g. fish other than JCS) were enumerated and immediately released.

Juvenile Coho Salmon Recapture and Movement Tracking

Movements of tagged JCS were determined using physical recapture in minnow traps deployed during repeat sampling event locations described above in the fish capture and tagging methods sub-section, and detection by in-stream pass-through PIT tag antenna sites. Seven PIT tag antenna sites were located within the Big Lake watershed, four of which were in the Meadow Creek sub-drainage and three in the Fish Creek sub-drainage (Figure 2). Within the Meadow Creek sub-drainage, two sites were located on main-stem sections of Meadow Creek, and the remaining two on the Lucille Creek and Herkimer Creek tributaries. The Fish Creek sub-drainage also had two antenna sites located on main-stem Fish Creek and one on the only major tributary - Threemile Creek. Main-stem antenna sites bounded the main-stem sampling locations in both sub-drainages. Antennae sites were strategically placed to divide Meadow Creek and Fish Creek sub-drainages into sections encompassing key watershed features in order to provide opportunity for inference about broad scale dispersal patterns with the limited set of arrays available for deployment.

Antennas were constructed following Steinke et al. (2011; Appendix 1) and were operable during both open-water and ice-covered seasons. Antennas were constructed using schedule 80 PVC, which is thicker than the more commonly used schedule 40 PVC, to ensure they could withstand ice events. The thickness of the PVC does not affect the antennas' ability to detect and decode PIT tags (Steinke et al. 2011). Each antenna site consisted of two to three separate antennas affixed to the in-stream substrate, positioned perpendicular to water flow. Antennas were configured to cover the entire wetted channel, and each group of antennas is hereafter referred to as an antenna array and the location is called an antenna site. Antenna arrays were orientated in one of two different ways: (1) Three antennas affixed side by side to encompass wider main-stem stream channels, or (2) two antennas each wide enough to encompass the entire wetted channel positioned parallel to one another 3 m apart. The parallel antenna configuration permitted detection of tagged fish directional movement (upstream or downstream). However, directional movement through the side by side antennas had to be inferred using the location of the tagging event or most recent tag detection relative to the antenna site. Antenna array sites were tested for detection efficiency monthly by releasing a series of neutrally buoyant drones each containing a PIT tag into the water above each antenna such that they passed through the antennas. Physical descriptions of each antenna array site including methods and results for antenna detection efficiency are addressed in Appendix 1.

Data Analysis

Juvenile Coho Salmon Size Distribution Comparisons

Minnow traps are effective passive JCS sampling devices. Their performance in deeper and more complex habitats is superior to more traditional gear types such as electrofishing (Habera et al. 1996) and seining (Pierce et al. 1990). However, they are limited to sampling smaller size classes (<150 mm, FL), and may not sample size classes within the population with equal probabilities through time. In order to determine if the JCS PIT tagged population was representative of the distribution of size classes captured in minnow traps, the length frequency distributions for all JCS captured and not PIT tagged was compared to the length frequency distributions for all of the PIT tagged individuals using the bootstrapping version of the Kolmogorov-Smirnov test. The ks.boot() function from the package *matching* (Sekhon 2015) was used in the R statistical software environment (version 3.2.2; R development core team 2010), 1,000 bootstrap iterations were run. Due to the size limitation for PIT tagging (minimum 55 mm, FL), both distributions were constrained to only represent JCS that were greater than the minimum tag-size threshold. Additionally, paired two sample *t*-tests were used to determine if the average size of captured JCS differed between years in Meadow Creek, and between sub-drainages in 2012; *t*-tests were run using the base packages in the R statistical software environment (version 3.2.2; R development core team 2010).

Movement Analysis

To determine coarse scale temporal movement patterns of JCS between habitats (main-stem, tributary, and lake), catch per unit effort (CPUE; JCS captured/hour) was computed as a relative index of abundance across sampled habitats. Changes in the relative abundance captured in each habitat type through time (e.g. each sampling month) provide the basis for inferring that JCS use different habitats seasonally. Minnow trapping catches are typically normalized to CPUE using individual trap soak times. However, because sampling effort was unequal between habitats and locations due to the proportional probability sampling design, the monthly total soak time was the metric of effort for this comparison. A monthly minnow trapping CPUE was calculated for each habitat type by dividing the number of JCS captured, by total minnow trap soak time within each habitat.

The movement timing of tagged JCS was examined using detections at antenna array sites. Detections were expressed as the number of unique PIT tags recorded at each antenna site per day. Unique tags were used to eliminate artificial inflation of detections due to tagged fish holding in range of the antenna for an extended time period. This data was used to create cumulative distributions of unique detections by day starting on 1 July, and ending on 31 December in both 2011 and 2012. Quartiles and the 90th percentile dates were calculated for the cumulative unique detection distribution to determine the median date and date range in which JCS were detected at antenna sites.

Individual movement profiles were constructed for each tagged JCS using the tagging location as a starting point and as the assumed summer rearing location, and each subsequent detection chronologically thereafter to determine the arrival at overwintering areas. Thus, tagging, recapture, and antenna detection data of PIT tagged JCS was used to create individual movement profiles which were used to determine overwintering areas within the Big Lake watershed occupied by JCS for the duration of the ice-covered winter months. Movement profiles were used to classify individuals into one of three categories of overwintering area selection. First were the “dispersers:” these individuals had movement profiles showing redistribution from a summer rearing area to different area for overwintering. Next were “residents:” individuals that overwintered in the same area in which they were tagged. Finally, fish with profiles that were incomplete and inconsistent with dispersion or residence were classified as “unknown.” Additionally, movement profiles were not constructed for tagged fish with only one detection (the tagging event). They were removed from the study as these individuals were assumed to have died after tagging; perhaps due to tagging-related or natural mortality. See Appendix 2 for examples of these three movement profiles.

Overwintering areas identified by the winter-long occupancy of “dispersers” or “residents” were described by their physical location within the watershed, the general classification of habitat types present, and the precision (drainage size) with which the overwintering area could be identified. In addition, the proportional occupancy of tagged fish in each overwintering area was calculated by dividing the number of tags determined to be in each overwintering area by the total number of PIT tags in all overwintering areas.

Classification Tree Modeling of Overwinter Location Choice

A recursive partition machine learning technique known as *classification and regression trees* (CART; Breiman et al. 1984) was used to assess the association between a set of dispersal predictor variables and overwintering area choice in the Big Lake watershed. Classification tree analysis was implemented to facilitate interpretation of the data in cases where predictor variables have nonlinear (e.g. thresholds) or interactive associations with overwinter location choice. The three predictor variables calculated for each fish included: 1) summer rearing area’s distance from the estuary (DE), 2) taxis direction (TD), and 3) fork length (FL). Distance from the estuary was calculated in river meters for each tagged fish, using an origin-destination-matrix created within ArcGIS v 10.3 (ESRI 2011). The matrix uses point and line shapefiles to create a network of lines (the streams) with summer rearing locations represented as points along the lines. Distances between all summer rearing location points and an estuary point at the confluence of Fish Creek and the Knik Arm were calculated and exported as a matrix. Taxis direction was determined using tagging location, recapture, and antenna detection data from movement profiles. Tagging location was used as the starting point for all TD observations; all subsequent detections (recapture and antenna) in each JCS movement profile were assessed to assign a TD. Tagged JCS were assigned to one of three unique TD groups, which were defined as: 1) upstream taxis: the individual was only observed dispersing upstream, 2) downstream taxis: the individual was only observed dispersing downstream, and 3) complex taxis: the individual was observed dispersing using any combination of upstream and downstream movements.

Classification trees are built using a recursive partitioning algorithm which starts with an initial split of the predictor variable data (e.g. DE, TD, FL). This splitting node is generally referred to as the “root” node as it is the base of the tree. Each partitioning split off the root node is made to maximize the homogeneity within groups within in each respective branch and maximize heterogeneity for groups across branches. This iterative splitting process results in branches which end in “leaf” nodes representative of the proportion of JCS choosing each respective overwintering area using the dispersal pathways as partitioned by predictor variable(s) along branches. The leaf node represents the proportion of individuals predicted to have chosen each respective overwintering area based upon the classification tree branching structure.

Classification tree analysis was cast in a random forest framework (e.g. Cutler et al. 2007 for applications in ecology). Random forests are boot-strapped combinations of hundreds or thousands of trees which combine predictions to improve classification accuracy. In this framework, for any respective tree within the ensemble of fitted trees, one third of the data is held out for model validation, termed the “out of bag” (OOB) sample, whereas the remaining two thirds of the data are used for model training. Error estimated using these samples is the OOB mean squared prediction error. Random forests were built in the R statistical software environment (version 3.2.2; R development core team 2010). All classification tree analyses were run with 20,000 boot-strap iterations using the *randomForest* package in R (Liaw and Wiener 2002) to obtain classification accuracy based upon OOB estimates, and unbiased predictor variable importance (VI) measures. All other classification tree model options using randomForest() calls were restricted to default parameters. Predictor VI assesses the reduction in model accuracy associated with randomly permuting a given predictor variable’s information amongst sample data. Briefly, the difference in OOB prediction error is calculated for each tree with predictor data ordered according to observed data and with one predictor’s data permuted. This difference is averaged over all trees and normalized by the standard deviation of differences for each predictor in turn (thus allowing for VI in units comparable across predictor variables). Subsequently, predictor variables can be ranked by their contribution to model accuracy in predicting OOB validation data and thereby assessed for their importance in explaining the modeled data (Liaw and Wiener 2002).

To aid in the visual interpretation of the random forest results and dispersal strategy pathways, a single tree was built using all sample data with the *rpart* package in R (Therneau and Atkinson 2009). Classification tree models were built separately for each sub-drainage (Fish Creek 2012 and Meadow Creek 2011 and 2012) to determine whether dispersal strategies to overwintering areas were consistent within the Big Lake watershed as a whole. The fish classified as “dispersers” were the only fish used to populate these models, as “residents” did not disperse from summer rearing locations by definition; additionally all overwintering areas that had less than 10 JCS disperse to them were removed from the model due to low sample size effects on OOB draws. The excluded overwintering areas include: Lucille Creek and Twin Lake from the Meadow Creek sub-drainage in 2011, Lucille Creek and Stephan Lake from the Meadow Creek sub-drainage in 2012, and Lucille Creek and Blodgett Lake from the Fish Creek sub-drainage. The full classification model structure is as follows:

Overwintering Area ~ DE + TD + FL.

RESULTS

Juvenile Coho Salmon Capture and Tagging

During the summers of 2011 and 2012 a total of 11,028 minnow trap sets (12,076 soak hours) in the Big Lake watershed captured 26,453 JCS (2.19 JCS/hour). A total of 4,565 fish (17.3%) were captured in 4,807 minnow trap sets (5,289 soak hours; 0.86 JCS/hour; Table 1) in the Meadow Creek sub-drainage in 2011, with 4,311 (16.3%; 2,875 traps; 3,299 soak hours; 1.31 JCS/hour) captured in 2012. The remaining 17,577 fish (66.4%) were captured in 3,346 minnow trap sets (3,488 soak hours; 5.04 JCS/hour) within the Fish Creek sub-drainage in 2012. PIT tags were deployed into 6,224 JCS (3,657 in the Meadow Creek sub-drainage and 2,567 in the Fish Creek sub-drainage, Table 2, Table 3). The first PIT tag was deployed on 6 July and the last on 20 September in 2011. In 2012, the first PIT tag was deployed on 19 June and the last on 3 October. Additionally, 51 juvenile Sockeye Salmon, 9,809 rainbow trout, 103,419 three-spine stickleback, 10 longnose suckers, 1,283 sculpin, 22 lamprey, and two arctic char were also captured (Table 4).

Juvenile Coho Salmon Size Distribution Comparisons

Pooling all fish collected with minnow traps across Fish Creek and Meadow Creek drainages and study years, tagged JCS fork lengths did not differ significantly from the fork lengths of all non-tagged JCS ($D = 0.125$, p-value = <0.005; Figure 3; Figure 4; Figure 5). Fish captured in the Meadow Creek sub-drainage in 2011 were an average of ten millimeters longer ($\bar{x} = 81.2$ mm, sd = 18.04, n = 4,174) than those captured in Meadow Creek in 2012 ($\bar{x} = 70.9$ mm, sd = 19.4, n = 4,197, two sample t = 25.1, df = 8,330, p-value = <0.005). Meadow Creek sub-drainage fish were 7 mm longer ($\bar{x} = 70.9$ mm, sd = 19.4, n = 4,197) on average than those sampled in the Fish Creek sub-drainage ($\bar{x}$ = 63.9 mm, sd = 17.2, n = 16,687) in 2012 (t = -21.3, df = 5,951, p-value = <0.005).

Juvenile Coho Salmon Recapture and Movement Tracking

In 2011, a total of 155 unique PIT tagged JCS were recaptured in Meadow Creek in minnow trap sets. The first recapture was on 11 July and the last on 19 October (Table 5). In 2011, a total of 165 minnow-trapping recapture events occurred, as ten individuals were recaptured twice. In 2012, 895 unique PIT tagged JCS were recaptured during minnow-trapping, of which 805 (90%), were captured in the Fish Creek sub-drainage, the remaining 90 (10%) recaptures were caught in the Meadow Creek sub-drainage. Only 19 (21%) of the Meadow Creek sub-drainage recaptures in 2012 were fish that were tagged in 2011, the remaining were tagged during 2012. The first minnow-trap recapture events of 2012 occurred on 4 April in the Meadow Creek sub-drainage, and on 21 June in the Fish Creek sub-drainage. The final minnow-trap recaptures of 2012 occurred on 3 October and 4 October, 2012 for Meadow and Fish Creek sub-drainages, respectively (Table 5). A total of 1,229 recapture events occurred during 2012; 253 individuals were recaptured more than once. All minnow-trap recaptures indicated that tagged fish exhibited a high level of summer rearing location site fidelity, where 85% (1,185) of all individual trap-based recaptures in 2011 and 2012 occurred in the same sampling location as the initial tagging event. Only 13% (183) of summer trapping recaptures migrated between sampling locations, and 2% (27) of recaptures migrated to sampling areas deemed overwintering areas before October (Table 6).

Due to the low percentage of trap-based recaptures in overwintering areas, movement detection at antenna sites was critical for determining the redistribution of JCS from summer rearing locations to overwintering areas. The antenna arrays sites successfully detected tagged fish migrating throughout the study area. The Meadow Creek arrays detected 2,955 PIT tags (1,029 unique JCS) in 2011 (Figure 6). In 2012, 5,125 PIT tag detections (2,436 unique JCS) were recorded throughout the Big Lake watershed (Figure 7). Of these, 2,493 were collected by the four Meadow Creek sub-drainage antennas array sites and 2,632 by the three Fish Creek sub-drainage antenna array sites

Movement of tagged fish through antenna sites was detected year round. However, a distinct peak occurred between 31 August and 30 September; this month-long period accounted for 50% (between quartiles) of the total number of unique detections at antenna sites in 2011 (Figure 6). This observed increase in antenna detections coincided with increased CPUE during trap-based capture of JCS in tributary and lake habitats, and decreased CPUE in main-stem habitats (Figure 8). This trend is indicative of a redistribution of tagged individuals from summer main-stem habitats to lake habitats in the winter over a relatively short period at the end of the summer season. The remaining 15% (to reach the 90^{th} percentile) of the 2011 detections at antennae array sites were recorded over a 41 day period after 30 September. Movements in 2012 were also detected year round, with a distinct peak of detections occurring between 15 August and 17 October, indicating a longer period of summer-to-winter habitat redistribution (approximately a two-fold increase in the number of days to account for the inner 50% quartile range of unique detections at antennae sites as compared to 2011). However, the day corresponding to the cumulative 90^{th} percentile of unique antennae detections was the same as 2011 and 2012, occurring on 10 November (Figure 7). As in 2011, the increased rate of detections at antenna sites in late summer coincided with decreased CPUE in main-stem and tributary environments, while lake habitats CPUE increased (Figure 9).

Overwintering Area Identification, Selection, and Proportional Occupancy

Seven overwintering areas were identified within the Big Lake watershed (Figure 10). Five were located within the Meadow Creek sub-drainage, and one in the Fish Creek sub-drainage. The seventh overwintering area was identified as “Big Lake proper,” which separates the Meadow and Fish Creek sub-drainages. Meadow Creek sub-drainage overwintering areas include: Blodgett Lake, Stephan Lake, Twin Lake, Lucille Creek, and “Upper Meadow Creek.” The Upper Meadow Creek area was outside the study area and is a relatively large section of the Meadow Creek sub-drainage that has numerous tributary and lake habitats present. Migration studies undertaken to identify overwintering areas with more precision within Upper Meadow Creek area have since been studied by the USFWS and results are forthcoming (USFWS, unpublished data).

