U.S. Fish and Wildlife Service

Juvenile Coho Salmon Migration and Habitat Use in Meadow Creek, Southcentral Alaska, 2011

Alaska Fisheries Data Series Number 2013-1

Anchorage Fish and Wildlife Field Office
Anchorage, Alaska
April 2013

The Alaska Region Fisheries Program of the U.S. Fish and Wildlife Service conducts fisheries monitoring and population assessment studies throughout many areas of Alaska. Dedicated professional staff located in Anchorage, Juneau, Fairbanks, Kenai, and King Salmon Fish and Wildlife Offices and the Anchorage Conservation Genetics Laboratory serve as the core of the Program's fisheries management study efforts. Administrative and technical support is provided by staff in the Anchorage Regional Office. Our program works closely with the Alaska Department of Fish and Game and other partners to conserve and restore Alaska's fish populations and aquatic habitats. Additional information about the Fisheries Program and work conducted by our field offices can be obtained at:

http://alaska.fws.gov/fisheries/index.htm

The Alaska Region Fisheries Program reports its study findings through two regional publication series. The **Alaska Fisheries Data Series** was established to provide timely dissemination of data to local managers and for inclusion in agency databases. The **Alaska Fisheries Technical Reports** publishes scientific findings from single and multi-year studies that have undergone more extensive peer review and statistical testing. Additionally, some study results are published in a variety of professional fisheries journals.

Alaska Fisheries Data Series Number 2013-1, April 2013
U.S. Fish and Wildlife Service

Juvenile Coho Salmon Migration and Habitat Use in Meadow Creek, Southcentral Alaska, 2011

Jonathon Gerken and Suresh Sethi

Abstract

Substandard culverts associated with extensive road development in the Matanuska-Susitna basin are a significant threat to connectivity of salmon habitats. Approximately 70% of more than 400 culverts surveyed were a barrier to juvenile salmon migration at certain flows. Understanding migratory patterns and identifying important rearing habitats would improve efforts to prioritize expensive culvert replacements. The goal of this project is to provide an assessment of juvenile coho salmon *Oncorhynchus kisutch* migration and habitat use by cohort in the Meadow Creek portion of the Big Lake drainage using passive integrated transponder (PIT) tags. In 2011, 2,295 PIT tags were implanted in juvenile coho salmon in Meadow Creek, Alaska, and tracked throughout the study reach using both mobile tracking and four fixed PIT tag antenna arrays. This interim report summarizes juvenile coho salmon migration, growth, and habitat use by cohort between June and November 2011. Assigned ages were based on fork lengths taken throughout the sampling period using a two-distribution Gaussian mixture model. Results indicate movement metrics between juvenile coho salmon cohorts (age-0 and age-1+) were not significantly different. Conversely, instantaneous growth rates were significantly different between cohorts with younger fish growing faster. Both cohorts exhibited a preference for main-stem and tributary habitats during summer months and lakes during fall and winter. These data will be used to assess fish passage at culverts and migration behavior among the three habitat types in this drainage, providing biological input to prioritize culvert replacement under a limited mitigation budget.

Introduction

The rivers and lakes of the Matanuska-Susitna (Mat-Su) region in Southcentral Alaska support some of North America's most viable and productive Pacific salmon *Oncorhynchus* spp. fisheries. This area is recognized as the fastest growing area in Alaska, prompting concerns for continued viability of salmon habitat. This nexus of high biological value coupled with rapid development; prompted formation of the Mat-Su Basin Salmon Habitat Partnership (Partnership). This Partnership operates under the auspices of the National Fish Habitat Partnership (NFHP), which is a national effort to protect and restore the nation's waterways and fisheries through science-based partnerships of affected stakeholders. The Partnership has developed a Strategic Action Plan (Mat-Su Basin Salmon Habitat Partnership 2008), which identifies objectives, actions, and research necessary to protect salmon and salmon habitat in the Mat-Su basin.

Authors: The authors are with the U.S. Fish and Wildlife Service. The primary can be contacted at the Anchorage Fish and Wildlife Field Office, 605 W 4th Avenue, Room G-61, Anchorage, AK 99501 or jonathon_gerken@fws.gov.

Salmon migration, spawning, rearing and ultimately production in these water bodies are dependent on connectivity of habitat. Culvert surveys have been conducted in the Mat-Su since 1999 and approximately 71% of the over 400 culverts surveyed were rated as a barrier to juvenile salmon at certain flows (Mat-Su Basin Salmon Habitat Partnership 2011). Restoration efforts to improve fish passage for the past 15 years and have resulted in replacement or removal of over 60 culverts, however, the selection process for identifying culverts for replacement or restoration can be significantly improved. To date, there has been no pre- or post-treatment evaluation of fish movement to demonstrate the degree of success from these efforts.

The Big Lake drainage near Wasilla, Alaska, has been identified as a high priority area for restoration efforts (Mat-Su Basin Salmon Habitat Partnership 2009). This watershed occupies over 100 square miles and is one of the fastest developing areas in the Mat-Su. With over 100 miles of streams, many less than 2 m wide and connected to lakes and large wetland complexes, fish habitat is widely dispersed. The watershed is a significant producer of sockeye *Oncorhynchus nerka* and coho salmon *O. kisutch*, contributing to commercial, sport, and personal use fisheries. Water comes from springs and groundwater, with no surface connection to higher elevation snowmelt sources. Approximately 79 culverts occupy potential salmon habitat, with most (64%) being assessed as potential fish passage barriers or partial barriers to juvenile salmon (Alaska Department of Fish and Game 2013). Overall, the Big Lake drainage was rated extremely high for both biological value and vulnerability to development; and therefore is among the top priorities for conservation efforts by the Partnership (Mat-Su Basin Salmon Habitat Partnership 2011). This watershed is of further interest because it is one of the few watersheds in Alaska with a large network of roads crossing over creeks, has a low gradient, and is a groundwater-fed system. In a state that is over 40% wetland (Alaska Department of Fish and Game 2006), assessment of this watershed provides an unprecedented study on the impacts of road crossings within a wetland-dominated system.

Understanding seasonal movements of fish during all life stages is a prerequisite to successful fisheries management (Cunjak 1996). Quantifying movement patterns may illuminate strategies used by fish to optimize fitness in a variable environment (Kocik and Ferreri 1998), such as variation in size and growth rate impacting survival (Hoar 1976; Quinn and Peterson 1996) and understanding the effects of these variables at the watershed scale is valuable for efficient allocation of restoration actions (Lawler and Schumaker 2004). Migrations in both upstream (Bustard and Narver 1975) and downstream directions (Swales et al. 1986; Brown and Hartman 1988; Nickelson et al. 1992) have been observed. Seasonal movement by juvenile coho salmon into tributaries is a life-history strategy that can result in enhanced survival (Bustard and Narver 1975; Kralik and Sowerwine 1977; Tschaplinski and Hartman 1983; Ebersole et al. 2006). In addition, Ebersole et al. (2006) indicated movement by juvenile coho salmon into tributaries was temporary as fish moved to overwintering areas. Of particular interest in this project, is how potential migratory barriers affect temporal movement and their spatial use of habitat for each cohort.

Areas of high human population growth can affect stream networks and impact watershed connectivity. Passive integrated transponder (PIT) tags can enable detection of fish movements over large temporal and spatial scales. The goal of this project is to provide a quantitative assessment of juvenile coho salmon migration and habitat use by cohort in the Meadow Creek drainage. The specific hypotheses for this interim report were (*i*) juvenile coho salmon > 55 mm exhibit extensive movements in the Meadow Creek drainage, (*ii*) juvenile coho salmon > 55 mm would select specific habitats seasonally within the Meadow Creek drainage, and (*iii*) seasonal growth rates of age-0 and age-1+ juvenile coho salmon in the Meadow Creek drainage would differ significantly. These data will be used to assess juvenile coho salmon passage at culverts and migratory behavior among habitat types in this drainage and provide biological input into an objective decision making optimization model (Kemp and O'Hanley 2010) to prioritize culvert replacement with a limited mitigation budget. This type of model provides a functional score to individual stream segments within a drainage based on fish ecology criteria; such as presence of adult spawning areas, presence of juvenile overwintering areas, and the severity of culvert blockage to fish passage. Functional scores can be evaluated throughout the watershed. For example, a large functional score could be indicative of a biologically important stream segment, such that, culverts restricting access to the stream segment would be weighted as more important for restoration.