The sole overwintering area identified within the Fish Creek sub-drainage was Threemile Lake (Figure 10). These overwintering areas varied with respect to watershed location, estimated area, habitat type(s) (lentic and lotic) present, and the determining method (e.g. antenna detection and/or minnow trap recapture; Table 7).

Individual movement profiles were constructed for 3,305 tagged fish in the Big Lake watershed in 2011 and 2012, of which 1,747 (52.8%) were classified as “dispersers,” 203 (6.1%) as “residents,” and 1,355 (41.1%) as “unknown.” Overall, a total of 1,950 JCS could be assigned a known overwintering area, which is the combined total of the “disperser” and “resident” groups. Big Lake proper had the highest proportional occupancy of overwintering PIT tagged fish (45.7%), followed by Blodgett Lake (21.3%), Threemile Lake (15.1%), Upper Meadow Creek (10.1%), Lucille Creek (5.7%), Stephan Lake (1.7%), and Twin Lake (0.4%). Proportional occupancies within identified overwintering areas differed between years in Meadow Creek, as well as between sub-drainages in 2012. In 2011, 667 fish were assigned to an overwintering area within the Meadow Creek sub-drainage. Blodgett Lake recorded the highest proportional occupancy at 48.4%, followed by Big Lake (22.4%), Upper Meadow Creek (21.7%), Lucille Creek 7.2% and Twin Lake (0.3%). In 2012, 343 tagged JCS could be assigned an overwintering area from the Meadow Creek sub-drainage. Big Lake had the highest proportional occupancy at 30.6% followed by Blodgett Lake (25.1%), Lucille Creek (18.1%), Upper Meadow Creek (14.9%), Stephan Lake (9.6%), and Twin Lake (1.7%). A total of 940 JCS tagged in the Fish Creek sub-drainage in 2012 dispersed to four different overwintering locations, of which two had 99.2% of the proportional occupancy amongst identified overwinter locations. These overwintering areas were Big Lake proper (67.9%), and Threemile Lake (31.3%). The remaining 0.8% overwintered in Blodgett Lake (0.7%) and Lucille Creek (0.1%).

Classification Tree Modeling of Overwinter Location Choice

Classification tree modeling indicated that JCS overwintering area choice was most strongly influenced by taxis direction and distance from the estuary. In all cases but one, the model selection process resulted in the removal of fork length as a predictor variable with low contribution to explaining variability in JCS overwinter site selection. Final random forest models were able to predict overwinter locations with low error in all sub-drainages and years (OOB prediction error <13%; Table 8). Overwintering area choice within the Fish Creek sub-drainage was most dependent on DE (VI = 1,456) followed by TD (VI = 535, OOB prediction error = 9%). Models differed for separate study years within the Meadow Creek sub-drainage as overwintering choice was dependent on all three predictor variables in 2011 (TD VI = 1,334, DE VI = 611, FL VI = 71; OOB prediction error = 12.8%) and dependent on TD (VI = 850) and then DE (VI = 470) in 2012 (OOB prediction error = 9.3%). Confusion matrices detailing overwintering area choice misclassification by sub-drainage and year are presented in Tables 9 - 11.

Downstream dispersal to overwintering areas was exclusive to the Meadow Creek sub-drainage in both years; all fish exhibiting a downstream dispersal overwintered in Big Lake (Figures 11, 12). Downstream dispersal in the Fish Creek sub-drainage was not observed (Figure 13). Upstream and complex dispersals were used in the Fish Creek sub-drainage to overwinter in Big Lake and Threemile Lake, and were the most prevalent dispersals to Blodgett Lake and Upper Meadow Creek within the Meadow Creek sub-drainage in both years (Figures 11, 12).

Classification trees for overwinter location choice indicated that the location of summer rearing distance from the estuary for tagged fish influenced overwinter location choice in a predictable way. As summer rearing area distance from the estuary increased within Meadow Creek, the propensity for fish to disperse downstream to an overwinter location in Big Lake decreased in both 2011 and 2012 (Figures 14, 15). The opposite was true for Upper Meadow Creek bound fish as their propensity to swim upstream to this location decreased with summer rearing areas closer to the estuary (Figures 14, 15). In both years the relative contribution of fish dispersing to Blodgett Lake remained consistent across a range of summer rearing location distances from the estuary, with greater propensity for tagged fish to migrate to Blodgett at intermediate distances (Figures 14, 15). Within the Fish Creek sub-drainage the relative contribution of fish selecting Big Lake and Threemile Lake was equal for fish with summer rearing area locations closest to the estuary. Threemile Lake's highest relative contributions of fish were rearing at distances between 7,000 - 8,500 and 9,000 - 10,000 river meters, distances found to be within Threemile Creek, and in close proximity to Threemile Creek confluence with Fish Creek. The highest relative contribution of Fish Creek tagged fish selecting Big Lake came from summer rearing areas with distances in excess of 10,000 river meters from the estuary (Figure 16).

The Meadow Creek 2011 best fit classification tree contained three branching nodes and four leaf nodes in predicting overwinter location choice (Figure 17). The first partition indicated that fish that migrated downstream were predicted to overwinter in Big Lake (24% of n = 592 fish classified along this path). The remaining branches for fish that did not move downstream and with summer rearing areas less than 39,000 river meters (a fork in the river) from the estuary were predicted to migrate to Blodgett Lake. Tagged fish which did not migrate downstream and originated from summer rearing locations further upstream of 39,000 river meters were predominately predicted to overwinter in Upper Meadow Creek; this simple model made up of only three branching nodes and splits based upon TD and DE produced high accuracy predictions for overwinter location selection, with OOB prediction error of only 12.8%. Fork length was determined to be insignificant as a predictor variable in the Meadow Creek 2011 model, as its inclusion only improved model accuracy by 1.6% and its VI was low, thus its exclusion from the classification tree despite remaining in the predictive model (Figure 17). The best fit classification tree for Meadow Creek 2012 fish (n = 216 JCS) was very similar to that of 2011, indicating that DE and TD were strong predictors of ultimate overwinter location choice (Figure 18; OOB prediction error 9.3%). The sole difference was an additional leaf node, indicating that fish with summer rearing locations less than 32,000 river meters from the estuary were predicted to select Big Lake as an overwinter location using a complex dispersal direction; fish with rearing locations between 32,000 m and 39,000 m were predicted to overwinter in Blodgett Lake. The 2012 Fish Creek (n = 919 JCS) best fit classification tree predicted similar general summer rearing to overwinter habitat selection behavior, whereby summer rearing location was pivotal in predicting overwinter location choice (Figure 19). This classification tree contained five splitting nodes, four of which predicted overwinter location choice based upon DE, and only a single node predicting overwinter choice based upon TD for the subset of fish with summer rearing areas located at intermediate distances from the estuary (<7,896 m but >7,080 m). Accuracy for the Fish Creek classification tree in predicting overwinter selection was also high, with an OOB prediction error = 9.0%.

DISCUSSION

Passive integrated transponder tags were used to track the seasonal movement of 3,305 JCS in two sub-drainages within the Big Lake watershed in Southcentral Alaska. While fish were tagged throughout both drainages - in 26 main-stem, 13 tributary and nine lake locations - during the summers of 2011 and 2012, of the 1,747 fish that left their summer rearing areas ("dispersers"), more than 99% moved to lakes to overwinter. These findings align with previous JCS overwintering area studies, in that the fish moved from main-stem summer rearing locations to off-channel overwintering areas (see Huusko et al. 2007). However, unlike in previous studies, almost all the fish observed moved from summer rearing areas to lakes to overwinter despite having access to other overwintering habitats including tributaries, wetland areas, beaver ponds, alcoves, and riverine ponds. Classification trees indicated that dispersal to overwinter locations followed predictable behavior, and that TD and DE played a major role in determining which lakes fish overwintered in. Lake selection was primarily determined by TD in Meadow Creek and by DE in Fish Creek.

The combination of PIT tag technology and a substantial amount of fieldwork facilitated the tracking of a sufficiently large number of individual fish to explain the mechanisms responsible for population-level JCS seasonal dispersal patterns (Juanes et al. 2000). Nearly half (41%) the fish tagged in this study may have died or successfully overwintered without being detected (the unknown category previously described), revealing the importance of tagging many fish in many rearing habitat types. In this study, 1,747 tagged individuals did undertake the summer-winter redistribution providing for a powerful analysis given the number of combinations of predictor variable and potential overwintering destinations. Of further importance was the considerable field effort employed to install and maintain the network of in-stream antenna array sites. This allowed the 24-hour per day, year round monitoring of each "disperser" providing unique insight into the overwintering habitat selection, timing, and use. This is in contrast to previous JCS overwintering habitat identification studies which used population level relative abundance indices (e.g. Swales et al. 1988). This study did use population level relative abundance indices to compare three coarse level habitat types (main-stem, tributary, lake; Figure 8; Figure 9), however unequal capture efficiency between habitat types made precise conclusions of overwintering habitat use difficult. The use of PIT tagging techniques to determine overwintering area choice was more precise and is a superior alternative to relative abundance indexes. Additionally, studies based on relative abundance indices rely on repeat sampling events in both habitats through time to ensure that the fish have remained in a habitat and not dispersed elsewhere (Bramblet et al. 2002). Previous studies used relative abundance techniques to infer movement between summer and winter habitats, but contended with study area sizes limited to small subsections of a watershed (Swales et al. 1986 and 1988). In contrast, PIT tagging allowed for the monitoring of a tagged population within an entire watershed, limited only by the survival of the tagged fish and the extent and resolution of the antenna array site network. By using a repeat sampling design during the ice-free summer months coupled with PIT tagging technology, this study was able to track individual-level movements of tagged fish throughout time, and make population-level inferences about overwinter habitat selection as well as the dispersal paths taken to reach overwinter locations, an important contribution for watershed connectivity restoration and management. This study differs from other overwinter habitat identification studies due to the PIT tagging component, with an emphasis on the antenna array site network. The use of PIT tag antenna array sites, specifically built to withstand ice events, provided individual level details not previously used in a JCS winter habitat identification study. This work demonstrates that PIT tagging is a viable and useful tool to explore fish movements in high latitude systems with seasonal ice cover.

Classification tree analysis set in a random forest framework proved to be effective in predicting overwintering area choice of JCS, with minimal predictor variable inputs. Only knowing the summer rearing area and movement direction of a PIT tagged fish was sufficient to predict overwintering area choice with high accuracy. Variable importance differed between sub-drainages; however, both DE and TD were included in each sub-drainage model. Two factors unique to the Meadow Creek sub-drainage were: 1) the observation of all three taxis types and 2) the presence of culverts which block dispersal pathways resulting in a subset of fish forced to use a complex dispersal. The presence of culverts resulting in more complex dispersals could potentially cause the VI of TD to be higher than DE. In contrast, the Fish Creek sub-drainage model resulted in DE having the highest VI, likely due to the lack of culverts influencing taxis dispersal and suggesting that summer rearing location is the best predictor of overwintering area choice.

The movement of PIT tagged JCS to alternative habitats during late summer and early fall suggests that many of the summer rearing locations in the Big Lake watershed may not be desirable (or potentially suitable) for overwintering, and that seasonal redistribution may have occurred to increase the probability of survival. If summer rearing areas were also favorable for overwintering, then the expected outcome would be a high proportion of tagged fish remaining "resident" year round (e.g. Heggenes and Dokk 2001) and thereby retaining energy reserves that would have otherwise been used on a overwinter redistribution migration. The overwinter redistribution observed in the Big Lake watershed indicates a preference for lakes over main-stem and tributary habitats during cold winter months. In addition, the benefit of selecting lakes for overwintering appears to outweigh the migration-related energy costs and predation risks. Weber et al. (2016) observed a reduced detection probability of PIT tagged juvenile Brown Trout and sculpin in a stream reach with increasing ice thickness, where tagged fish moved both upstream and downstream out of the study area. Redistribution to lakes from main-stem and tributary rearing areas where winter ice coverage is less influential suggests a preference for locations with greater water depth, higher ice stability (Simpkins et al. 2000; Brown et al. 2000), and reduced velocity to conserve energy (Cunjak 1996). The exception was the small proportion of “resident” JCS in this study which successfully overwintered in Lucille Creek, a tributary of Lucille Lake. Lucille Lake is inaccessible to JCS due to a water control structure situated at its outflow. Kikuchi et al. (2012) found that the largest increase in Lucille Creek surface discharge occurs 10 - 15 km downstream of the Lucille Lake outflow, and estimated that 45% - 75% of the streams discharge originates from the regional aquifer in the form of groundwater. Opportunistic site visits to groundwater seepage sites in Lucille Creek during the winter of 2012 found areas with no ice cover and JCS present despite prolonged air temperatures well below 0^{o}C, indicating that groundwater seepage sites could provide a stable thermal environment for overwintering. Siikavuopio et al. (2009) found increased survival and growth rates for juvenile Arctic Char overwintering in groundwater seepage sites.

The installation and maintenance costs of PIT tag antenna array sites limited the coverage achieved in this study and thereby the identification of all overwintering areas within the Meadow Creek sub-drainage; however, this study elucidated seven overwintering locations. The few detected fish which moved to overwintering areas without antenna arrays were found in lakes such as Stephan Lake and Twin Lake, which are located in the Meadow Creek sub-drainage (Figure 10). Opportunistic thru-ice sampling of these lakes in the winter months of

2012 was conducted by using baited minnow traps and by ice fishing, which resulted in catches of JCS, providing physical evidence that JCS use these lakes for overwintering. Deployment of additional antenna arrays on these lakes would have provided greater refinement on overwinter dispersal timing and increased sample size, but likely not changed the result of this study. For overwintering areas which had year-round PIT tag antenna site coverage (Big Lake, Blodgett Lake, Upper Meadow Creek, Lucille Creek and Threemile Lake), tagged JCS were observed dispersing into these sites in the fall, and were not detected leaving until May of the following year after the ice cover had melted proving they provided adequate overwintering habitat. However, the lack of complete antenna site coverage on all tributaries within the Meadow Creek sub-drainage may have contributed to the difference in the OOB classification error between sub-drainages. The lower OOB error estimate for the Fish Creek sub-drainage may be attributed to complete antenna coverage within the study area, and the high proportion of JCS selecting just two overwintering areas in this relatively less complex stream network as compared to Meadow Creek (e.g. Figure 2).

The lakes monitored in this study were not selected equally by tagged fish, indicating that other factors (e.g. environmental cues) may drive the selection of a specific lake for overwintering. This thesis was focused on understanding JCS migrations and did not test the suite of environmental covariates which may influence overwintering area choice. Differences in the selection of overwintering areas by JCS were observed between drainages. A small fraction of the fish tagged in the Fish Creek sub-drainage (n = 95 JCS) were observed migrating to overwintering areas in the Meadow Creek sub-drainage. An additional 61 individuals originating from Fish Creek were observed migrating into Meadow Creek before moving back downstream into Big Lake to overwinter. A single tagged fish originating from the Meadow Creek sub-drainage moved downstream to overwinter within the Fish Creek sub-drainage. Off-channel habitats are far less abundant in the Fish Creek sub-drainage, which resulted in the high relative abundance of fish tagged in the Fish Creek sub-drainage choosing Big Lake or Threemile Lake as an overwintering area. There were 516 fish classified as “unknown” in this study, which were tagged in the Fish Creek drainage and were not detected moving into or out of Big Lake or Threemile Lake. Of these, 75% (385) survived the winter and were identified at the fyke net operated by the Alaska Department of Fish and Game near the Fish Creek outflow. This indicates that a fraction of the Fish Creek sub-drainage tagged population did not disperse from the main-stem and successfully overwintered at an unknown location within the Fish Creek sub-drainage. Thus, some main-stem habitats provide viable overwintering options, but lake habitats may present a better alternative due to the fact that a greater number of fish tagged in both sub-drainages selected lake habitats for overwintering.

Despite the successes stated above, the study design did have some limitations. Trap-based recapture events of tagged JCS were rare, accounting for less than 5% of the total fish caught in both years and sub-drainages; however, the majority of recaptures revealed a high level of site fidelity during the summer rearing months. The bi-weekly sampling schedule with repeat visits to the same stream sections is conducive to recapturing individuals which have established a feeding territory. Once dispersal from summer rearing areas initiated, the ability to recapture a tagged fish decreased because recapture could only occur if a fish moved into an area in which a sampling event was scheduled for that day, significantly reducing the recapture probability. As the primary objective of this study was to identify overwintering areas, off channel habitats (e.g. lakes) hypothesized to support successful overwintering were sampled. Minnow trapping efficiency in lakes was poor, and did not provide the resolution needed to determine overwintering area locations solely based upon recapturing PIT tagged individuals in minnow traps. The use of antenna array sites negated this limitation. However, the antenna arrays did not have perfect tag detection efficiency, so it was probable that some tagged fish swam past antenna arrays without being detected (see Appendix 1). There were several instances where antenna arrays were not operating properly for extended periods of time (~5 days), so any movement through antennas during these times were not recorded. Three of the seven antenna sites were installed using the side by side antenna configuration; these sites did not provide directional data, thus for any fish detected at these antenna sites the direction was assumed by the researcher using the tagging location as a reference point to the antenna location. Even with detection and directional movement limitations at each of the antenna sites, they provided a much clearer picture of the fall redistribution timing and overwintering area site selection by tagged fish than minnow trapping or relative abundance based methods.