Current funding for this project extends through November 30, 2014, and following project completion a final report will be submitted. However, it is our intent to provide interim results throughout the project time frame. This is the first interim report for July 1, 2011, through November 15, 2011. This time period was chosen because it represents the summer rearing period for juvenile coho salmon up to their winter residence. This report provides results of tagging, migration timing and distances, observations regarding migration cues, general environment preference, and criteria for discriminating juvenile coho salmon cohorts by fork length within that time frame. Future reports will describe movements and habitat use of juvenile coho salmon using more extensive analytical procedures over longer time periods. In addition, the final report will summarize all project information and provide an optimization-based decision analysis to prioritize culvert replacement as a fish habitat restoration measure (Kemp and O'Hanley 2010). This type of decision-model has not been applied in the state of Alaska, though it has been used with success elsewhere in the continental United States.

Study Area

The Big Lake watershed drains more than 230 km^2 within the Cook Inlet basin (Figure 1). Streams in the Big Lake watershed are largely groundwater driven (Jokela et al. 1991; Hogan 1995) and the headwaters begin approximately 10 km northwest of Wasilla, flowing westward through Meadow Creek into Big Lake. Meadow Creek is a meandering stream that begins at the confluence of Little Meadow Creek and Lucille Creek. Curran and Rice (2009) described a 29 km section of the main-stem Meadow and Little Meadow creeks as dominated by run habitat and covered with instream vegetation. Off-channel habitats varied from beaver ponds, lakes, and narrow tributaries. Meadow Creek is the most extensive watercourse in the Big Lake watershed, fed by many lakes and streams, and is the major surface-water inflow to Big Lake. The primary outlet for Big Lake is Fish Creek which meanders south 23 km terminating in the Knik Arm of Cook Inlet. Meadow Creek was identified as the one of the primary spawning grounds for coho salmon in a 2009–2010 U.S. Fish and Wildlife Service (USFWS) radio-telemetry project (USFWS, unpublished data). Within Meadow Creek and its tributaries, five major coho salmon spawning areas were identified with spawning timing occurring in September and October (USFWS, unpublished data). These areas are interspersed between approximately 30 culverts (Figure 2).

Methods

Fish Tagging and Tracking

Sampling for juvenile coho salmon using minnow traps was completed in main-stem, lake, and tributary environments during summer and fall. Fish were tagged with PIT tags and movement between environments was monitored with fixed PIT tag arrays and mobile tracking. The study area was confined to a 14 km section of Meadow Creek and Little Meadow Creek between two culverts; the downstream boundary was located at Beaver Lake Road and the upstream boundary located at a railroad track crossing located south of Meadow Lake Loop (Figures 2 and 3). This section of the Meadow Creek watershed was identified as the primary spawning area for radio-tagged coho salmon in 2009 and 2010 (USFWS, unpublished data). This study area was chosen because of the large presence of spawning salmon and the expected presence of juvenile coho salmon.

Temporal and spatial distributions and movement of juvenile coho salmon were described between three coarse-scale environments: main stem, tributary, and lake. This scale was important for identifying gross fish movement patterns similar to Ebersole et al. (2006). These three environment types are prevalent within the Meadow Creek drainage, persist within the study area, and can be accessed throughout the sampling period (Figure 3). A main-stem environment was defined as moving water composing the principle wetted channel within the Meadow Creek drainage. A lake environment was defined as a body of standing water. A tributary environment was defined as the connecting waterway between lake and main-stem environments.

Minnow trap sampling began in June and continued until ice-up on November 15, 2011. A biweekly sampling frequency was used to schedule sampling events and to maximize the number of recaptures throughout the study period. Because the total amount of area for each environment differed, the number of sampling reaches was disproportional (Figure 3), as such a proportion probability sampling design (PPS) was used. A PPS sets the number of reaches per environment based on the proportion of area each environment represents within the study area (Hankin 1984).

Lapointe et al. (2006) noted the use of minnow traps to sample the offshore littoral zone of lakes were ineffective with a sampling reach size of 1,000 m^2, while Bryant (2000) indicated minnow trap effectiveness at a radius of 2 m in pool type habitats. Minnow traps have advantages over electrofishing and seining because they are less harmful to the fish, minimize stream disturbance, can be used efficiently in complex habitats, and are not dependent on water chemistry (Habera et al. 1996; Reynolds 1996). Repeated minnow trap sampling by the USFWS Anchorage Field Office Fisheries Branch in the Knik Arm in 2010 (Benolkin 2011) indicated two 2-person crews could deploy and collect 30 minnow traps daily or 180 traps in a 6 day sampling week. Conversely, this project had less travel time to sites and therefore the number of traps deployed could be doubled to 60 per day. Minnow traps were baited with salmon eggs and deployed for a minimum of 60 minutes (Dolloff 1986) next to suspected juvenile habitat such as woody debris, root wads, or undercut banks (Bryant 2000) in tributary and main-stem environments and underwater structures within lakes.

Sampling reaches located in main-stem and tributary environments are typically not structured in terms of area, instead these reaches are usually expressed in terms of linear distance. Because lakes are an important habitat for juvenile coho salmon in this study, we used surface area to define a common sampling reach size among all three habitat types. Also, paramount to this study was the need to define sampling reaches at a scale observable using a geographic information system (GIS) analysis and identifiable with global positioning system (GPS) technology in the field environment. Johnson and Barton (2004) indicated the accuracy of a handheld GPS is within 30 m. Therefore, a sampling reach size was defined as 250 m^2. A mean bankfull width of 10 m on main-stem environments and 3 m on tributary environments was used for calculations. These widths were based on observations attained in a 2009-2010 radio-telemetry study (USFWS, unpublished data). In order to maintain a 250 m^2 sampling reach, a linear length of 25 m was used in main-stem environments and 83 m was used in tributary environments. Lakes chosen for sampling within the study area were Corcoran Lake, Herkimer Lake Blodgett Lake, and Twin Lake. These lakes differed in depth and observable habitat characteristics, the former two being shallow (< 1 m) and primarily composed of mud bottom and the latter two being deep (> 10 m) and composed of rocky or gravel substrates. These two lake types were representative of other lakes within the watershed. In addition, these lakes were chosen because access was available at a public boat launch or permission to trespass was obtained through a private landowner. The overall proportion of each environment relative to the entire study area is shown in Table 1. In addition, the proportional sampling selection accounted for the number of traps to be deployed daily, the sampling unit size of a minnow trap (250 m^2), and the bi-weekly sampling frequency.

Sampling reaches were composed of sub-reaches to minimize transportation and access time (Figure 4). A main-stem reach was composed of 15 sub-reaches whereas lake and tributary reaches were composed of 5 sub-reaches. The number of minnow traps deployed for each environment are as follows: area sampled for main-stem reaches was 3,750 m^2 (a linear length of 375 m with 30 minnow traps deployed), 1,250 m^2 for tributary reaches (a linear length of 415 m with 10 minnow traps deployed), and 1,250 m^2 for lake reaches with 30 minnow traps deployed. Reach location starting points within each environment type were randomly selected prior to the onset of fieldwork. These reaches remained fixed throughout the study. Additional sampling reaches were added as field personnel became more efficient; Rainbow Lake Pond, Hidden Gem Lake, Stepan Lake, and a main-stem sampling reach located downstream of Hidden Gem Lake (Figure 4).

Given that we had little to no prior information on the abundance or movement habits of juveniles in the study system, nor the effectiveness of sampling efforts to capture and recapture marked individuals, probabilistic statements to determine tag allocation and timing was not possible. Decisions regarding a) how many tags to release, b) when to release tags, and c) where tags should be released in the three environment types was made in response to the release of a target of 2,000 tags (financially imposed target), field personnel constraints, and a goal of maximizing the number of detections to observe fish movement. Therefore, tags were released as early on in the study as feasible, in order to get the most movement and distribution information as possible. Thus, tagging allocation across environment types mirrored the sampling effort. This sampling approach was designed to provide equal detection effort and tagging release effort per unit area of specific environment types throughout the study.

Fish Tagging

Tagging methods were evaluated in the Ship Creek Hatchery located on Joint Base Elmendorf-Richardson Air Force Base in Anchorage, Alaska, prior to field sampling. Hatchery fish were subjected to field protocols to evaluate tag retention and tagging mortality. Tagged fish were placed in a separate hatchery runway and monitored daily for 3 days. After 3 days, the fish were euthanized, checked for tags and internal injury, and disposed.