Prioritizing culvert removal around available overwintering habitats is especially important for JCS as they exhibit extended freshwater residency of up to four years; a life history trait observed in the Big Lake watershed (USFWS, unpublished data). This study only documented the redistribution and overwintering habitat selections of age 0 and age 1+ fish, as minnow traps are selective for smaller size classes (<150 mm, FL), and found that different age classes (predicted by FL; see Sethi et al. 2017) used the same overwintering areas. The opposite is true for summer rearing habitats, as Bradley et al. (2016) found differential habitat use by age class within the Big Lake watershed. Size classes of JCS greater than 150 mm do exist within the Big Lake watershed but are rare, and constitute a small proportion of freshwater rearing population. Preliminary results of a 2015 USFWS study using miniature fyke nets soaked overnight in lake habitats within the Big Lake watershed found that only 8% (164 of 1,988) of the captured JCS were greater than 150 mm (USFWS, unpublished data). Similarly, the Cook Inlet Aquaculture Association (Weber 2009) found that only 8.4% of all JCS smolts out-migrating from the Big Lake watershed in 2007 were greater than 150 mm.

Habitat connectivity restoration efforts aimed at removing and replacing barriers (e.g. culverts) which limit fish passage should account for both summer rearing and multi-directional passage. Opening access to overwintering habitats is expected to lower the competition pressure within previously available habitats, increasing survival, growth, and the production potential for the watershed as a whole (Marshall and Britton 1990). The proximity of summer rearing area to overwintering area should also be included in the barrier removal assessment process as fish generally select the nearest overwintering habitat dependent upon direction. This thesis revealed that a better understanding of the locations of overwintering habitats characterized by lake and ice-free stream channels, and the pathways to these habitats, can be utilized to support informed decision making in the process of prioritizing habitat restoration projects.

CONCLUSION

This thesis observed individually PIT tagged JCS dispersing from summer rearing habitats to ice-covered lakes and year round ice-free tributary habitats for the duration of the winter season. The strong signal of redistribution to such overwintering habitats suggests that they provide refugia from winter conditions leading to increased JCS survival outcomes which may be better than choosing to remain localized at summer rearing locations. Information on seasonal habitat preferences and migration patterns along summer to winter redistributions may be important to consider when making habitat restoration decisions based on fish passage and habitat connectivity improvement goals. Identifying and prioritizing the restoration of overwinter habitats can increase the amount of available and exploitable resources fish need to survive differing seasonal conditions in high latitude watersheds. Future study investigating environmental cues associated with overwintering habitat selection could provide insight to measurable variables further aiding in restoring overwintering habitats directly, as well as access to such habitats through fish passage projects. Finally, exploration of JCS survival outcomes across different overwinter location choice strategies will further aid in understanding the population-level consequences of access to different overwinter habitat areas.

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TABLES

Table 1. Juvenile Coho Salmon capture statistics in the Big Lake watershed, Alaska, 2011-2012.

Meadow Creek 2011				
Habitat	N	Traps Set	Soak Hours	CPUE
Main-stem	2,738	2,251	2,449	1.12
Tributary	601	441	479	1.25
Lake	1,226	2,115	2,361	0.52
Pooled	4,565	4,807	5,289	0.86
Meadow Creek 2012				
Habitat	N	Traps Set	Soak Hours	CPUE
Main-stem	3,211	956	1,168	2.75
Tributary	522	266	278	1.88
Lake	578	1,653	1,853	0.31
Pooled	4,311	2,875	3,299	1.31
Fish Creek 2012				
Habitat	N	Traps Set	Soak Hours	CPUE
Main-stem	15,663	2,546	2,607	6.01
Tributary	1,842	264	302	6.10
Lake	72	536	579	0.12
Pooled	17,577	3,346	3,488	5.04

Table 2. Number of PIT tags deployed into juvenile Coho Salmon in the Big Lake watershed, Alaska 2011-2012.

Meadow Creek 2011					
Habitat	June	July	August	September	October
Main-stem	-	1,051	595	155	-
Tributary	-	184	114	70	-
Lake	-	18	33	75	-
Total	-	1,253	742	300	-
Meadow Creek 2012					
Habitat	June	July	August	September	October
Main-stem	214	440	186	-	-
Tributary	10	24	53	146	-
Lake	-	59	19	136	75
Total	224	523	258	282	75
Fish Creek 2012					
Habitat	June	July	August	September	October
Main-stem	296	1,336	305	-	-
Tributary	72	427	61	-	-
Lake	-	-	55	9	6
Total	368	1,763	421	9	6

Table 3. Number of PIT tags deployed in each sampling location, within each sub-drainage in the Big Lake watershed, Alaska 2011-2012.

Meadow Creek			Fish Creek	
Location	2011	2012	Location	2012
Main-stem			Main-stem	
400	138	40	4500	5
850	183	46	5625	95
1525	293	45	6750	135
2050	101	19	7125	103
2925	59	9	8625	129
3825	102	41	9525	102
4400	81	54	10500	202
6275	174	125	12000	203
6950	218	133	13875	147
8300	253	174	15750	213
11025	118	147	16500	260
12375	35	7	18750	218
MLL	46	-	19875	125
Subtotal	1,801	840	Subtotal	1,937
Tributary			Tributary	
50	21	5	500	66
100	15	6	1200	138
330	42	11	2000	346
612	65	1	4000	10
797	106	7		
267	22	8		
849	37	34		
1263	60	15		
Upper Lucille	-	146		
Subtotal	368	233	Subtotal	560
Lake			Lake	
Twin	1	7	Threemile	70
Herkimer	42	-		
Corcoran	6	-		
Blodgett	77	185		
Hidden Gem	-	12		
Rainbow	-	25		
Stephan	-	60		
Subtotal	126	289		70
Total	2,295	1,362	Total	2,567

Table 4. Number of fish, by species, captured in minnow traps by sub-drainage in the Big Lake watershed, Alaska 2011-2012.

	Meadow Creek		Fish Creek	
	2011	2012	2012	Total
Coho Salmon	4,565	4,311	17,577	26,453
Sockeye Salmon	7	-	44	51
Rainbow trout	2,318	1,884	5,607	9,809
Three-spine Stickleback	42,971	30,777	29,671	103,419
Sculpin	677	372	234	1,283
Longnose sucker	6	3	1	10
Lamprey	-	13	9	22
Arctic char	-	-	2	2

Table 5. Number of PIT tagged juvenile Coho Salmon recaptured in minnow traps by habitat type, in the Big Lake watershed, Alaska 2011-2012.

Meadow Creek 2011						
Habitat	June	July	August	September	October	Total
Main-stem	-	22	47	53	2	124
Tributary	-	6	13	11	-	30
Lake	-	-	-	6	5	11
Total	-	28	60	70	7	165
Meadow Creek 2012						
Habitat	June	July	August	September	October	Total
Main-stem	5	12	62	13	3	95
Tributary	1	1	1	2	-	5
Lake	-	-	-	10	2	12
Total	6	13	63	25	5	112
Fish Creek 2012						
Habitat	June	July	August	September	October	Total
Main-stem	5	168	401	131	1	706
Tributary	-	95	166	147	1	409
Lake	-	-	-	-	2	2
Total	5	263	567	278	4	1,117

Table 6. Number of PIT tagged juvenile Coho Salmon recaptured in minnow traps by movement type, in the Big Lake watershed, Alaska 2011-2012.

	2011		2012		Combined	
Recapture Type	N	%	N	%	N	%
No movement	125	75.8	1,060	86.2	1,185	84.9
Movement	28	17.0	155	12.6	183	13.1
Overwinter area	12	7.3	15	1.2	27	1.9
Total	165	100.0	1,230	100.0	1,395	100.0

Table 7. Physical descriptions of identified juvenile Coho Salmon overwintering areas within the Big Lake watershed, Alaska using PIT tags in 2011 and 2012.

Overwintering Area	Sub-drainage	Estimated Area (km^2)	Habitat Type	Determination
Big Lake	Big Lake	12.66	Lentic	Antenna
Blodgett Lake	Meadow Creek	0.29	Lentic	Antenna & Trap-based Recapture
Upper Meadow Creek	Meadow Creek	0.68	Lentic & Lotic	Antenna & Trap-based Recapture
Threemile Lake	Fish Creek	0.48	Lentic	Antenna & Trap-based Recapture
Lucille Creek	Meadow Creek	0.03	Lotic	Antenna & Trap-based Recapture
Twin Lake	Meadow Creek	0.26	Lentic	Trap-based Recapture
Stephan Lake	Meadow Creek	0.25	Lentic	Trap-based Recapture

Table 8. Random forest models including OOB prediction error estimates and variable importance (VI) measures. The best fitting models are denoted by *.

Model	Model Drainage	OOB Error (%)	VI1	VI2	VI3
OW~DE+TD+FL	Meadow 2011	12.8*	TD (1,334)	DE (611)	FL (71)
OW~DE+TD	Meadow 2011	14.4	TD (1,453)	DE (743)	-
OW~DE+TD+FL	Meadow 2012	9.7	TD (776)	DE (368)	FL (10)
OW~DE+TD	Meadow 2012	9.3*	TD (850)	DE (470)	-
OW~DE+TD+FL	Fish 2012	9.9	DE (1,191)	TD (491)	FL (121)
OW~DE+TD	Fish 2012	9*	DE (1,456)	TD (535)	-

Table 9. Confusion Matrix showing random forest classification error of predicted overwintering area choice of juvenile Coho Salmon in the Fish Creek sub-drainage 2012. Columns denote the actual location and rows denote the predicted values based on random forest results.

Fish Creek 2012			
	Big Lake	Threemile Lake	Classification Error
Big Lake	604	33	0.18
Threemile Lake	50	232	0.05

Table 10. Confusion matrix showing random forest classification error of predicted overwintering area choice of juvenile Coho Salmon in the Meadow Creek sub-drainage 2011. Columns denote the actual location and rows the predicted values based on random forest results.

Meadow Creek 2011				
	Big Lake	Blodgett Lake	Upper Meadow	Classification Error
Big Lake	142	5	1	0.04
Blodgett Lake	2	292	20	0.07
Upper Meadow	1	47	82	0.37

Table 11. Confusion Matrix showing random forest classification error of predicted overwintering area choice of juvenile Coho Salmon in the Meadow Creek sub-drainage 2012. Columns denote the actual location and rows the predicted values based on random forest results.

Meadow Creek 2012				
	Big Lake	Blodgett Lake	Upper Meadow	Classification Error
Big Lake	99	4	0	0.04
Blodgett Lake	3	65	4	0.09
Upper Meadow	0	9	32	0.22

FIGURES

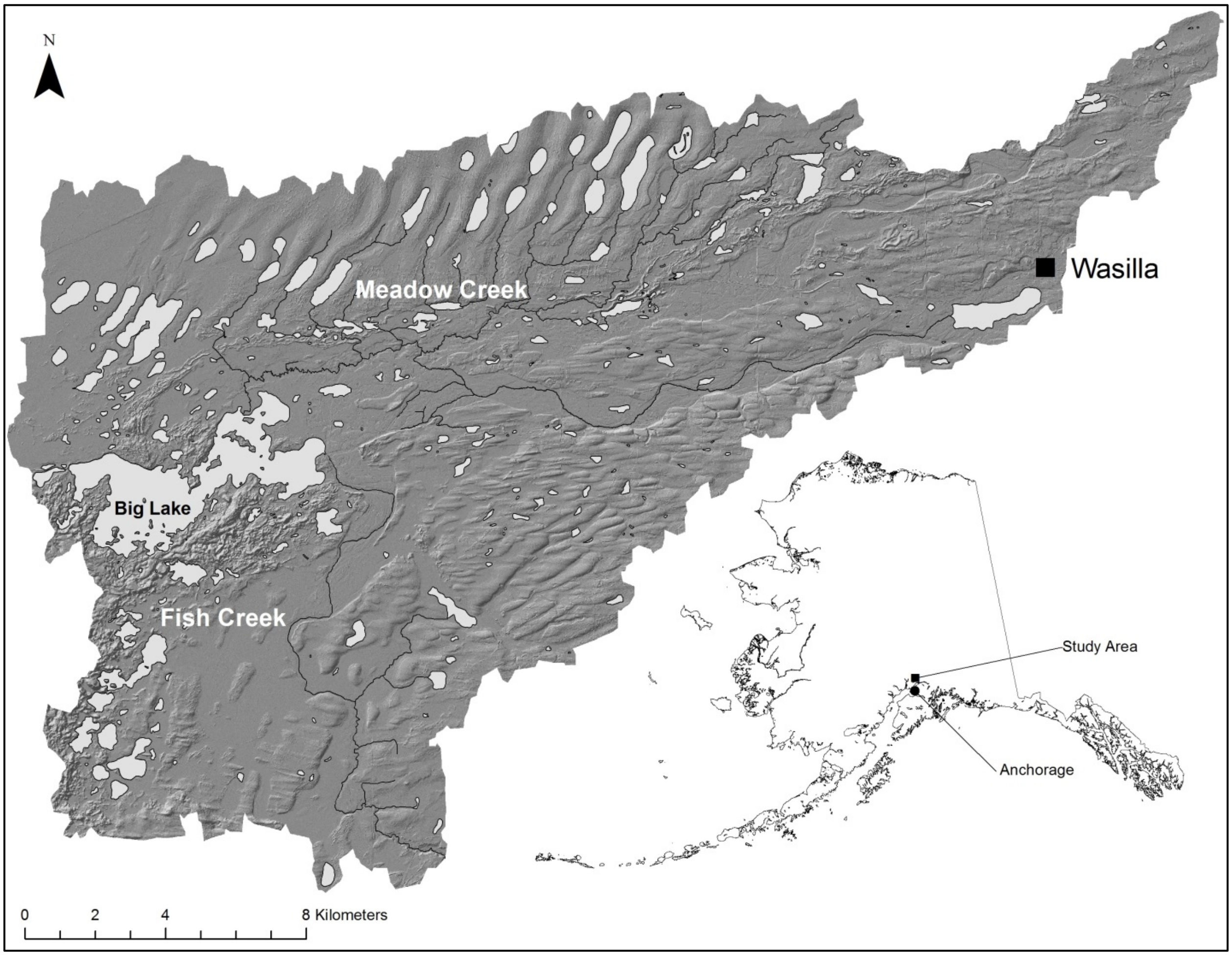

Figure 1. Shaded relief map of the Big Lake watershed located in Southcentral Alaska.

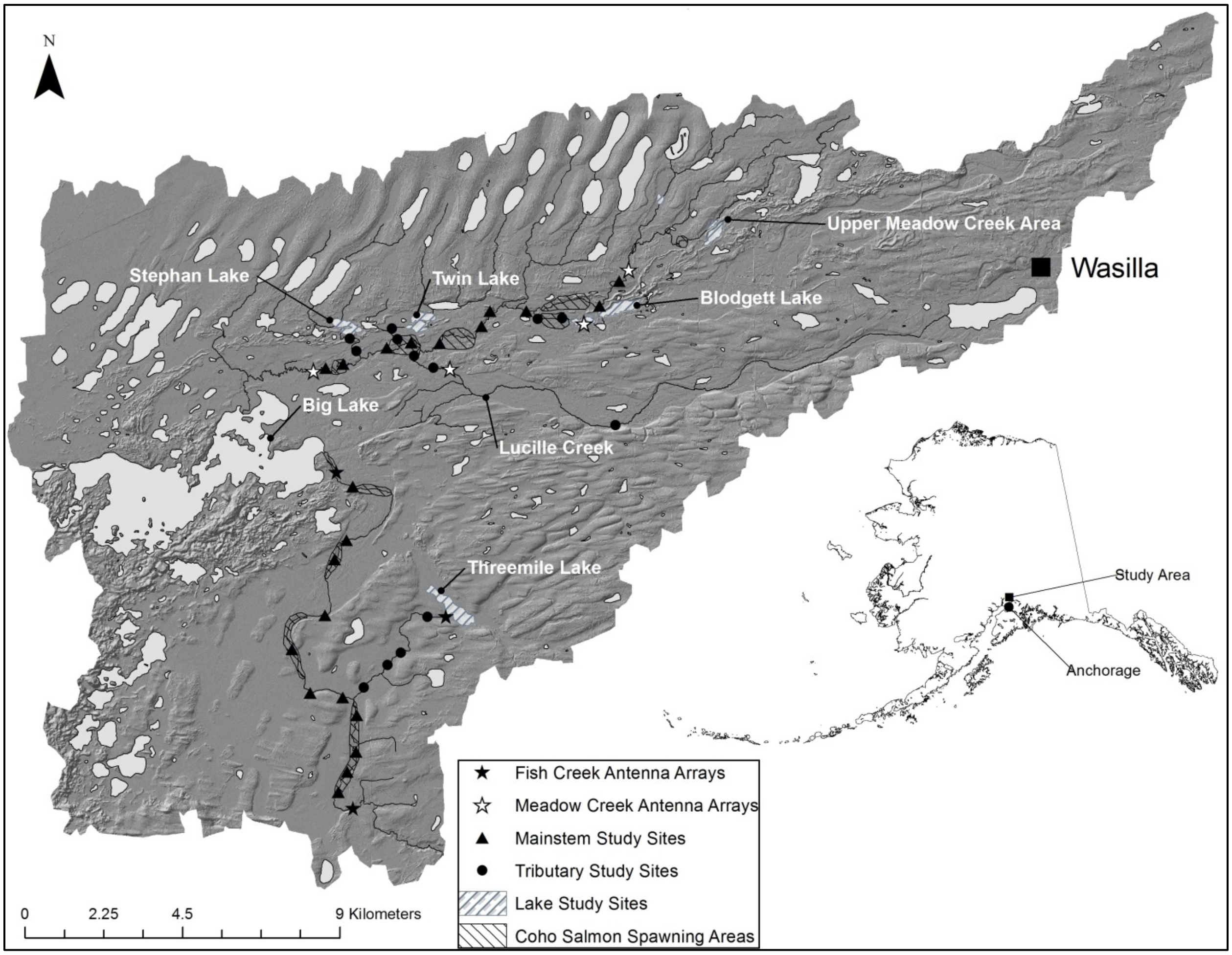

Figure 2. Shaded relief map of the Big Lake watershed by sub-drainage, showing juvenile Coho Salmon sampling sites, and in-stream antenna array sites.

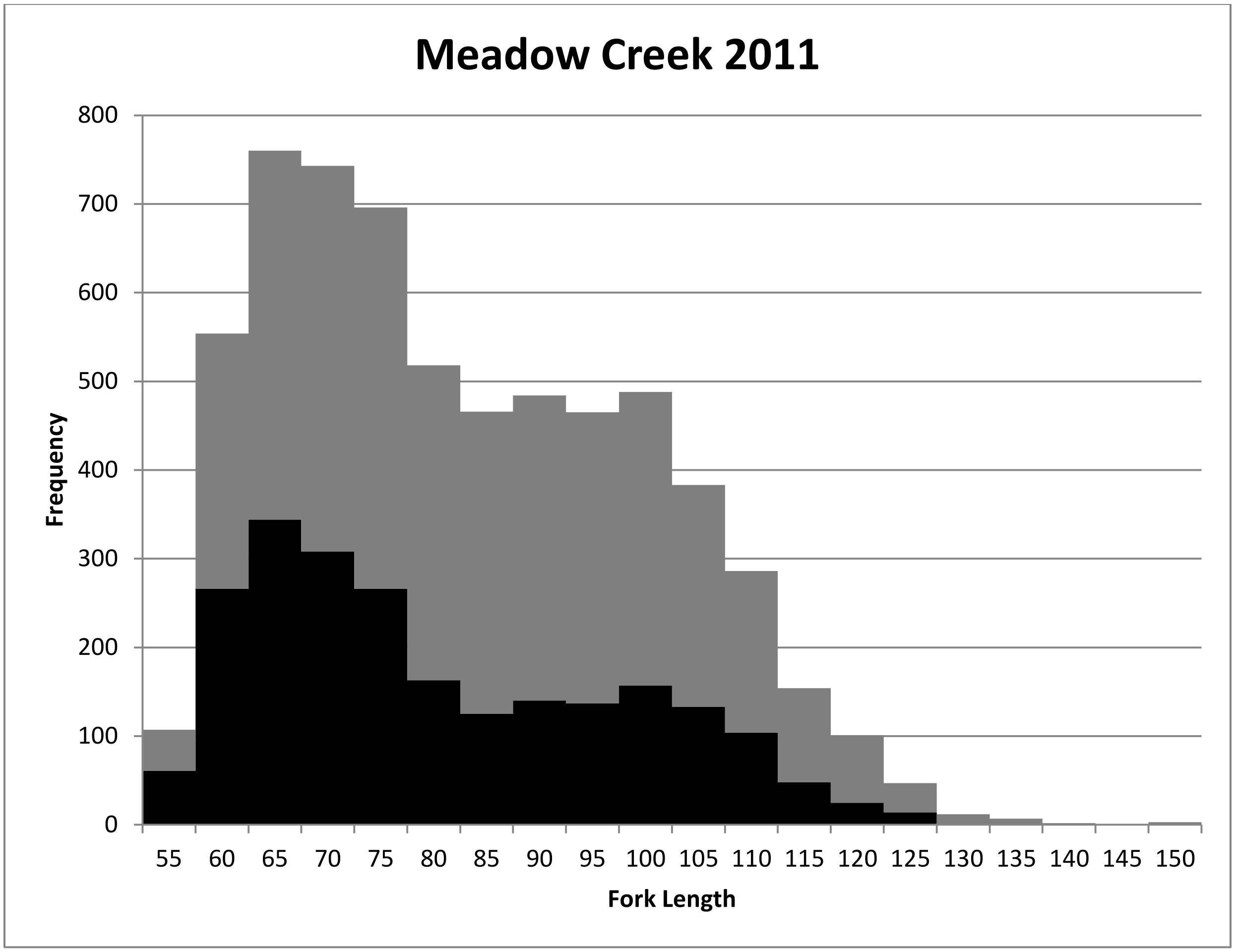

Figure 3. Frequency distribution of size classes for all juvenile Coho Salmon captured (grey) vs. PIT tagged (black) in the Meadow Creek sub-drainage of the Big Lake watershed in 2011.

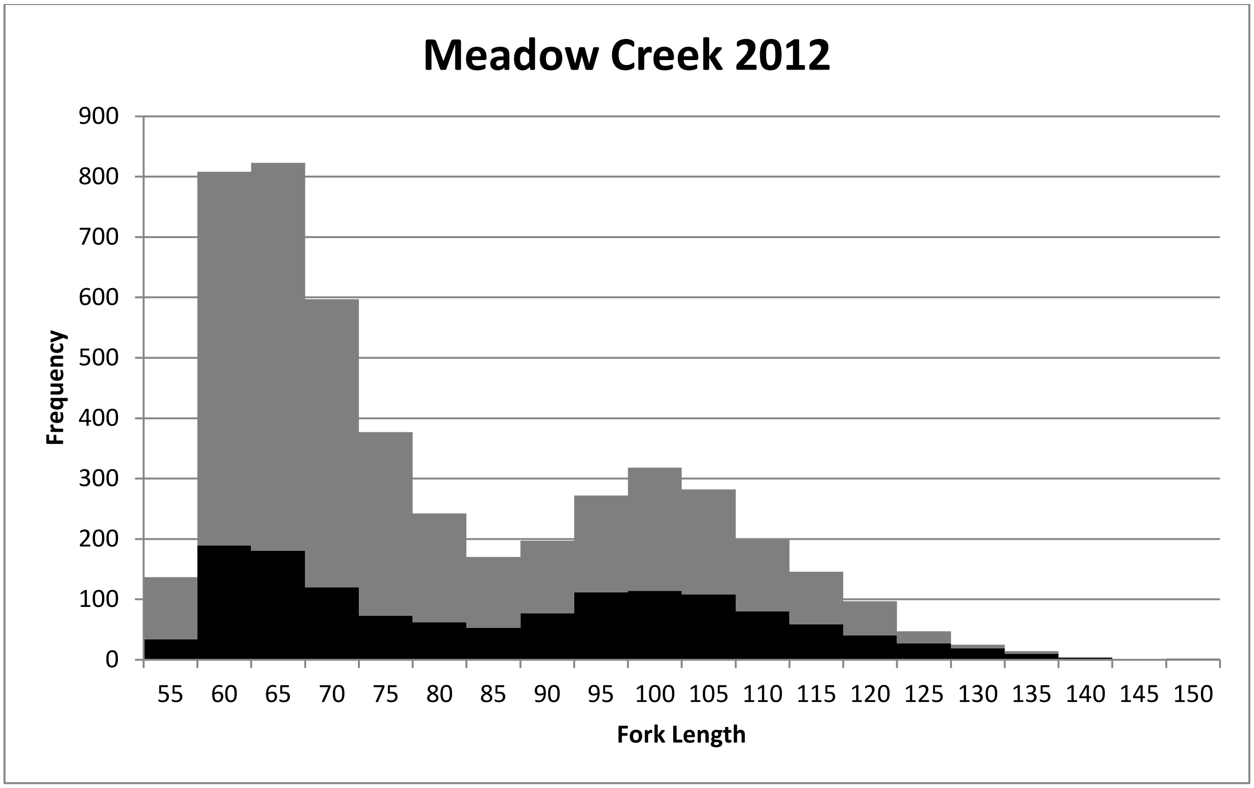

Figure 4. Frequency distribution of size classes for all juvenile Coho Salmon captured (grey) vs. PIT tagged (black) in the Meadow Creek sub-drainage of the Big Lake watershed in 2012.

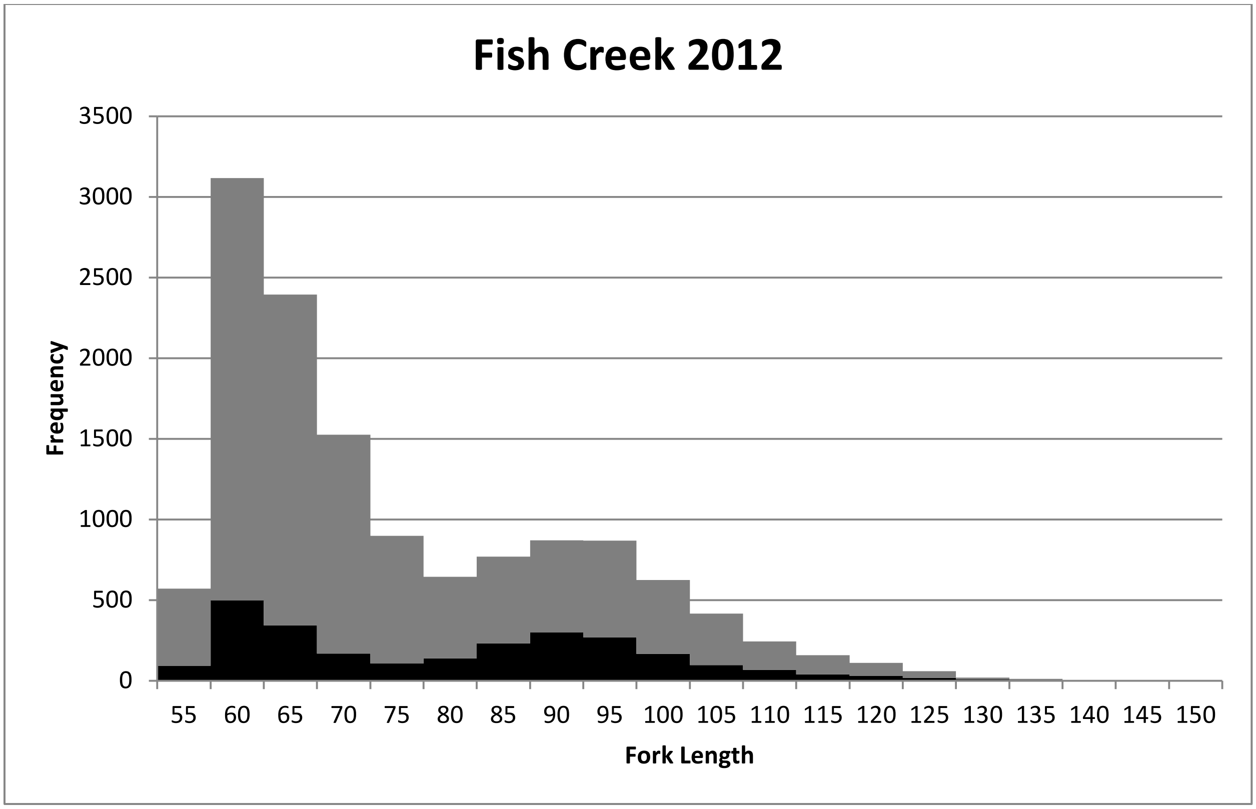

Figure 5. Frequency distribution of size classes for all juvenile Coho Salmon captured (grey) vs PIT tagged (black) in the Fish Creek sub-drainage of the Big Lake watershed in 2012.

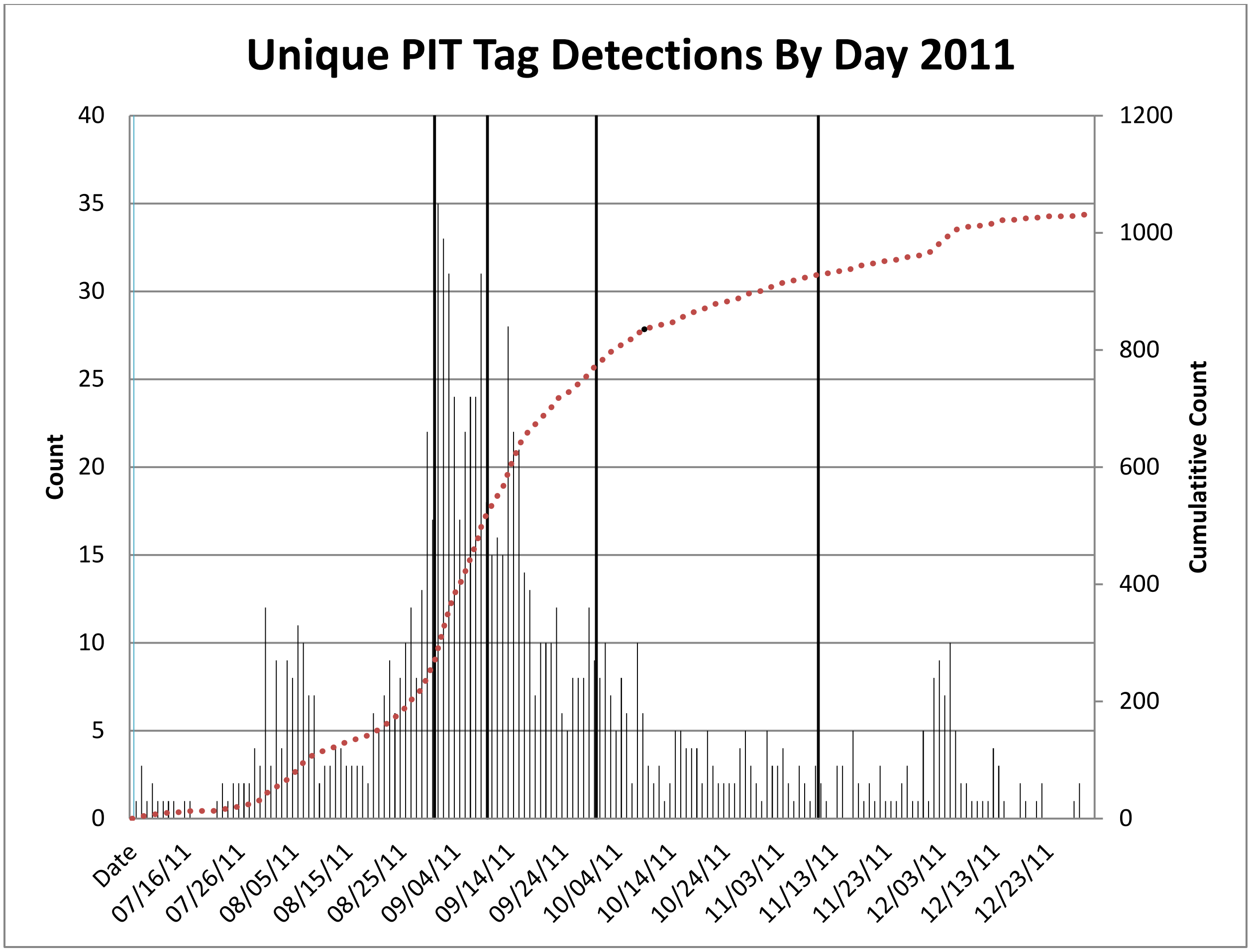

Figure 6. Number of detections of unique PIT tags detected at antenna sites within the Meadow Creek sub-drainage from July 1 to December 31, 2011. Vertical bold lines identify the quartiles, median date, and the 90th percentile of unique individual detections. The dotted line indicated the cumulative detection count through time.