All captured fish were anesthetized using a 40 mg/L buffered stock solution of MS-222 (Schoettger and Julin 1967) and measured (mm) to fork length. Fish greater than 55 mm fork length were marked with a PIT tag (Brakensiek and Hankin 2007). A Biomark® MK-25 implant gun with a 12-gauge needle preloaded with a 12.5 mm long, 2.1 mm diameter, 134.2 kHz, full duplex, international organization for standardization (ISO) PIT tag was used to insert tags into the abdominal cavity of the fish. Each PIT tag transmits a unique electronic signal when passed through an antenna. Fish were allowed 30-60 minutes to recover and returned to the area of capture.

<u>*Fish Tracking*</u>

Mobile tracking is defined as the repeated sampling of reaches throughout the project time frame with minnow traps. Fish captured in minnow traps were scanned using a handheld ISO reader to identify PIT tags.

Four pass-through style fixed PIT tag antenna arrays were located within the project area at separate culvert crossings. Antennas were constructed with schedule 40 or 80 PVC dependent upon manufacturer and arranged in 3'x10', 4'x10', or 5'x5' geometry. Arrays were composed of two or three antennas powered by an on-grid electrical connection or by off-grid Global Thermoelectric hybrid 5060L-SI-SO thermal generator and solar panels. Arrays were orientated in two different ways: (1) side by side to cover a larger wetted width (Appendix A) or; (2) parallel (Appendix B). Direction of travel of tagged fish could be determined with the parallel configuration, but not with the side by side configuration. Unique characteristics of radio frequency (RF) noise, waterway channel dimensions, and land ownership at each location resulted in different setup orientations. Array 1, Hatchery fixed array, was located at Beaver Lake Road and was the only side by side setup (Appendix A). Array 2, Lucille fixed array, was located at Big Lake Road and Lucille Creek (Appendix B). Array 3, Herkimer fixed array, was located at Ridgecrest Road and Herkimer Creek (Appendix C). Array 4, Railroad fixed array, was located at a railroad crossing southwest of Meadow Lake Loop Road (Appendix D, Figure 3). An array was comprised of an antenna, a Destron Fearing FS1001M multiplexing transceiver, a thermoelectric generator or on-grid connected power source under agreement with a landowner, and any associated cables, enclosures, solar panels, and batteries. Antennas were affixed to the substrate and placed into the stream to span the channels wetted width. Arrays were monitored and transceivers downloaded weekly throughout the project.

Certain aspects of fish behavior, stream characteristics, and electronic limitations will affect PIT tag detection. The influence of these aspects was monitored by testing the array efficiency and tag detection during project onset and monitoring RF noise weekly when data was downloaded. Array efficiency, measured as the proportion of PIT tags detected was estimated by inserting 10 PIT tags into neutrally buoyant drones and floating through each antenna in an array. The process was repeated 10 individual times resulting in a validation sample of 100. The proportion of tags that were detected by each antenna was calculated and used as the estimate of array efficiency.

Movement

<u>*Movement Distance*</u>

GIS interpretation was used to calculate the mean, maximum, and minimum distance traveled by juvenile coho salmon. The mean distance travelled by fish from their initial capture environment to their last detected location was compared between age classes (age-0 and age-1+) using Wilcoxon paired-sample test and results were considered significant at $P \leq 0.05$.

<u>*Movement Direction*</u>

Direction of movement was determined using the initial tagging location, fixed, and mobile tracking information. Direction was determined by comparing the initial tagging location of an individual tag with the location when it was detected at an array or captured in mobile tracking.

Drivers of Movement

Water temperature and increasing flows or high water in rivers are thought to initiate downstream movement of fish (Jonsson 1991). In addition, various studies correlate movement with smolt migration (Solomon 1978; Jonsson and Rudd-Hansen 1985) and note movement from main-stem habitats to tributary habitats with increased flow (Bramblett et al. 2002). Bisson and Bilby (2002) observed juvenile coho salmon avoid areas of high turbidity (>70 NTU). These water quality variables may drive or initiate movement. A YSI 6600 V2 Sonde was affixed to the substrate near the Hatchery array, marking the lower boundary of the study area. The Sonde recorded hourly measurements of water temperature, specific conductivity, pH, optical dissolved oxygen saturation, and turbidity. Water discharge was recorded daily by the Alaska Department of Fish and Game (ADF&G) using a SonTech ADV or Teledyne StreamPro Acoustic Doppler at the same location (T.A. Cappiello, the Alaska Department of Fish and Game, personal communication). The combined daily count of tag detections observed at fixed antenna sites was compared to daily water quality variables in an effort to evaluate if a relationship between movement and water quality existed.

Environment Use Patterns

Catch per unit effort (CPUE; fish/h) was calculated for juvenile coho salmon captured in minnow traps for each trapping event, and CPUE between environments was compared using the nonparametric Kruskal-Wallis test (Zar 1999).

Fish Age and Growth

Fish fork lengths were used to determine age class and differentiate between age-0 and age-1+ juvenile coho salmon. The objective of the age-length verification analysis was to choose a fork length size that best discriminated juvenile coho salmon into age-0 or age-1+ cohorts. A two-distribution Gaussian mixture model approach to estimate the population mixture distribution of age-0 and age-1+ fish using fork lengths from captured fish was implemented. Based upon the fitted mixture distribution, an optimal age-discriminating fork length was chosen by minimizing misclassification error using the following procedure:

1. Fit a two-distribution Gaussian (i.e., normal) mixture model to the observed sample of fork lengths.
2. Randomly draw $i = 1,2,\ldots,n$ lengths, l_i, of known membership from the fitted mixture distribution; this will result in a large number of known age (i.e., age-0 or age-1+)-length data.
3. Using the simulated age-length data from step two, choose an optimal fork length threshold, $l*$, which minimizes misclassification error:

$$\min_{l^*} \sum_{i=1}^{n} \left(C(l_i|l^*) - A(l_i) \right)^2$$

where, classifier $C(l_i|l^*) = \begin{cases} 1 \; if \; l_i > l^* \\ 0 \; if \; l_i \leq l^* \end{cases}$ and $A(l_i) = \begin{cases} 1 \; if \; known \; age \; of fish \; i \; is \; age \; 1^+ \\ 0 \; if \; known \; age \; of fish \; i \; is \; age \; 0 \end{cases}$ and the assumption is made that central tendency of the distribution of age-1+ fish is larger than that for age-0 fish.

As fish grow through time, the underlying mixture distribution of lengths will change. The above mixture analysis procedure was conducted over temporal strata, resulting in an optimal age-discriminating fork length threshold for each month. Mixture model analysis was conducted using the 'mclust' package in R (Fraley and Raftery 2006; R Development Core Team 2010).

Fish Age

Scale samples were collected from juvenile fish mortalities by scraping from tail to head using a scalpel to remove 5-10 scales from the preferred area as described by Mosher (1963). Samples were collected throughout the project time frame; and additional vouchers were collected in an effort to have two specimens per 10 mm fork length class. Fish placed on a slide and examined with a microscope were aged using the standards and guidelines of Mosher (1968). Aged fish were validated by two readers and discrepancies between readers were resolved with a third reader. Ages are reported using the European methods notation by Jerald (1983).

Growth

Instantaneous growth rate (IGR) will provide an estimate of growth over a short time period.

$$G = \frac{\log_e L_2 - \log_e L_1}{t_2 - t_1}$$

Where, G is growth rate, t_1 is initial time measured in calendar days, t_2 is final time, and L_1 and L_2 are the corresponding lengths for those times.

Tagged fish were included in IGR analysis if they were recaptured more than once in mobile tracking events with at least 28 days, a period where tagging and handling effects may bias results (Ebersole et al. 2006) between the initial tagging event and the recapture event. Negative IGR values were removed from the analysis. Negative values were a result of fork lengths recorded as smaller in the recapture event, indicative of sampling error in recording fork length during the tagging or recapture event. The IGRs were compared between cohorts using the Mann-Whitney rank sum test. Results were considered significant at $P \leq 0.05$.

Results

Fish Tagging and Tracking

Fish Tagging

A total of 119 juvenile coho salmon were tagged at the Ship Creek Hatchery prior to field sampling occurring. There were four mortalities (3%) noted on the first day. No additional mortalities were observed in the remaining three days of observation. Of the 115 remaining tags, 4 tags (3%) were shed. All fish were examined for internal injuries and disposed after the three-day observation period. There were 18 of the 115 fish that showed signs of internal hemorrhaging, likely due to the hypodermic style 12-gauge needles. Hypodermic needles are reusable and need to be sharpened after each use, decreasing the overall sharpness of the needle, making tag entry incisions jagged after the initial use. No attempt was made to estimate tag retention or mortality in the natural environment.