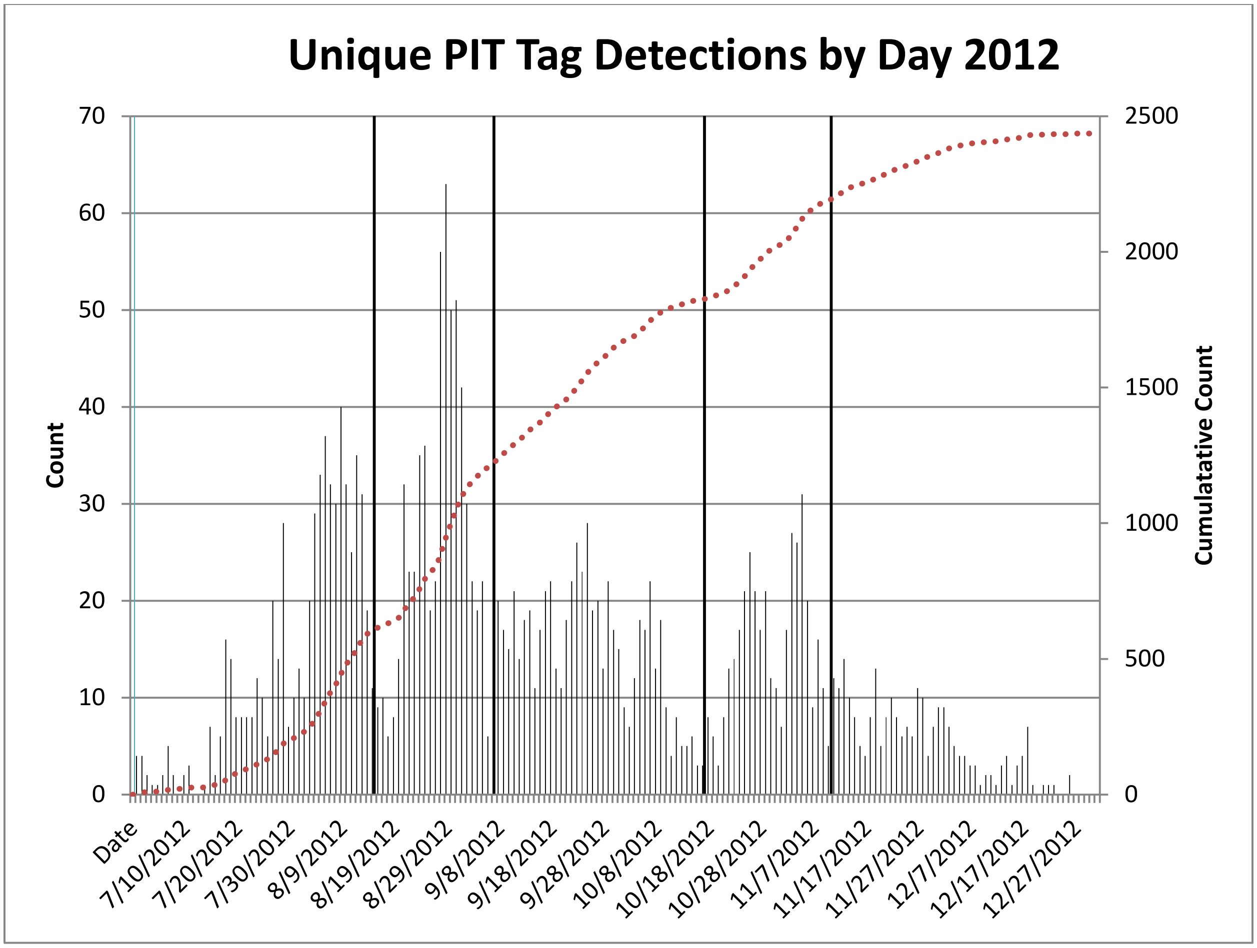

Figure 7. Number of detections of unique PIT tags detected at antenna sites within the Meadow Creek and Fish Creek sub-drainages from July 1 to December 31, 2012. Vertical bold lines identify the quartiles, median date, and the 90th percentile of unique individual detections. The dotted line indicated the cumulative detection count through time.

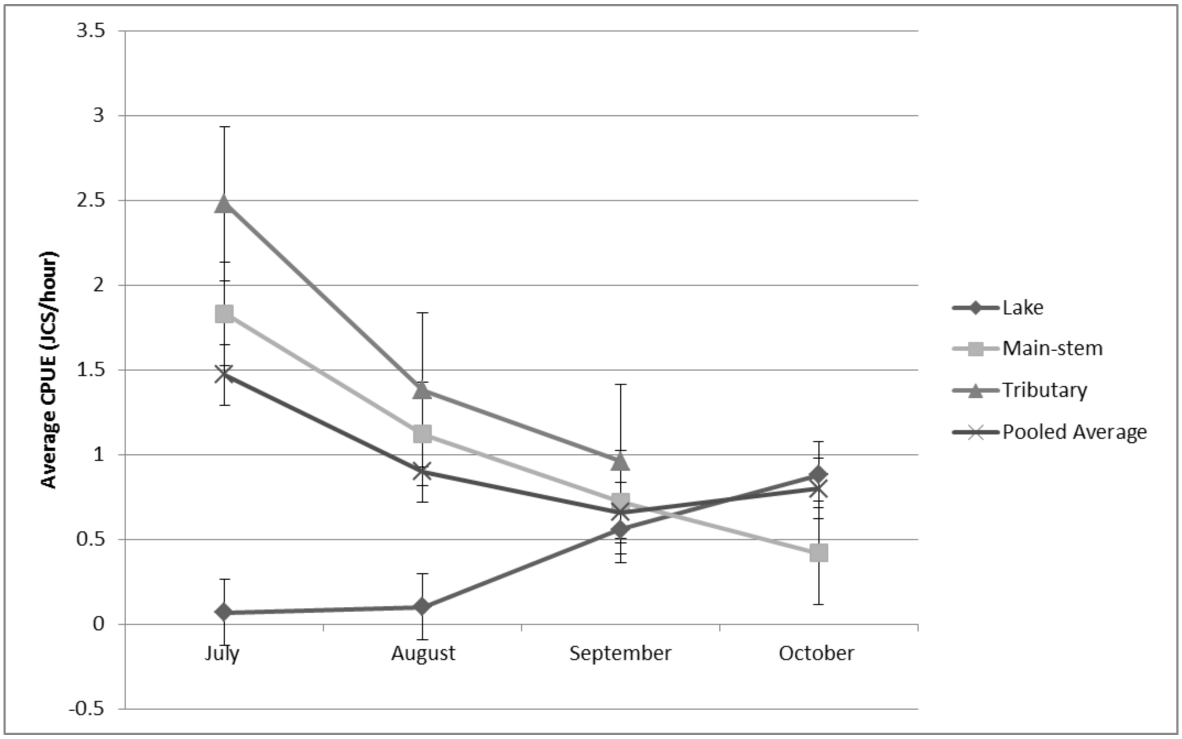

Figure 8. Average monthly juvenile Coho Salmon CPUE by coarse scale habitats in the Big Lake watershed 2011. Error bars represent standard error.

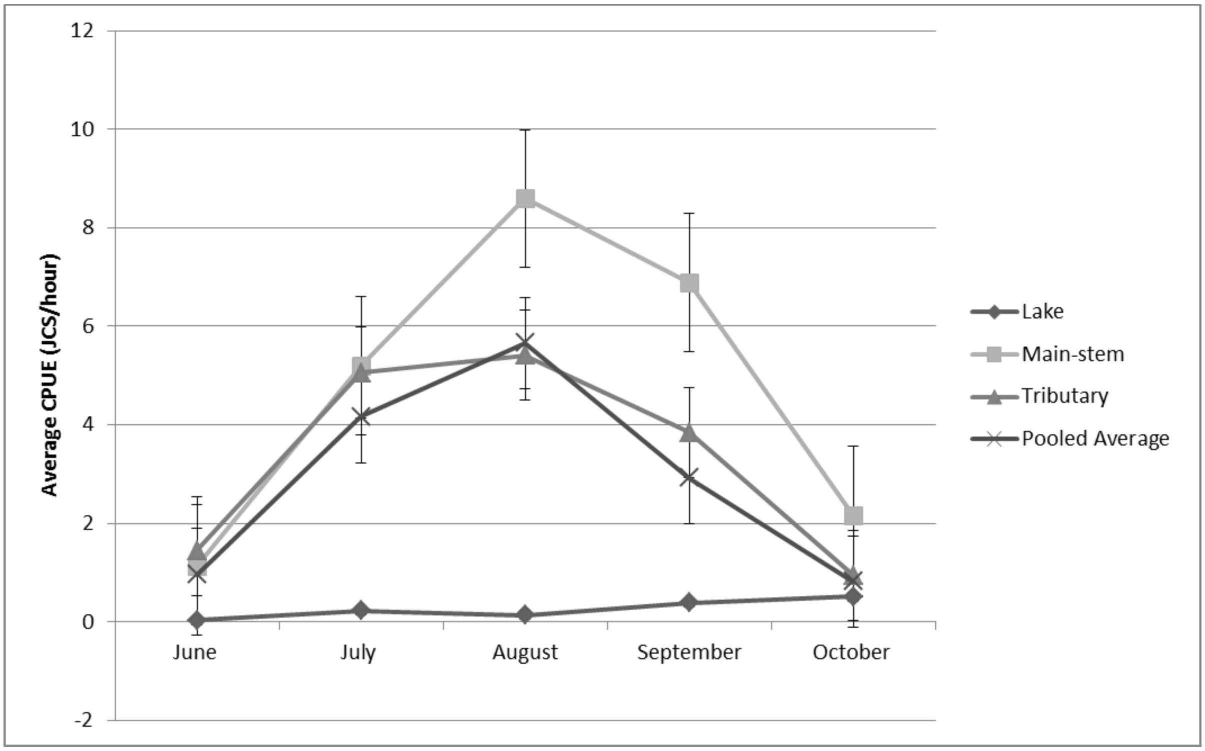

Figure 9. Average monthly juvenile Coho Salmon CPUE by coarse scale habitats in the Big Lake watershed 2012. Error bars represent standard error.

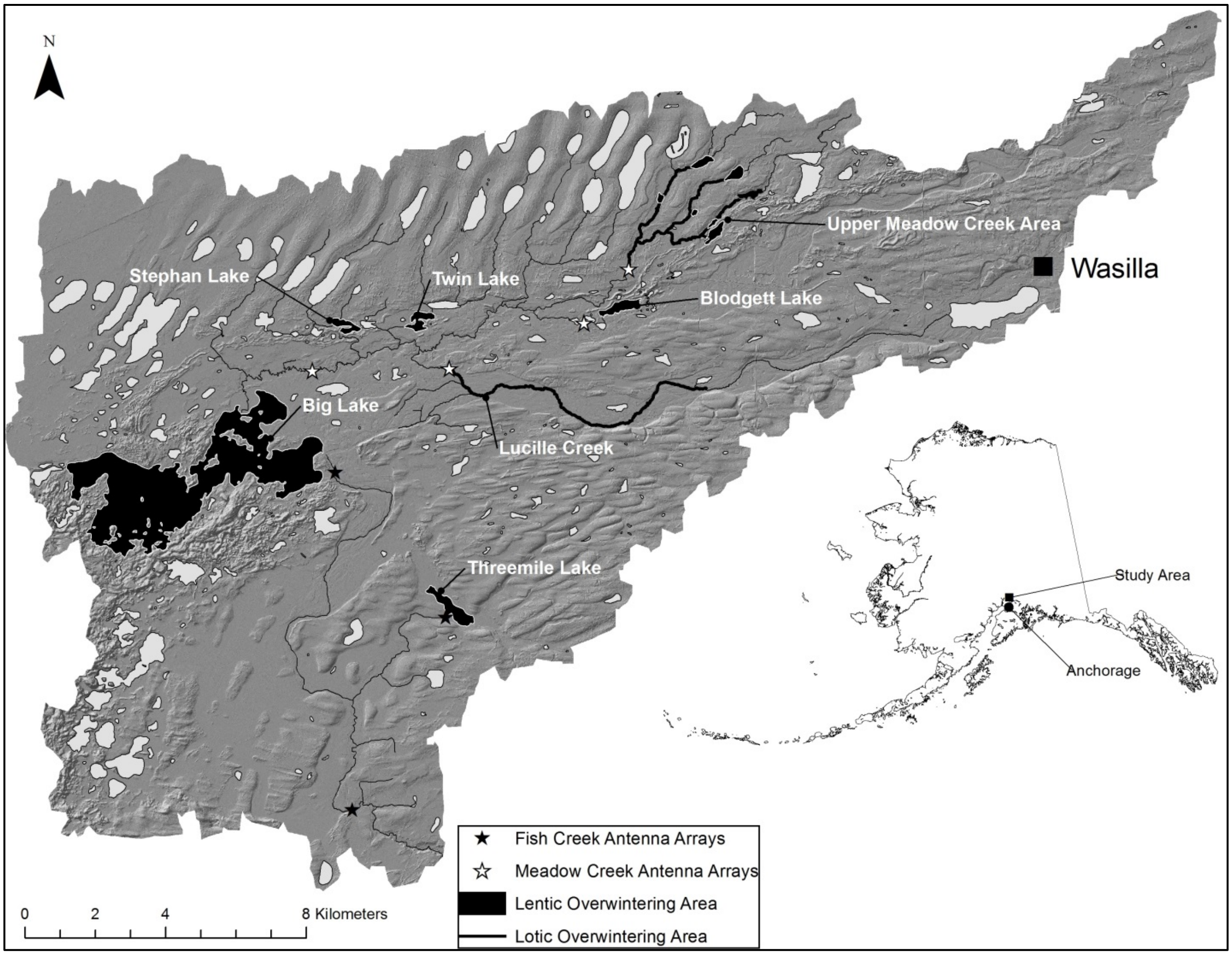

Figure 10. Shaded relief map of juvenile Coho Salmon overwintering areas identified using PIT tag technology within the Big Lake watershed, Alaska

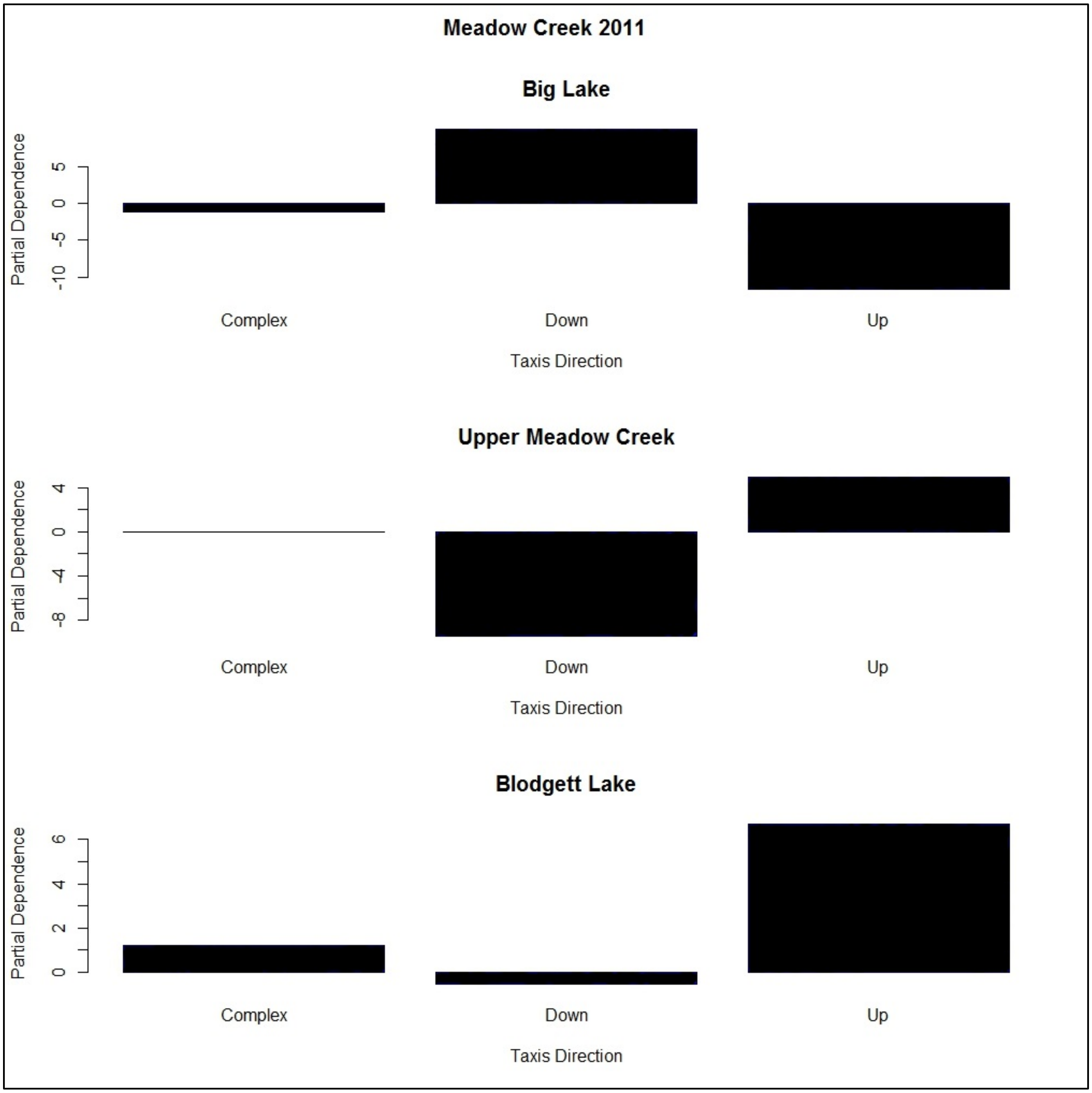

Figure 11. Partial dependence plot of taxis direction on overwintering area choice in the Meadow Creek sub-drainage 2011 from the best fit random forest model.