A total of 4,174 juvenile coho salmon were captured throughout the study period (Table 2). Length-frequency distributions by environment are displayed in Figure 5. Fish sampling began June 15, 2011, with trap effort (number of traps multiplied by number of soak hours) being greatest in the main-stem environments. Only opportunistic sampling in the tributary and main-stem environments occurred in June (Table 3). Installation of the fixed antennas was priority during this time frame and was completed in late-June.

Tagging or implanting PIT tags into juvenile coho salmon began on July 6, 2011, and ended on September 20, 2011. In total, 2,295 PIT tags were implanted. Tags were deployed as quickly as fish were captured to maximize the number of detections. Trap effort was greatest in the main-stem environments during July, August, and September. In addition, 7 sockeye salmon, 2,318 rainbow trout, 42,971 three-spine stickleback, 6 longnose sucker, and 677 sculpin were captured.

The number of fish captured and consequently the number of fish tagged reflects the location and seasonal environment preference of juvenile coho salmon within the sampling area throughout the project time frame (Table 3). For example, while 32% of the trapping effort during August was conducted in lake environments, only 33 total fish (2% of the total August catch) were captured; indicating low preference for lake environments. Conversely, 66% of the trapping effort in July was allocated to main-stem environments, resulting in nearly 1,100 (80% of the total July catch) fish captured; indicating seasonal preference for the main-stem environments during July.

Most fish were tagged in main-stem environments (78%) as compared to the tributary environments (16%) and lake environments (6%). Tagged fish were mainly age-0 fish (n = 1,469, 64%) as compared to age-1+ fish (n = 826, 36%, Figure 6). As such, age-0 fish were the dominant cohort in nearly all environment and sampling month combinations. However, during July in tributary environments, age-1+ were tagged in greater proportion (81%) than age-0 fish (19%, Table 4).

A result of tagging fish using this method was that within an environment, certain sampling reaches had a greater number of tags deployed (Table 5). The largest number of tags were deployed in main stem sampling reaches; 850 (n = 183), 1525 (n = 293), 6275 (n = 174), 6950 (n = 218), and 8300 (n = 253). Tags were deployed primarily in July (n = 1,253). Tributary sampling reach 795, located on Herkimer Tributary, had the largest number of tags deployed (n = 106). Sampling reach 795 is located just downstream of Herkimer Lake and on the migratory path to Blodgett Lake. Blodgett Lake had the largest number of tags (n = 77) deployed within all lakes.

Fish Tracking

For nearly 6 months, July 1 – October 20, 2011, the study area within Meadow Creek was sampled bi-weekly at all sampling reaches. Mobile tracking was conducted to recapture tagged fish by two person crews working downstream to upstream. Approximately, 5,300 hours of minnow trapping was completed to tag and recapture juvenile coho salmon. A total of 153 tagged fish were recaptured with mobile tracking; 143 fish were recaptured once and 10 fish were recaptured more than once. Analogous to results for fishing effort and capture for tagging, recaptured fish were identified in main-stem environments greater than other environments with recaptures being greatest in August and September (Table 6).

A total of 2,719 detections occurred between July 8 and November 15, 2011. Individual metrics of each array are listed in Table 7.

Hatchery Array - This array was located at an old picket weir site (Appendix A), as such there are metal stanchions and weir parts embedded in the substrate and banks as well as low lying power lines that are known to increase RF noise. Consequently, the RF noise at this location was the highest of any of the array sites. To compensate for RF noise the antenna amperage was increased to 5.94 A in the central antenna. Use of smaller geometry antennas facilitated the large amperage level. A total of 185 tag detections were recorded on 146 unique tags or 6% of the total tagged population. A power outage on August 3-5, 2011 resulted in no information being collected.

Lucille Array - This array was located immediately downstream of a 3'x 7' bottomless arch culvert (Appendix B). A total of 652 detections were recorded on 42 unique tagged fish. The largest number of detections occurred in August, comprised of 28 unique tags or 1% of the total tagged population. All tagged fish swam upstream through the antennas and returned downstream within a few minutes because the culvert prohibits juvenile coho salmon upstream movement (Appendix E). Four tagged fish attempted to move upstream in multiple months and one tagged fish remained in lower Lucille Creek in close proximity to the array throughout the study period. Of the 42 unique tags that failed to pass the culvert, 13 were later detected in the Herkimer Array, 1 was detected in the Hatchery Array, 3 were detected in the Railroad Array, and the remaining tags were not redetected prior to November 15, 2011. No tagged fish from reach 1263, located upstream of the culvert, were recorded at the Lucille Array suggesting no downstream movement. Tagged fish from reach 1263 were recaptured during mobile tracking indicating that a suitable overwintering area exists within Lucille Creek.

Herkimer Array - This array was located downstream of a 3'x 2' bottomless arch culvert (Appendix C). A total of 1,806 detections were recorded on 386 unique tagged fish accounting for 17% of the tagged population. All tags were identified moving upstream and as of November 13, 2011, none of the tags were redetected at the array, indicating overwintering was occurring upstream, likely within Blodgett Lake (as evident by four tagged fish being recaptured in Blodgett Lake with prior detections at the Herkimer array).

Railroad Array - This array was located downstream of a 5'x 5' circular culvert situated below a railroad track (Appendix D). A popular ATV trail intersects Meadow Creek near one of the antenna at the culvert exit. A total of 76 detections were recorded on 39 unique tagged fish accounting for 2% of the tagged population. A number of problems occurred with the Railroad array operation. The downstream antenna was disturbed and displaced by an ATV collision on July 4. The array was inactive for 3 days to provide repairs and relocation of the antenna farther downstream. A motherboard failure in the transceiver occurred on August 24, 2011, and information was lost between August 24 and September 6, 2011. The thermal electric generator was inoperative between of September 24-29, 2011 and October 1-14, 2011, resulting in loss of data for those dates. A new upstream antenna and thermal electric generator were installed on October 18, 2011. Consequently, the Railroad array was inoperative for 21 days between July 5 and November 15, 2011.

Movement

Figure 7 displays histograms of the daily tag detection counts over time for each fixed array. Each tag represents a unique fish and not an individual detection as tagged fish frequently hold within the array detection range generating numerous detections. The Railroad Array was not sufficiently active to accurately assess passage past this site. The number of tagged fish at the three remaining antennas increased in late August and peaked in September, indicating movement of juvenile coho salmon to overwintering areas. Variation in timing at each array was noticeable. Juvenile coho salmon movement based on the Lucille array appears to begin earliest, followed by the Hatchery array and the Herkimer array.

Movement Distance

In total, 704 tagged fish (31% of tagged fish) were detected after the initial tagging event through mobile tracking or fixed array methods (Table 8). All metrics for migration distance were similar and not significantly different (Wilcoxon paired sample test, $P > 0.05$) between age classes.

Movement Direction

Both age classes typically moved upstream as opposed to moving downstream or not moving. Overall, age-0 fish moved upstream in greater proportion (74%) than downstream (18%) or not moving (9%). Age-1 fish also moved upstream in greater proportion (48%) than downstream (34%) or not moving (18%).

Movement was uni-directional at most fixed locations. Although it was not possible to detect direction of movement at the Hatchery array, all tagging occurred upstream of this detection site and it appears reasonable that all movement (146 unique tags) at this site was downstream and out of the study area. All attempted movement at the Lucille Creek array (28 unique tags) was upstream further into the tributary. However, the Lucille Creek culvert under Big Lake Road is a barrier to upstream migration of juvenile coho salmon and all tagged fish detected at this site subsequently moved downstream. All movement at the Herkimer array (386 unique tags) was upstream into Corcoran Lake, Lily Lake, and Blodgett Lake. It was possible to detect direction of travel at the Railroad array; however, operational status was sporadic. All tagging occurred downstream of this detection site and most movement (39 unique tags) was upstream where all three environment types were available.

Drivers of Movement

Water quality values were measured at the Hatchery array. A histogram of the combined daily count of tag detections at all arrays over time plotted against the daily mean water temperature is presented in Figure 8. A gross pattern, although not conclusive, of movement appears to initiate when water temperatures decrease to 13°C which occurred in early and late-August. No discernible movement cues were observed with other water quality parameters. Most movement related to water discharge occurred after the highest discharge values were observed in early to mid-August (Figure 9); however, the first mode observed in movement (early August) occurred as discharge ramped up. No discernible patterns were evident between tag detections at all arrays over time and any other water quality parameter. However, these data represent six months of information and additional insight is needed.