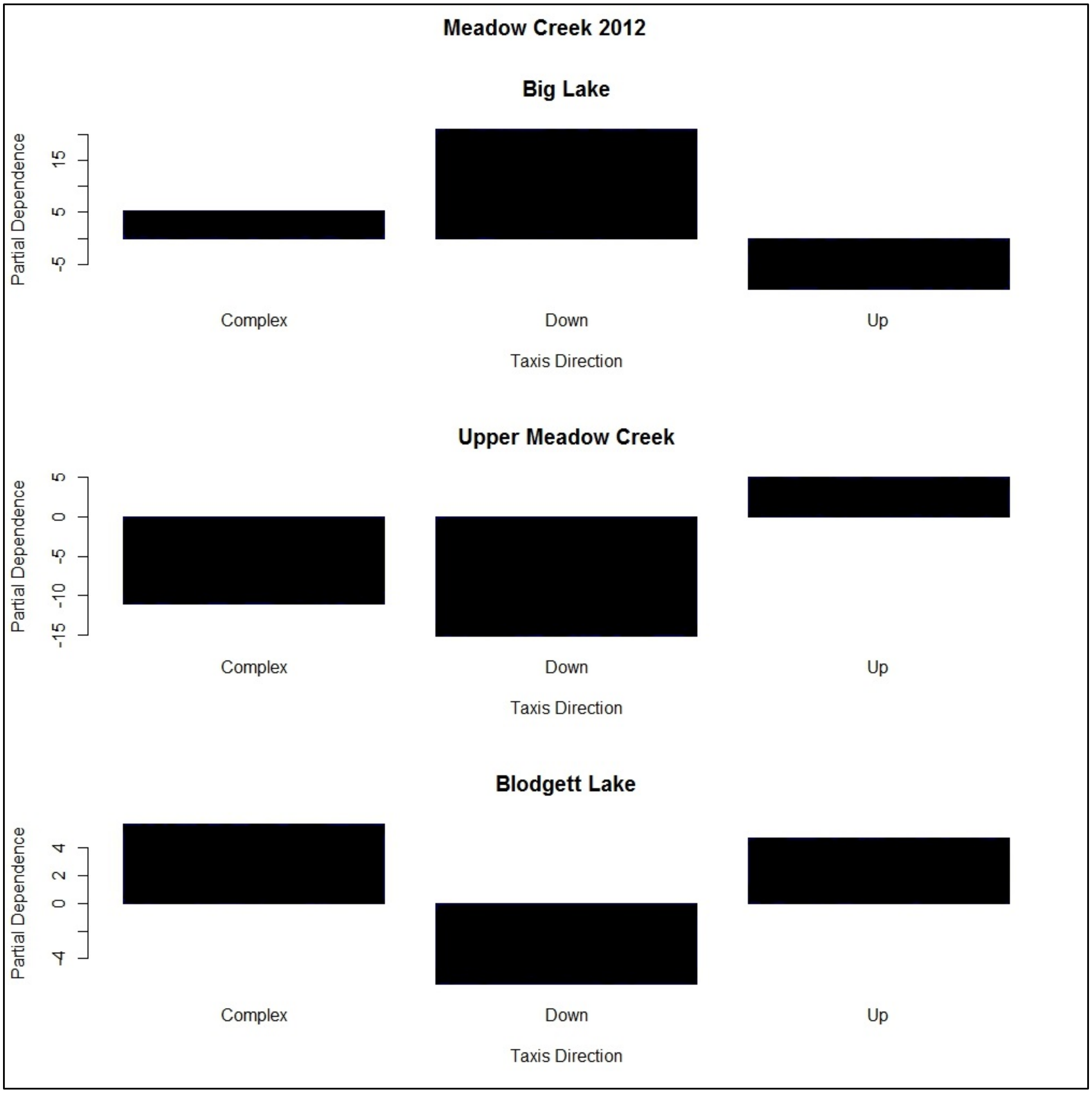

Figure 12. Partial dependence plot of taxis direction on overwintering area choice in the Meadow Creek sub-drainage 2012 from the best fit random forest model.

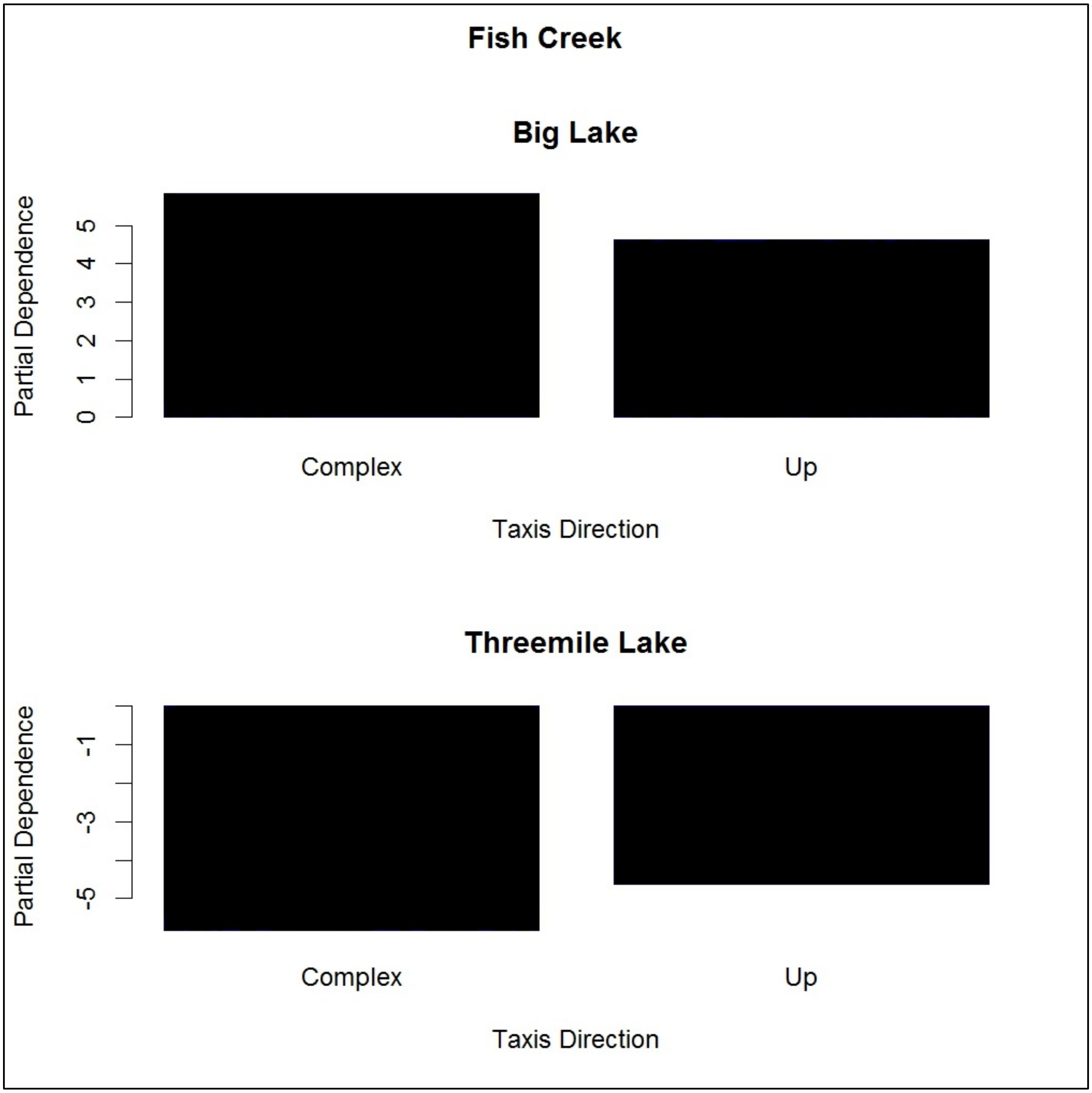

Figure 13. Partial dependence plot of taxis direction on overwintering area choice in the Fish Creek sub-drainage 2012 from the best fit random forest model.

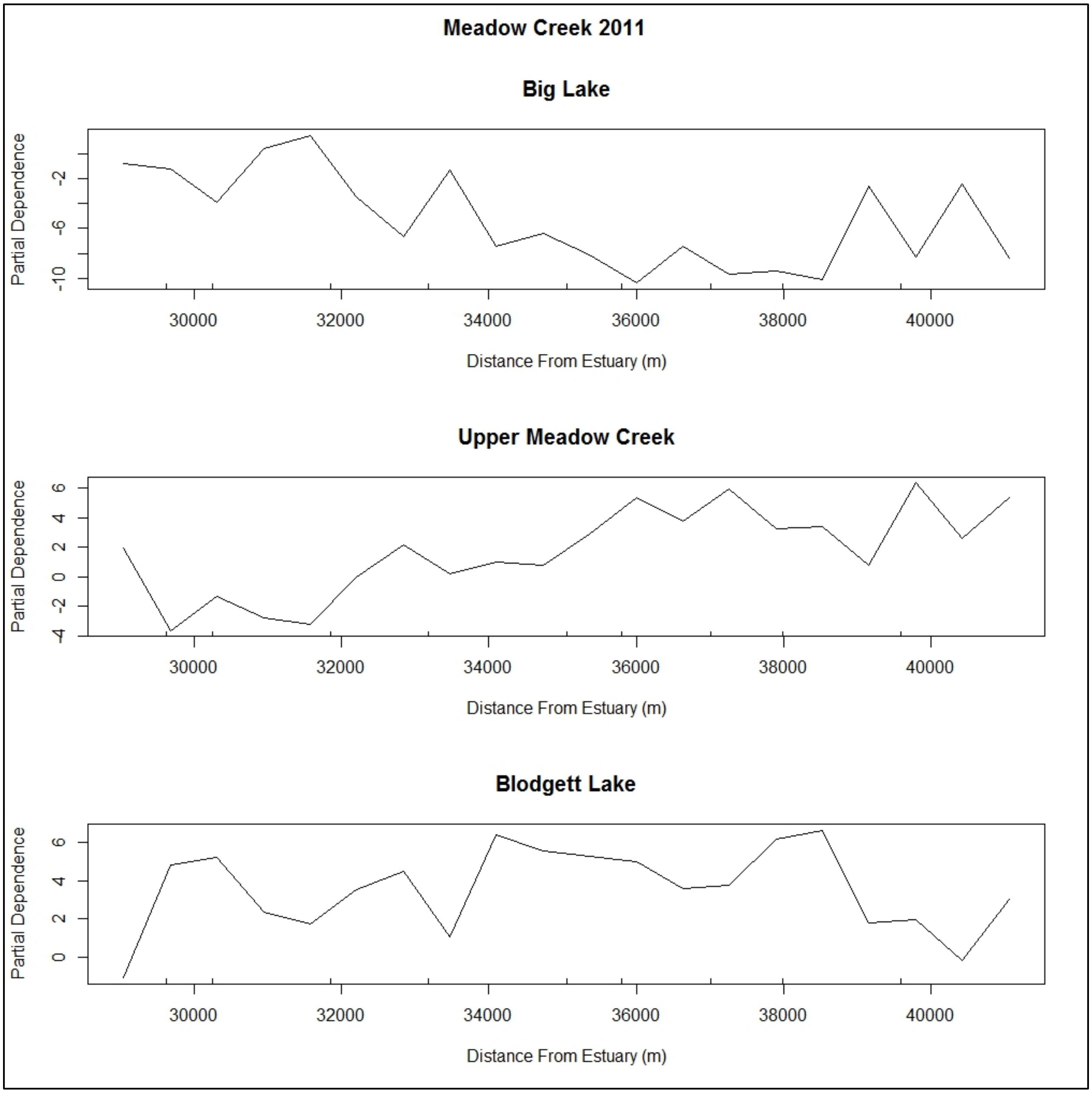

Figure 14. Partial dependence plot of distance from the estuary on overwintering area choice in the Meadow Creek sub-drainage 2011 from the best fit random forest model.

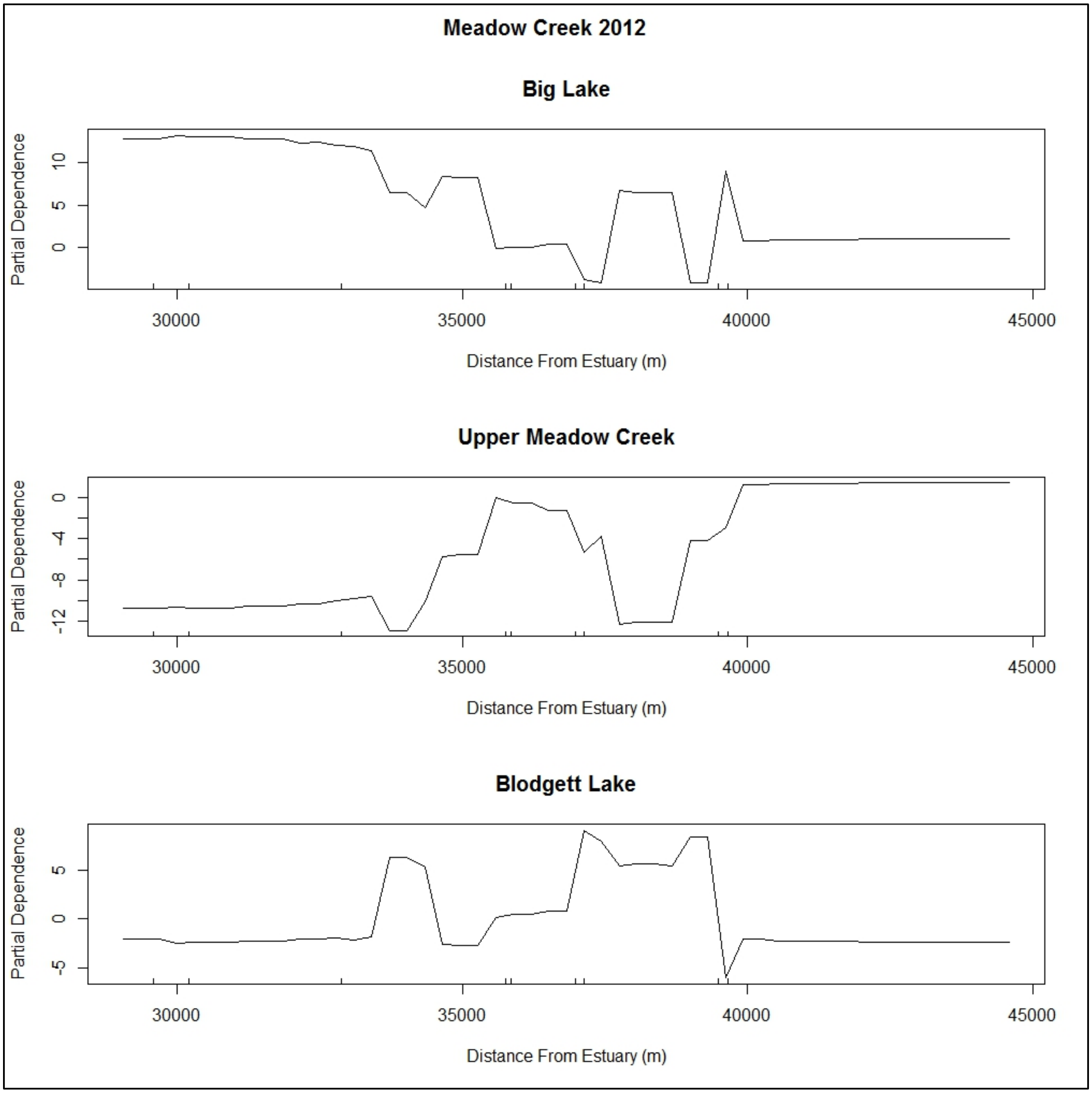

Figure 15. Partial dependence plot of distance from the estuary on overwintering area choice in the Meadow Creek sub-drainage 2012 from the best fit random forest model.