Environment Use Patterns

Mean monthly CPUE (numbers of fish captured/trap soak time) was used to infer general patterns of use within each environment (Figure 10). Results indicate predominant use of main-stem and tributary environments in July and August during summer rearing. The CPUEs between environments were different (Kruskal Wallis test, $P < 0.0001$). Main-stem CPUE steadily declined throughout the summer and into September. Conversely, CPUE in the tributary and lake environments increased in September and within lake environments in October, likely indicating movement into overwintering areas. Sampling was not conducted in the tributary environment in October due to ice-up conditions.

Fish Age and Growth

Age structure determination using only fork length data produced acceptable resolution between age groups, although predictably the method performed more poorly at low sample sizes and when age groups overlapped. A clear signature of two age classes was discernible throughout the analyses. Figure 11 (left panels) shows change in mean length at age distributions over time by environment type (including pooled across environment types). Samples taken in lake environments exhibited the strongest growth, whereas samples taken from tributary environments exhibited the least growth. Consistent across environment types, age-0 fish tended to grow more than age-1+ fish. Growth was highest in August, slowing in late summer and early fall, with little to no growth in September and October. The proportion of age-1+ steadily dropped off June through August, however, proportions of age-0 and age-1+ tended to stabilize by October (Table 9, Figure 11).

There were 53 juvenile coho salmon aged. Fish were collected between July 17 and October 17, 2011. Results were compared to those predicted by the mixed model using the pooled fork length threshold values in Table 8 for each month (Table 10). Model prediction performance was accurate based on error percentages, excluding the fork length group's 90-99 mm and 100-109 mm, error percentages were 25% and 17%.

The IGR for 76 individual fish was based on fork lengths from 37 age-0 fish and 39 age-1+ fish. The IGRs were significantly different between the age classes (Mann-Whitney rank sum test, $P < 0.001$) with age-0 fish exhibiting greater growth (mean IGR = 0.0026, SE = 0.0004, range = 0.00064 – 0.015, 95% C.I. = 0.00086) than age-1+ fish (mean IGR = 0.0011, SE = 0.00009, range = 0.00013 – 0.00240, 95% C.I. = 0.00019).

Discussion

This is the first interim report in a multi-year study of juvenile coho salmon migration and habitat use. Ultimately, the goal is to utilize these data in an optimization model to quantify gains in fish production from various restoration choices, including culvert replacements. This discussion includes the initial year of tagging and tracking of tagged juvenile coho salmon through summer rearing into winter habitats and anticipated future work.

Study Design

The sampling intensity and tracking effort appears adequate to accurately portray habitat use and migratory patterns. The sampling area builds upon the distribution of spawning coho salmon estimated from the 2009-2010 telemetry study. The sampling area chosen for tagging and tracking fish was designed to encompass the primary spawning locations where juvenile coho salmon originate, as well as the likely habitats they could migrate to and reside. Most tags were deployed on age-0 or age-1+ fish in main-stem environments that were also primary spawning areas. Young-of-the-year fish were tagged at 55 mm fork length, which largely occurs while they still reside in the area and habitat from which they hatched and emerged. Therefore, the sampling effort represents a valuable insight into which habitats juvenile coho salmon use temporally and spatially, beginning from an individual's natal locations.

The effect of PIT tags on movement was not tested in this study; however, Prentice et al. (1990) observed no effect of PIT tags compromising swimming performance. Therefore, all tagged fish were used in the analysis. Providing a preseason training session for crew members prior to field tagging was beneficial for improving tagging efficiency and likely decreased tagging mortality. The mortality rate from PIT tagging associated with preseason training was similar to that reported by Ombredane et al. (1998) on juvenile brown trout, *Salmo trutta*. Tagging mortality in the field was not tested, but was likely less than the rate observed in preseason training as different PIT tagging equipment was used. Field tagging used a pre-loaded tag, whereas hatchery methods used a plunger style 12-gauge hypodermic needle. Hypodermic needles have been correlated with a higher mortality of juvenile salmon (Gries and Letcher 2002).

The fishing effort appears to have captured and tagged a sufficient fraction of the rearing juvenile population such that meaningful numbers of tag detections were achieved. Both mobile and fixed tracking provided meaningful insights into migratory patterns and habitat use. Although the fixed antenna recapture detections were more numerous than mobile recaptures, the information gathered from the mobile tracking was important with regard to understanding growth and validating the mixed model for predicting age of fish. The location of the tributary arrays was important in identifying destinations and preferred habitats. Most notable are Blodgett Lake and Lucille Creek as overwintering areas. The Railroad array was not operational for much of the study period and conclusions about migration through this site are uncertain. Sampling in Hidden Gem and Rainbow Lake was implemented as a result of the Railroad array being inoperable. In addition, another main-stem environment sampling reach was added upstream of the Railroad array. Excluding Stepan Lake, the additional reaches were sampled to evaluate whether tagged fish had passed through the Railroad array during times when the array was inoperable. Stepan Lake and the additional main-stem sampling reach were added to supplement sampling consistent with the proportional sampling selection methodology. Sampling in the additional reaches was useful in validating that tagged fish moved upstream through the Railroad array undetected. Of particular note was the presence of tagged fish in Hidden Gem and the Rainbow Lake Pond, but not within Rainbow Lake. Rainbow Lake, according to local landowners, is known to contain Northern pike *Esox lucius* an invasive species in Southcentral Alaska which may account for the lack of juvenile coho salmon being captured. Rainbow Lake Pond is connected to Rainbow Lake via a culvert passing under Pittman Road. The culvert is classified as green, unrestrictive, for fish passage (O'Doherty 2010).

Of some concern for future sampling is size bias of minnow traps by excluding larger juveniles. The use of minnow traps as a sampling device imposes a bias in the size or length of juvenile fish captured and limits sampling to fish of a specific size. Smaller fish could escape capture by moving through the mesh of the minnow traps and larger fish would be unable to pass through the concave opening of the minnow trap. Size metrics of captured fish were within the ranges reported by Bloom (1976) and Bramblett et al. (2002). Beachum and Murray (1990) and Drucker (1972) captured juvenile coho salmon between 32 mm and 182 mm, indicating that minnow trapping captured nearly all size and age classes of juvenile coho salmon within Meadow Creek.

Fish greater than 149 mm are likely excluded from our analysis. Observations from field technicians in this project suggest there were juvenile coho salmon greater than 149 mm attempting to enter minnow traps, but were too large. We hypothesize those fish were an older cohort. If this hypothesis is accurate, then these fish are likely age-3 freshwater fish and are not represented in this analysis. However, this cohort likely represents a small proportion of the population within the study area; therefore, they do not impose any bias on the habitat preference or movement conclusions in this report. Collection and analysis of outmigrant fish captured in

ADF&G fyke net in 2012-2014 should provide empirical data to investigate this hypothesis in the future.

Migration and Habitat Use

In general, each cohort of rearing juvenile coho salmon utilized main-stem or tributary environments while rearing during summer. Migration and movement from these initial rearing environments increased in late summer and early fall and appears to coincide with dropping water temperatures in the main stem and in eutrophic lakes such as Herkimer Lake, or possibly the arrival of spawning sockeye. The timing of movement is earlier than that reported by Bramblett et al. (2002) in Southeast Alaska tributaries for juvenile coho salmon; although differences in the climate and geomorphic features of each study area exist. The net migration from summer to winter habitats is generally upstream, both in the main-stem and in tributary environments. Movement of juvenile coho salmon from main-stem to tributary environments is similar to those reported by Peterson (1982), Tschaplinski and Hartman (1983), and Bramblett et al. (2002) and the selection of low velocity habitats for overwintering is similar to that reported by McMahon and Hartman (1989) and Shirvell (1990).

A primary winter habitat is Blodgett Lake, with 17% of the tagged population migrating past the Herkimer array, mostly in September (Figure 7). To date, none of these tagged fish have emigrated downstream. If winter habitat is a bottleneck to production, then this lake and similar habitats in the drainage are of extremely high importance. Despite being a small and low flow water body, Lucille Creek also provided important rearing and likely winter habitat. To date, none of the fish tagged in Lucille Creek have migrated out of that area. Some rearing fish (2% the tagged population) attempted to migrate upstream into Lucille Creek, but were unable to do so. It is unclear why areas like Blodgett Lake and Lucille Creek are preferred winter areas. For instance, other tributary and lake habitats to Meadow Creek, such as Ryan Creek (tributary to Twin Lake) and Twin Lake were sampled and only a few juvenile coho salmon were captured. Winter habitat exists in tributaries and lakes upstream from the Railroad array, potentially in the Meadow lakes group of water bodies. Big Lake is not used as rearing or winter habitat to any significant degree by juvenile coho salmon that originate from the Meadow Creek drainage.