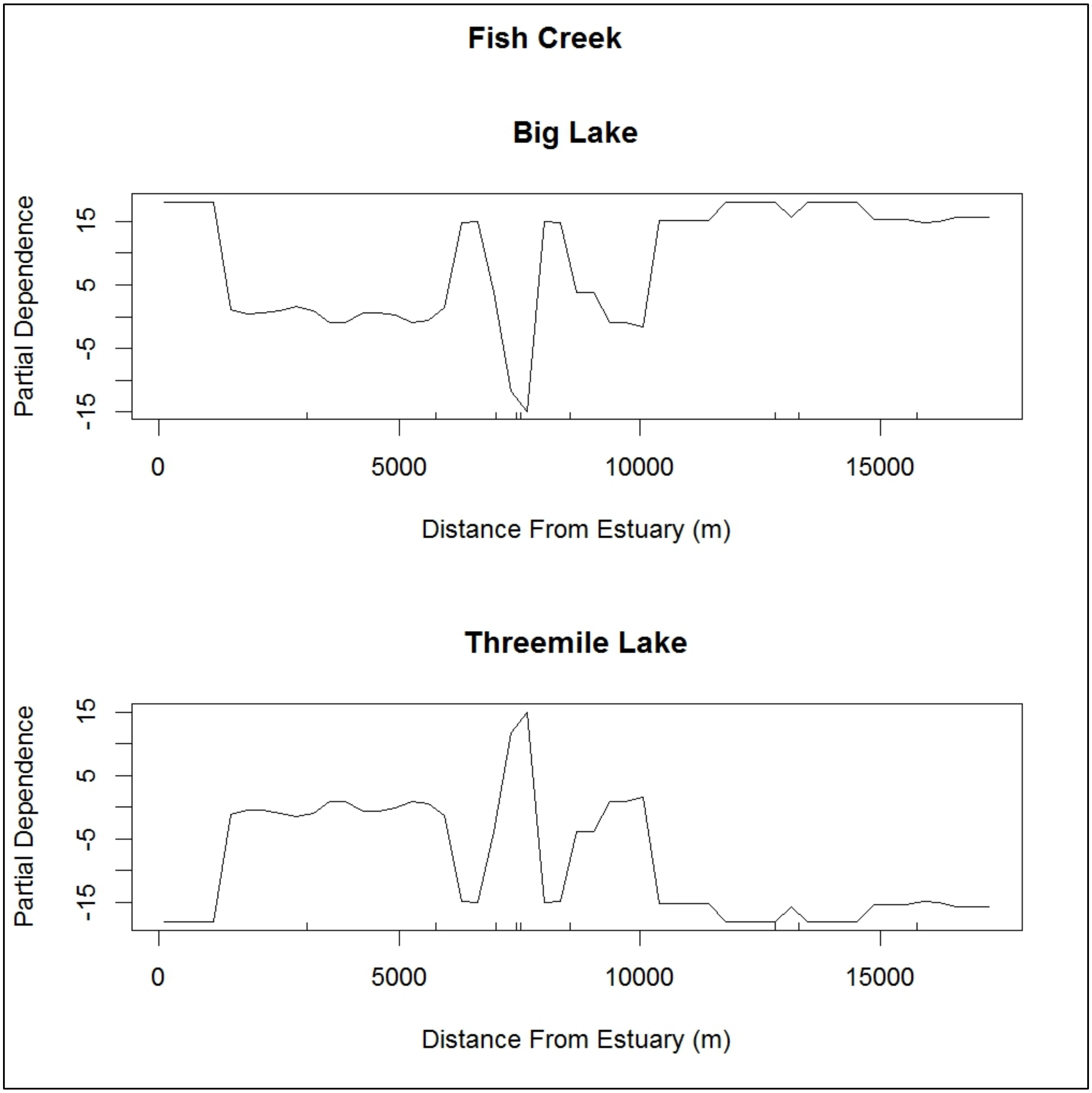

Figure 16. Partial dependence plot of distance from the estuary on overwintering area choice in the Fish Creek sub-drainage 2012 from the best fit random forest model.

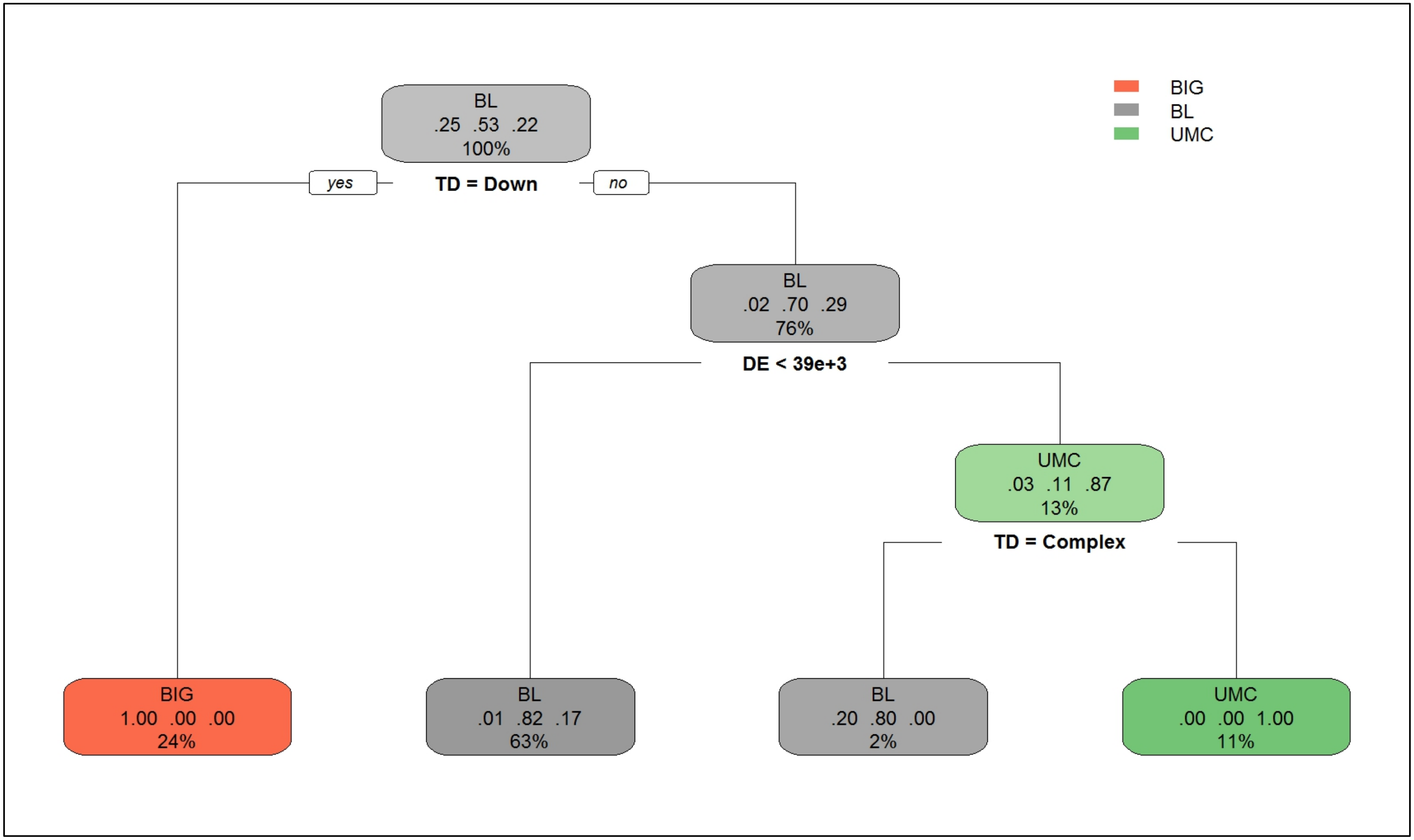

Figure 17. Classification tree detailing dispersal pathways of JCS to overwintering areas (Big= Big Lake, BL= Blodgett Lake, UMC=Upper Meadow Creek) within the Meadow Creek sub-drainage in 2011. Proportional values are presented in the same order for each leaf node (Big, BL, UMC).

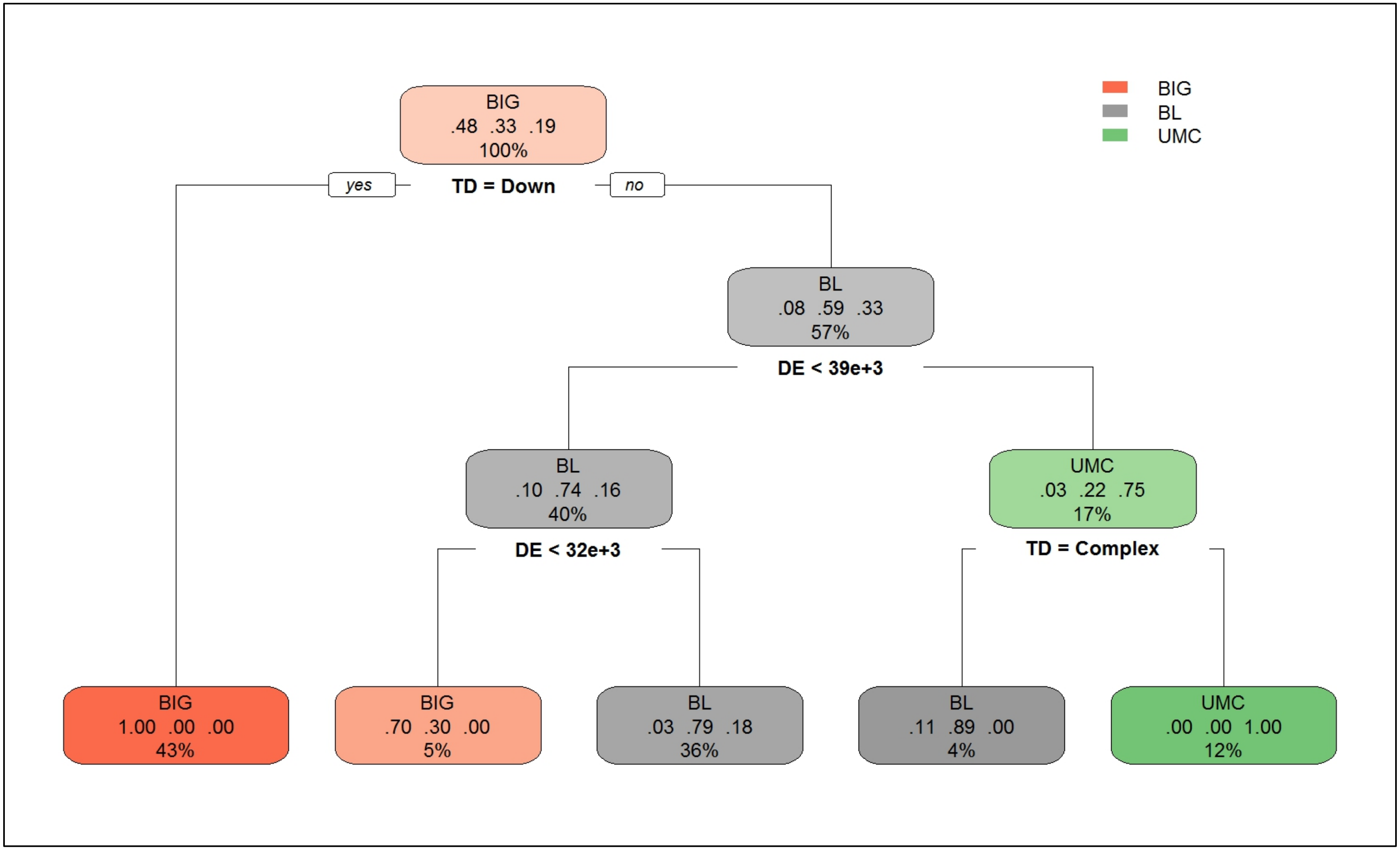

Figure 18. Classification tree detailing dispersal pathways of JCS to overwintering areas (Big= Big Lake, BL= Blodgett Lake, UMC=Upper Meadow Creek) within the Meadow Creek sub-drainage in 2012. Proportional values are presented in the same order for each node (Big, BL, UMC).

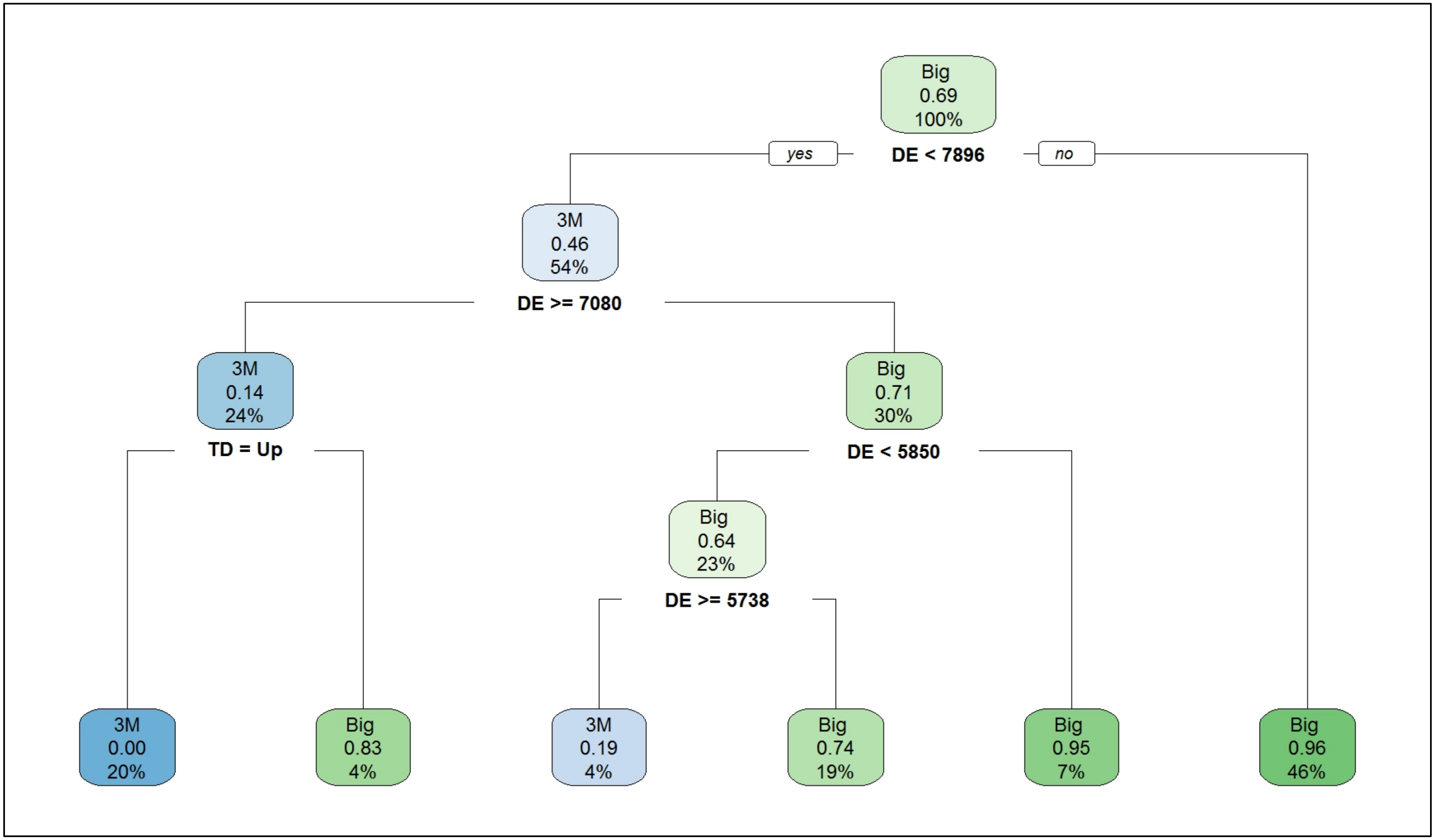

Figure 19. Classification tree detailing dispersal pathways of JCS to overwintering areas (Big= Big Lake, 3M= Threemile Lake) within the Fish Creek sub-drainage in 2012. Proportional values within each node are for Big Lake.

APPENDIX 1

Seven antenna array sites were used to track the movements of tagged JCS in the Big Lake watershed (Figure A1.1). Table A1.1 provides additional detail on each of the seven array sites, including the sub-drainage location, coarse scale habitat (main-stem or tributary), number of antennas, antenna orientation, and power source. All antenna array sites consisted of a waterproof battery box which contained two 12v batteries wired in series to generate 24v DC current, used to power a Biomark FS1001M multiplexer (MUX) unit also enclosed within the waterproof box. The MUX unit was used to power the antennas, to detect PIT tags as they passed through the antennas, and to record information (tag code, antenna number, date, and time). Batteries were continuously charged in one of two ways dependent upon array site. On-grid array sites used AC grid power which was passed through an AC-24vDC converter used to continuously power the MUX unit while maintaining the charge on the 24V battery bank backup used to prevent array failure in the event of a power loss. Off grid antenna array sites used a hybrid solar-thermoelectric generator (Model 5060L-SI-SO; Global Thermoelectric, Calgary, Canada); to continuously charge the battery bank using a combination of solar power and the propane fueled thermoelectric generator. Antenna array sites were tested monthly for detection efficiency by floating neutrally buoyant drones containing a PIT tag through each antenna. Detection efficiency ranged between sites (40 - 100%), and it was noticed that tag orientation as it passed through the antenna affected detection efficiency. Tags that floated parallel to the antenna were rarely detected, while tags that floated perpendicularly (in the same manner that a tagged fish would swim) were detected. Additional details for each antenna array site including physical description, specific antenna efficiency estimates, durations of site failures, total number of unique tags detected, and site pictures can be found in each of the following antenna area site sub-sections of Appendix 1.