Fish Passage

The Lucille Creek culvert was definitively a complete barrier to upstream passage of juvenile coho salmon at all water levels. A total of 42 tagged fish migrated upstream through the Lucille Creek array, but none passed through the culvert and all migrated back downstream through the array. Some moved upstream to other tributary destinations. This culvert has a series of baffles that appear to be retro-fitted into the culvert, creating a perch of approximately 6-8 inches dependent upon water level. This culvert is correctly rated as Red, indicative of a barrier to juvenile fish migration (O'Doherty 2010). Juvenile coho salmon were tagged in Lucille Creek and appear to overwinter in upper portions of the tributary and these fish must have originated from spawning in Lucille Creek upstream of the culvert. Lucille Creek has supported some spawning coho salmon (USFWS, unpublished data), and while most of Lucille Creek is isolated from access to juveniles that were spawned in the main stem, it is evident fish are trying to access the tributary upstream of the culvert.

Growth and Differentiation of Cohorts

IGR and mixed model data do not track the growth fate of individual fish. Therefore, it is not possible to directly attribute differences in growth to difference in environment types because fish moved between environment types throughout the study period. Reported IGR rates did not include fish captured on June 15-16, 2011, because tagging did not occur. At this time, only opportunistic sampling occurs in Lucille Creek. However, information for from fish captured in June is noteworthy because these fish had the largest mean fork length (n = 12, mean = 90 mm) as compared to other sampling months (July: mean = 70 mm, August: mean = 77 mm, and September: mean = 78 mm) in tributary environments (Figure 11) and suggests that larger fish were migrating out of the tributary during the middle portion of June. This timing coincides with the peak outmigrant numbers observed in an ADF&G fyke net near the drainage outflow to saltwater (M. Willette, the ADF&G, personal communication, 2011).

Mixed model results suggest that July and August is high growth time for young-of-the-year fish. In addition, it appears overwinter growth for young-of-year fish does occur because the (estimated) older age class of fish start the season at (an estimated) mean length longer than the end of summer length of the younger age class. For example, looking at data pooled across all environment types (Figure 11 lower left panel), age-0 fish grew on average 20-25 mm over June through October. Age-1+ fish also started the season approximately 20-25 mm larger than age-0 fish at the end of the October suggesting that overwinter growth from November through May is comparable to that through summer for young-of-year fish. However, this may be an artifact of the model as comparable growth rates between summer and winter have not been reported. Capture of tagged fish during winter months and capture of additional tagged fish in months outside the current study will provide additional insight. The observed IGRs substantiate model results by indicating growth throughout the season with age-0 fish growing faster. The range between observed IGRs did vary between cohorts and additional analysis comparing growth rates between environments will be investigated in future work.

Future Work

Tracking at fixed arrays will continue throughout the year. These arrays will be used to track and measure winter movements, emigration from winter habitats at the Herkimer, Lucille Creek, and Railroad arrays; and smolting (Hatchery array). Continued mobile tracking should provide recaptures of age-1+ and age-2+ rearing fish and information about their summer rearing habitats. In addition, comparing the size of captured fish between different gear types; seine, electro-fishing, and minnow traps should illuminate if size bias in gear persists. This will be important for estimating the proportion of the age-3 freshwater component within the overall juvenile coho salmon population and estimating the range in fork length of age-3 freshwater fish in the Big Lake drainage.

In 2012, a second year of tagging was conducted in Meadow Creek to verify the 2011 results. Of particular interest was measuring migration through the Railroad array, which was not operational during much of 2011. Tagging was also conducted in Fish Creek and a fixed array network was established. Fish Creek was the other major spawning destination (aside from Meadow Creek) for coho salmon (USFWS, unpublished data). Tagging goals and study design were similar to that in Meadow Creek. Arrays were established at the outlet of Big Lake, near the ADF&G adult weir in lower Fish Creek, and in the only notable tributary (Threemile Creek).

ADF&G operates a fyke net capture program in lower Fish Creek to sample emigrating smolt. We anticipate the recapture of tagged smolts emigrating from Meadow Creek and from both drainages in 2013, providing insight on size-at-age of smolts from different environments and drainages, downstream migration rates, freshwater mortality and survival, and if differences occur between different age classes with regard to smolt timing.

In 2013, ADF&G will expand operation of the adult weir in lower Fish Creek for coho salmon, including scanning for PIT tagged adult coho salmon. If PIT tag signals can be detected in adult fish, which is potentially difficult given the extra biomass accumulated since tagging as a juvenile, then questions regarding saltwater mortality and survival and fidelity to natal streams could be explored.

Of particular interest is identifying and modeling habitat parameters that constitute high value rearing habitats, specifically, winter habitats as potential bottlenecks to production. Additional interests include investigating patterns in water temperature including cold water refugia from lethal water temperatures, which could be exacerbated from climate change. This may be increasingly important in eutrophic lakes that function as connections to overwintering habitats, some of which currently exhibit water temperatures in the mid to high 20° C range for most of the summer. Water temperatures are annually measured in both Meadow and Fish creeks (Mauger 2011). As an example during 2009, water temperatures exceeded 20º C in these streams for 12 and 13 days, respectively. To further identify and examine groundwater input, airborne thermal infrared (TIR) image acquisition was conducted during 2011 for Meadow and Fish creeks. Preliminary analysis of TIR imagery and results of this study suggest an association between fish presence and cold water inputs. Catch per unit effort was typically highest downstream of an incoming water source such as an upwelling (reaches 1525 and 6275) or larger order tributary confluence (reaches 850, 6950, and 8300). The TIR imagery will assist in identifying incoming water sources that mitigate warmer water temperatures in summer or colder water temperatures in winter.

Juvenile coho salmon information from this project will be used to construct an optimization model for prioritizing restoration activities (Kemp and O'Hanley 2010). The model will use fish life history, habitat preference, and barrier assessment; specifically temporal and spatial juvenile coho salmon distribution within the Big Lake drainage as a function of fish passage. Fish passage criteria is currently based on the swimming ability of juvenile coho salmon and this project provides insight into the ability of juvenile coho salmon to pass culverts at different life stages, identifies constraints in upstream and downstream culvert passage, and addresses fish passage year round, particularly in winter months when stream flow is lowest and culverts are covered, blocked, or impregnated with ice and snow.

Acknowledgements

Thanks to the Alaska Sustainable Salmon Fund for providing funding for this study. This study was conducted by the USFWS, Anchorage Fish and Wildlife Field Office. Mike Bethe, Ken Bouwens, and Gillian O'Doherty with the Alaska Department of Fish and Game, and Jeff Davis from Aquatic Research and Restoration Institute provided project guidance. Appreciation goes to the private landowners that allowed access to sampling areas and equipment storage. Acknowledgement and appreciation to the field crew: Josh Ashline, Veronica Corbett, Jamie Giganti, Steve Schwartz, and Stephen Sims. Ryan Koch and Marshall Barrows of the USFWS Columbia River Fisheries Program Office assisted in antenna setup and continue to provide insight and advice on antenna maintenance and operation. Jeffry Anderson and Mike Buntjer with the USFWS provided valuable editorial comments and insight.

References

Alaska Department of Fish and Game. 2006. Our wealth maintained: a strategy for conserving Alaska's diverse wildlife and fish resources. Alaska Department of Fish and Game, Juneau, Alaska. xviii+824 p.

Alaska Department of Fish and Game. 2013. Fish Resource Monitor. 7, January 2013. Alaska Department of Fish and Game, Anchorage, Alaska. Available as part of interactive mapper at URL: http://gis.sf.adfg.state.ak.us/FlexMaps/fishresourcemonitor.html

Benolkin, E. B. 2011. Inventory of fish distribution in the Matanuska-Susitna Basin, southcentral Alaska, 2010. U.S. Fish and Wildlife Service Data Series Report Number 2011-10. Anchorage, Alaska.

Bisson, P. A., and R. E. Bilby. 1998. Organic matter and trophic dynamics. Pages 373-398 *in* R. J. Naiman and R. E. Bilby, editors. *River ecology and management: lessons from the Pacific coastal ecoregion.* Springer-Verlag, New York, New York, USA.

Bloom, A. M. 1976. Evaluation of minnow traps for estimating populations of juvenile coho salmon and Dolly Varden. Progressive fish-culturist 38: 99-101.

Brakensiek, K. E., and D. G. Hankin. 2007. Estimating overwinter survival of juvenile coho salmon in a northern California stream: Accounting for effects of passive integrated transponder tagging mortality and size-dependent survival. Transactions of the American Fisheries Society 136(5): 1423-1437.

Bramblett, R. G., M. D. Bryant, B. E. Wright, R. G. White. 2002. Seasonal use of small tributary and main-stem habitats by juvenile steelhead, coho salmon, and Dolly Varden in a Southeastern Alaska drainage basin. Transactions of the American Fisheries Society 131: 498-506.

Brown, T. G. and G. F. Hartman. 1988. Contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Transactions of the American Fisheries Society 117(6): 546-551.

Bryant, M. D. 2000. Estimating fish populations by removal methods with minnow traps in Southeast Alaska streams. North American Journal of Fisheries Management 20: 923-930.

Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon *(Oncorhynchus kisutch)* and steelhead trout *(Salmo gairdneri)*. Journal of Fisheries Research Board Canada. 32: 667-680.

Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53: 267-282.

Curran, J. H., and W. J. Rice. 2009. Baseline channel geometry and aquatic habitat data for selected streams in the Matanuska-Susitna Valley, Alaska: U.S. Geological Survey Scientific Investigations Report 2009–5084, 24 p. Reston, Virginia.

Dolloff, C. A. 1986. Effects of stream cleaning on juvenile coho salmon and Dolly Varden in Southeast Alaska. Transactions of the American Fisheries Society 115 (5): 743-755.

Drucker, B. 1972. Some life history characteristics of coho salmon of the Karluk River system, Kodiak Island, Alaska. Fishery Bulletin: 70 (1): 79 - 94.

Ebersole, J. L., P. J. Wigington Jr., J. P. Baker, M. A. Cairns, M. R. Church, B. P. Hansen, B. A. Miller, H. R. LaVigne, J. E. Compton, S. G. Leibowitz. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. Transactions of the American Fisheries Society 135(6): 1681-1697.

Fraley, C. and A.E. Raftery. 2006. MCLUST Version 3 for R: Normal Mixture Modeling and Model-based Clustering. Technical Report No. 504, Department of Statistics, University of Washington (revised 2009).

Gries, G. and B. H. Letcher. 2002. Tag retention and survival of age-0 Atlantic salmon following surgical implantation with passive integrated transponder tags. North American Journal of Fisheries Management 22(1): 219-222.

Habera, J. W., R. J. Strange, B. D. Carter, and S. E. Moore. 1996. Short-term mortality and injury of rainbow trout caused by three-pass AC electrofishing in a southern Appalachian stream. North American Journal of Fisheries Management 16: 192-200.

Hankin, D. G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Canadian Journal of Fisheries and Aquatic Sciences 41: 1575-1591.

Hoar, W. S. 1976. Smolt transformation: evolution, behavior, and physiology. Journal of the Fisheries Research Board of Canada 33: 1234-1252.

Hogan, E. V. 1995. Overview of environmental and hydrogeologic conditions near Big Lake, Alaska: U.S. Geological Survey Open-File Report 95-403, 10 p. Anchorage, Alaska.

Jerald, A. 1983. Age determination. Pages 301-324 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Johnson, C. E., and C. Barton. 2004. Where in the world are my field plots? Using GPS effectively in environmental field studies. Frontiers in Ecology and the Environment 2: 475-482.

Jonsson, B., and Ruud-Hansen, J. 1985. Water temperature as the primary influence on timing of seaward migrations of Atlantic salmon (*Salmo salar*) smolts. Canadian Journal of Fisheries and Aquatic Sciences 42: 593–595.

Jonsson, N. 1991. Influence of water flow, water temperature and light on fish migration in rivers. Nordic Journal of Freshwater Research 66: 20–35.

Jokela, J. B., J. A. Munter, and J. G. Evans. 1991. Ground-water resources of the Palmer-Big Lake Area, Alaska: A conceptual model. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, Report of Investigations, 90-4, 38., 2shets, scale 1:25;000. Juneau, Alaska.

Kemp, P. S., and J. R. O'Hanley. 2010. Procedures for evaluating and prioritizing the removal of fish passage barriers: a synthesis. Fisheries Management and Ecology 17: 297-322.

Kocik J. F., and P. C. Ferreri. 1998. Juvenile production variation in salmonids: population dynamics, habitat, and the role of spatial relationships. Canadian Journal of Fisheries and Aquatic Sciences 55: 191-200.

Kralik, N. J., and J. E. Sowerwine. 1977. The role of two northern California intermittent streams in the life history of anadromous salmonids. M.S. Thesis, Humboldt State University, Arcata, CA.

LaPointe, N. W. R., L. D. Corkum, and N. E. Mandrak. 2006. A comparison of methods for sampling fish diversity in shallow offshore waters of large rivers. North American Journal of Fisheries Management 26: 503-513.

Lawler, J. J., and N. H. Schumaker. 2004. Evaluating habitat as a surrogate for population viability using a spatially explicit population model. Environmental Monitoring and Assessment 94: 85–100.

Mat-Su Basin Salmon Habitat Partnership. 2008. Conserving salmon in the Mat-Su basin, the strategic action plan of the Mat-Su salmon partnership. Available at: http://conserveonline.org/workspaces/MatSuSalmon/documents/mat-su-salmon-strategic-action-plan.

Mat-Su Basin Salmon Habitat Partnership. 2009. Salmon watersheds in the Mat-Su basin, a map atlas to prioritize conservation. Available at: http://conserveonline.org/workspaces/MatSuSalmon/documents/salmon-watersheds-map-atlas.

Mat-Su Basin Salmon Habitat Partnership. 2011. Mat-Su salmon passage improvement plan. Available at: http://conserveonline.org/workspaces/MatSuSalmon/document/mat-su-salmon-passage-improvement-plan.

Mauger, S. 2011. Stream temperature monitoring network for Cook Inlet salmon streams 2008-2010. Report by Cook Inletkeeper. Available at www.inletkeeper.com.

McMahon, T. E., and G. F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46: 1551-1557.

Mosher, K. H. 1963. Racial analysis of red salmon by means of scales. International North Pacific Fisheries Commission, Bulletin 11:31-56. Vancouver, British Columbia.

Mosher, K. H. 1968. Photographic atlas of sockeye salmon scales. Fishery Bulletin 67:243-280.

Murphy, M. L., J. Heifetz, S. W. Johnson, K. V. Koski, and J. F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. Canadian Journal of Fisheries and Aquatic Sciences 43: 1521 - 1533.

Nickelson, T. E., J. D. Rodgers, S. L. Johnson, and M. F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon *(Oncorhynchus kisutch)* in Oregon coastal streams. Canadian Journal of Fisheries Science 49: 783-789.

O'Doherty, G. O. 2010. ADF&G fish passage program: summary of existing inventory and assessment data and gap analysis, September 2009. Alaska Department of Fish and Game, Special Publication No. 10-17, Juneau, Alaska.

Ombredane, D., J. L. Bagliniere, and F. Marchand. 1998. The effects of passive integrated transponder tags on survival and growth of brown trout (*Salmo trutta* L.) and their use for studying movement in a small river. Hydrobiologia 371/372**:** 99–106.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. Pages *317-322 in* N. C. Parker, A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editors. Fish-marking techniques. American Fisheries Society, Symposium 7, Bethesda, Maryland.

Quinn, T. P., and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon *(Oncorhynchus kisutch)* in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:1555–1564.

Peterson, N.P. 1982. Immigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Canadian Journal of Fisheries and Aquatic Sciences 39: 1308-1310.

R Development Core Team. 2010. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Reynolds, J. B. 1996. Electrofishing. Pages 221-253 *in* B. R. Murphy, and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Schoettger, R. A., and A. M. Julin. 1967. Efficacy of MS-222 as an anesthetic on four salmonids. United States Bureau of Sports Fisheries and Wildlife Investigations in Fish Control No 13, Washington, D.C.

Shirvell, C. S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows. Canadian Journal of Fisheries and Aquatic Sciences 47: 852-861.

Solomon, D. J. 1978. Some observations on salmon smolt migration in a chalkstream. Journal of Fish Biology 12: 571–574.

Swales, S., R. B. Lauzier, and C. D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology, 64: 1506-1514.

Tschaplinski, P. J., and G. F. Hartman. 1983. Winter distribution of juvenile coho salmon before and after lagging in Carnation Creek, British Columbia, and some implications for overwinter survival. Canadian Journal of Fisheries and Aquatic Science, 40: 452-461.