Meadow Creek Antenna Arrays

Hatchery Array

The Hatchery array was the farthest downstream antenna site within the Meadow Creek sub-drainage. It was placed 5.0 km upstream of the Meadow Creek confluence with Big Lake and just downstream of a pair of 6' diameter, 70' long culverts passing under Beaver Lake road (Figure A1.2). Detection efficiency estimates ranged from 40 - 81%. A total of 213 detections of 196 unique tags were detected in 2011. The first detection was on 10 July and the last on 29 December. In 2012, a total of 554 detections of 420 unique tags were detected, with the first on 1 July and the last on 26 December. This site experienced operational failures in 2011 which resulted in the site losing power (and thus, PIT tag detection capability) from 3 August to 5 August due to an unknown on-grid power outage.

Lucille Array

The Lucille array site was located on Lucille Creek approximately 1.0 km upstream of the confluence with Meadow Creek, and just downstream of a 7' diameter, 108' long culvert which passes under Big Lake road (Figure A1.3). Detection efficiency estimates ranged from 86 - 100%. A total of 805 detections of 179 unique tags were detected in 2011. The first detection was on 23 July and the last on 14 December. In 2012, a total of 227 detections of 60 unique tags were detected, with the first on 21 July and the last on 11 November. This site experienced no operational failures in either 2011 or 2012.

Herkimer Array

The Herkimer array site was located on a short (<500m) channel which connected Herkimer and Corcoran Lakes, upstream of the Herkimer Lake tributary confluence with

Meadow Creek, and just downstream of a single 3’ diameter, 37’ long culvert which passed under South Ridgecrest road (Figure A1.4). Detection efficiency estimates ranged from 70 - 100%. A total of 1,777 detections of 554 unique tags were detected in 2011. The first detection was on 9 July and the last on 20 November. In 2012, a total of 1,350 detections of 261 unique tags were detected, the first occurred on 1 July and the last on 12 December. This site experienced no operational failures in 2011 or 2012.

Railroad Array

The Railroad array site was the farthest upstream site in the Meadow Creek sub-drainage, and was located just downstream of a 5’ diameter, 60’ long culvert passing under the Alaska Railroad (Figure A1.5). Access to this site was a trail paralleling the railroad tracks, accessible by ATV and snowmobile. Detection efficiency estimates ranged from 60 - 82%. A total of 160 detections of 100 unique tags were detected in 2011. The first detection was on 8 August and the last on 22 December. In 2012, a total of 312 detections of 178 unique tags were detected, with the first on 4 July and the last on 13 December. This site experienced numerous operational failures in 2011 which resulted in the array being non-operational for a total of 21 non-consecutive days between the dates of 1 July and 31 December. There were no operational failures in 2012.

Fish Creek Antenna Arrays

Weir Array

The Weir array site was the farthest downstream site within the Fish Creek sub-drainage l and was installed just upstream of the ADFG salmon weir site and approximately 4.6 km upstream of the confluence with the Knik Arm (Figure A1.6). The location was not associated with a culvert. Detection efficiency estimates ranged from 40 - 63%. A total of 55 detections of 38 unique tags were detected in 2012. The first detection was on 16 July and the last on 30 November. A majority of these detections were of fish moving upstream from a tagging event that erroneously released fish downstream of this antenna site. All fish tagged upstream of this site which were detected moving downstream were detected again at a later date, and upstream movement was assumed. This site experienced no operational failures in 2012.

Threemile Array

The Threemile array site was located on Threemile creek, just downstream of the Threemile Lake outflow (Figure A1.7). The location was not associated with a culvert. Detection efficiency estimates ranged from 50 - 75%. A total of 626 detections of 289 unique tags were detected in 2012. The first detection was on 17 July and the last on 22 November. This site experienced no operational failures in 2012.

Bridge Array

The Bridge array site was located on Fish Creek just downstream of a fish passage friendly water control structure at the outflow of Big Lake, under the Big Lake Road bridge (Figure A1.8). This location was not associated with a culvert. Detection efficiency estimates ranged from 74 - 80%. A total of 1,951 detections of 1,190 unique tags were detected in 2012. The first detection was on 17 July and the last on 26 December. This site experienced no operational failures in 2012.

Table A1.1 Site specific details for each of the antenna array sites located in the Big Lake watershed, Alaska.

Antenna Array	Sub-drainage	Habitat	No. Antennas	Antenna Size	Antenna Orientation	Power Source
Hatchery Site	Meadow Creek	Main-stem	3	3'x10'	Side by side	On Grid
Lucille Site	Meadow Creek	Tributary	2	3'x10'	Parallel	Off Grid
Herkimer Site	Meadow Creek	Tributary	2	3'x10'	Parallel	On Grid
Railroad Site	Meadow Creek	Main-stem	2	4'x4'	Parallel	Off Grid
Weir Site	Fish Creek	Main-stem	3	4'x10'	Side by side	Off Grid
Threemile Site	Fish Creek	Tributary	2	3'x3'	Parallel	Off Grid
Bridge Site	Fish Creek	Main-stem	3	3'x10'	Side by side	Off Grid

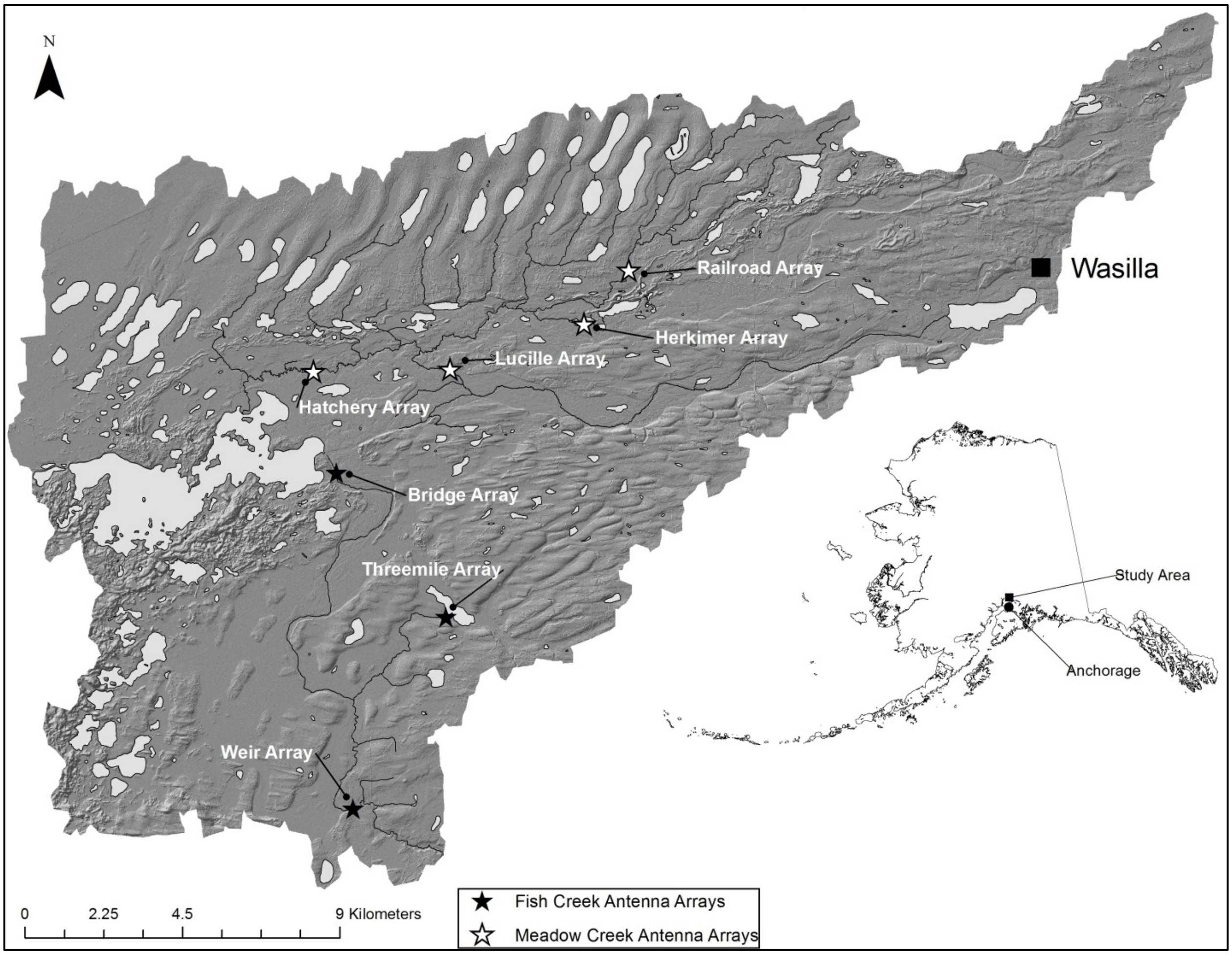

Figure A1.1. Shaded relief map with locations and names of all seven in-stream PIT tag antenna array sites.

Figure A1.2. Photographs of the Hatchery antenna array site.

Figure A1.3. Photographs of the Lucille antenna array site.

Figure A1.4. Photograph of the Herkimer antenna array site.

Figure A1.5. Photographs of the Railroad antenna array site.

Figure A1.6. Photographs of the Weir antenna array site.

Figure A1.7 Photographs of the Threemile antenna array site.

Figure A1.8 Photograph of the Bridge antenna array site.

APPENDIX 2

Movement profiles were created and analyzed for every JCS that had at least one detection event (recapture or antenna) following the initial tagging event. JCS with only a single entry in their movement profile (the tagging event) were removed from the study as they were assumed to have deceased after being tagged (Table A2.1.) Each JCS movement profile was created chronologically so the first row represents the tagging event followed by physical recapture and/or antenna detections. Example movement profiles with detailed descriptions of movement by row are shown in Tables A2.2. - A2.6.

Table A2.1. Movement profile for a JCS that was removed from the study as it was never detected after its initial tagging event.

JCS_ID	Date	Month	Year	Location	Reach	PIT_Tag	Environment	Drainage	FL	Weight
2301	6/28/2012	June	2012	2050	9	3D9.1C2DFE5524	Mainstem	Meadow_Creek	55	1.7

Table A2.2. Movement profile of a JCS that was tagged in the Meadow Creek sub-drainage main-stem sampling site 2050 on 28 June, 2012, and was detected at the hatchery antenna site on 3 November, 2012, indicative of a downstream dispersal to the Big Lake overwintering area.

JCS_ID	Date	Month	Year	Location	Reach/Antenna	Event	PIT_Tag	Environment	Drainage	FL	Weight
2302	6/28/2012	June	2012	2050	9	Tagging	3D9.1C2DFE571B	Mainstem	Meadow_Creek	110	14.7
2302	11/3/2012	November	2012	Hatchery	2	Antenna	3D9.1C2DFE571B	Mainstem	Meadow_Creek	NA	NA

Table A2.3. Movement profile of a JCS which was tagged in the Fish Creek sub-drainage main-stem sampling site 10500 on 4 July, 2012, and was recaptured 3 times between 2 August and 29 August 2012 in main-stem sampling site 16500. The final detection at the Bridge antenna site was on 26 October 2012, indicative of an overall upstream dispersal from sampling site 10500 to the Big Lake overwintering area.

JCS_ID	Date	Month	Year	Location	Reach/Antenna	Event	PIT_Tag	Environment	Drainage	FL	Weight
2529	7/4/2012	July	2012	10500	6	Tagging	3D9.1C2E00132A	Mainstem	Fish_Creek	75	4.8
2529	8/2/2012	August	2012	16500	10	Recapture	3D9.1C2E00132A	Mainstem	Fish_Creek	76	5.3
2529	8/15/2012	August	2012	16500	10	Recapture	3D9.1C2E00132A	Mainstem	Fish_Creek	78	5.6
2529	8/29/2012	August	2012	16500	9	Recapture	3D9.1C2E00132A	Mainstem	Fish_Creek	78	NA
2529	10/26/2012	October	2012	Bridge	5	Antenna	3D9.1C2E00132A	Mainstem	Fish_Creek	NA	NA

Table A2.4. Movement profile of a JCS which was tagged in the Meadow Creek sub-drainage main-stem sampling site 8300 on 19 June, 2012. Subsequent detections of this JCS at the Herkimer antenna site on 10 September 2012, show upstream movement past the antennas followed by downstream movement. This can be determined by the chronological antenna sequence 3-5-5-3, as the downstream antenna ID is 3 and the upstream antenna ID is 5. This JCS would be classified as an "unknown," as an overwintering area cannot be accurately determined by this movement profile.

JCS_ID	Date	Month	Year	Location	Reach/Antenna	Event	PIT_Tag	Environment	Drainage	FL	Weight
2897	6/19/2012	June	2012	8300	1	Tagging	3D9.1C2DFE5EB6	Mainstem	Meadow_Creek	57	3.1
2897	9/10/2012	September	2012	Herkimer	3	Antenna	3D9.1C2DFE5EB6	Tributary	Meadow_Creek	NA	NA
2897	9/10/2012	September	2012	Herkimer	5	Antenna	3D9.1C2DFE5EB6	Tributary	Meadow_Creek	NA	NA
2897	9/10/2012	September	2012	Herkimer	5	Antenna	3D9.1C2DFE5EB6	Tributary	Meadow_Creek	NA	NA
2897	9/10/2012	September	2012	Herkimer	3	Antenna	3D9.1C2DFE5EB6	Tributary	Meadow_Creek	NA	NA

Table A2.5. Movement profile of a JCS which was tagged in the Meadow Creek sub-drainage main-stem sampling site 2925 on 21 June 2012. Subsequent detections of this JCS at the Lucille antenna site on 23 June, 2012 show upstream movement past the antennas followed by downstream movement. This can be determined by the chronological antenna sequence 1-5-5-1, as the downstream antenna ID is 1 and the upstream antenna ID is 5. Later in the sampling season on 21 October, 2012, this JCS was detected again at the Hatchery antenna site moving downstream to the Big Lake overwintering area. This JCS would be classified as a "complex" dispersal direction as it was detected migrating both upstream and downstream.

JCS_ID	Date	Month	Year	Location	Reach/Antenna	Event	PIT_Tag	Environment	Drainage	FL	Weight
2822	6/21/2012	June	2012	2925	9	Tagging	3D9.1C2DFFA664	Mainstem	Meadow_Creek	116	19
2822	6/23/2012	June	2012	Lucille	1	Antenna	3D9.1C2DFFA664	Tributary	Meadow_Creek	NA	NA
2822	6/23/2012	June	2012	Lucille	5	Antenna	3D9.1C2DFFA664	Tributary	Meadow_Creek	NA	NA
2822	6/23/2012	June	2012	Lucille	5	Antenna	3D9.1C2DFFA664	Tributary	Meadow_Creek	NA	NA
2822	6/23/2012	June	2012	Lucille	1	Antenna	3D9.1C2DFFA664	Tributary	Meadow_Creek	NA	NA
2822	10/21/2012	October	2012	Hatchery	3	Antenna	3D9.1C2DFFA664	Mainstem	Meadow_Creek	NA	NA

Table A2.6. Movement profile of a JCS which was tagged in the Meadow Creek sub-drainage main-stem sampling site 1525 on 28 July, 2011. Subsequent detection of this JCS at the Herkimer antenna site on 9 September, 2011 shows upstream movement. This JCS was later recaptured in Blodgett Lake, an identified overwintering area within the Big Lake watershed.

JCS_ID	Date	Month	Year	Location	Reach/Antenna	Event	PIT_Tag	Environment	Drainage	FL	Weight
1615	7/28/2011	July	2011	1525	5	Tagging	3D9.1C2D6FF481	Mainstem	Meadow_Creek	96	NA
1615	9/9/2011	September	2011	Herkimer	3	Antenna	3D9.1C2D6FF481	Tributary	Meadow_Creek	NA	NA
1615	9/9/2011	September	2011	Herkimer	5	Antenna	3D9.1C2D6FF481	Tributary	Meadow_Creek	NA	NA
1615	9/22/2011	September	2011	Blodgett	29	Recapture	3D9.1C2D6FF481	Lake	Meadow_Creek	112	NA