Zar, J.H. 1999. Biostatistical Analysis, 4th ed. Prentice Hall, Upper Saddle River, NJ.

Table 1. Proportional sampling by environment type in Meadow Creek study area, Alaska in 2011.

Environment	Total area (m^2)	Proportion of total area (%)	Number of sampling days bi-weekly	Number of reaches sampled bi-weekly
Main stem	162,243	0.47	6	175
Tributary	22,981	0.13	1	25
Lake	148,896	0.40	5	160

Table 2. Descriptive statistics of all fish captured in Meadow Creek study area, Alaska in 2011.

Environment	N	Mean	SD	SE
Main stem	2,498	78.07	17.55	0.35
Tributary	566	74.37	17.30	0.73
Lake	1,110	91.61	15.01	0.45
Pooled	4,174	81.17	18.05	0.28

Table 3. Minnow trapping metrics and number of juvenile coho salmon captured in Meadow Creek study area for each sampling environment, June-October, 2011.

June	Main stem	Tributary	Lake
No. of traps deployed	2	2	0
No. of fish captured	14	14	0
Total soak hours	2	2	0
Trap effort (trap hours)	4	4	0
July	Main stem	Tributary	Lake
No. of traps deployed	500	217	140
No. of fish captured	1,097	260	18
Total soak time	534	230	153
Trap effort (trap hours)	267,155	49,886	21,363
August	Main stem	Tributary	Lake
No. of traps deployed	887	150	619
No. of fish captured	972	361	33
Total soak hours	928	156	660
Trap effort (trap hours)	822,693	23,414	408,348
September	Main stem	Tributary	Lake
No. of traps deployed	544	103	242
No. of fish captured	361	164	461
Total soak hours	573	104	249
Trap effort (trap hours)	311,837	10,732	60,147
October	Main stem	Tributary	Lake
No. of traps deployed	334	0	1,113
No. of fish captured	54	0	598
Total soak hours	342	0	1,194
Trap effort (trap hours)	114,234	0	1,329,323

Table 4. Proportion of age-0 and age-1+ fish tagged in each Meadow Creek study area environment, July-September, 2011.

	Tagging proportion	
Environment	Age-0	Age-1+
Main stem		
July	61%	39%
August	71%	29%
September	76%	24%
Tributary		
July	19%	81%
August	74%	26%
September	84%	16%
Lake		
July	78%	22%
August	88%	12%
September	97%	3%

Table 5. Number of PIT tags deployed for each reach, July-September, 2011.

Reach ID	July	August	September	Total
Main stem				
400	58	50	30	138
850	82	70	31	183
1525	196	65	32	293
2050	77	22	2	101
2925	51	5	3	59
3825	18	84		102
4400	24	57		81
6275	133	25	16	174
6950	149	46	23	218
8300	211	40	2	253
11025	26	92		118
12375	26	4	5	35
Meadow Lp		35	11	46
Subtotal	1,051	595	155	1,801
Tributary				
50		13	8	21
100			15	15
330	18	11	13	42
612	19	29	17	65
797	86	9	11	106
267	6	16		22
849	16	21		37
1263	39	15	6	60
Subtotal	184	114	70	368
Lake				
Twin			1	1
Herkimer	18	11	13	42
Corcoron			6	6
Blodgett		22	55	77
Subtotal	18	33	75	126
Total	1,253	742	300	2,295

Table 6. Number of PIT tagged fish recaptured by mobile tracking on Meadow Creek study area, Alaska, 2011.

	Sampling Month			
Environment	July	August	September	October
Main stem	21	45	46	1
Tributary	6	13	9	
Lake			6	6
Total	28	58	61	7

Table 7. Metrics for fixed site PIT tag arrays deployed in Meadow Creek study area, Alaska, 2011.

Characteristic	Hatchery	Lucille	Herkimer	Railroad
Wetted width (ft)	30	10	10	5
Depth (ft)	2	1	1	3
Make	Biomark Lite	Biomark Lite	Biomark Lite/USFWS	USFWS
Orientation	Side by side	Parallel	Parallel	Parallel
Geometry (ft)	3x10	3x10	3x10, 4x10	5x5
Number of antenna	3	2	2	2
Directional	No	Yes	Yes	Yes
Power source	on grid	off grid	on grid	off grid
Start date	22-Jun	22-Jun	22-Jun	5-Jul
Working RF noise (%)	25 - 34	0 - 2	0 - 3	0 - 5
Working amps (A)	3.85 - 5.63	3.30 - 3.40	3.30 - 4.20	3.30 - 4.0
Antenna efficiency (%)	81,77, 84	98	98	92
Date of first tag detection	10-Jul	8-Jul	7-Jul	8-Aug
Total no. of unique tags	146	42	386	39
Total no. of detections	185	652	1,806	76

Table 8. Summary of movement statistics for PIT tagged fish recaptured or detected, July 6 - November 15, 2011, *n*=704.

Metric	Age-0	Age-1+
Distance (m)		
Mean	3,733	3,431
Max	14,746	14,485
Min	0	0
Direction (#)		
Upstream	306	139
Downstream	73	99
No movement	36	50
Total	415	288
Direction (%)		
Upstream	0.74	0.48
Downstream	0.18	0.34
No movement	0.09	0.17

Table 9. Estimated demographic parameters for samples of juvenile cohos from Meadow Creek, AK, drainage 2011 from different months and habitat types as inferred by Gaussian finite mixture model analysis on fork length (FL) data[1].

[1] Data are presented as (lower 95% confidence interval bound, point estimate, upper 95% confidence interval bound). Confidence intervals are determined using a bootstrap routine. Samples were not available for all habitat type – month combinations. Age group A is the younger of the two groups and likely represents young of the year (i.e. animals emerged in 2011), whereas group B corresponds to age 1+ (i.e. animals emerged in 2010 or earlier). FL threshold is the fork length which best discriminates between the two age groups. The misclassification error rate is the expected classification error rate associated with the estimated optimal age-discriminating fork length threshold. An "*" indicates that the mixture model was forced to fit two component distributions; in all other fits, the number of component distributions was freely estimated to be two.

		Age Group A			Age Group B					
Month	Habitat	Mean (mm)	Variance	Proportion	Mean	Variance	Proportion	FL Threshold (A vs. B)	Misclassification Rate	*N*
July	Lake*	56.2, 58.6, 60.3	4.84, 14.6, 18.8	0.513, 0.794, 0.939	63.9, 71.0, 75.4	4.84, 14.6, 18.8	0.060, 0.206, 0.487	63.0, 66.4, 155.0	0.002, 0.042, 0.405	18
August	Lake	61.8, 66.2, 69.1	24.3, 63.4, 82.8	0.643, 0.885, 0.970	77.3, 92.5, 107.8	24.3, 63.4, 82.8	0.031, 0.115, 0.357	71.0, 84.6, 94.0	0.001, 0.027, 0.081	33
September	Lake	91.8, 93.5, 94.6	109.0, 133.0, 154.8	0.820, 0.900, 0.942	114.0, 121.6, 127.7	109.0, 133.0, 154.8	0.058, 0.104, 0.182	111.0, 117.9, 123.0	0.027, 0.054, 0.100	461
October	Lake*	83.9, 85.4, 86.6	78.7, 92.0, 104.2	0.714, 0.787, 0.850	104.5, 107.5, 110.9	78.7, 92.0, 104.2	0.150, 0.213, 0.286	98.0, 102.0, 106.0	0.064, 0.094, 0.120	598
June	Main	43.1, 44.2, 61.0	1.7, 6.8, 216.9	0.369, 0.428, 0.658	83.7, 89.7, 100.2	16.9, 179.2, 234.1	0.342, 0.572, 0.631	50.0, 52.8, 84.4	0.000,0.002, 0.027	14
July	Main	62.7, 63.2, 63.8	67.4, 72.6, 78.0	0.622, 0.649, 0.673	97.6, 98.4, 99.2	67.4, 72.6, 78.0	0.323, 0.351, 0.378	81.0, 81.9, 83.0	0.014, 0.019, 0.023	1,097
August	Main	68.2, 69.2, 70.2	48.9, 58.6, 69.6	0.594, 0.675, 0.734	92.1, 96.8, 101.3	127.7, 180.1, 236.1	0.267, 0.325, 0.406	81.0, 83.7, 87.0	0.042, 0.073, 0.119	972
September	Main	77.4, 79.2, 80.7	95.3, 109.7, 121.2	0.685, 0.780, 0.840	98.8, 103.2, 106.8	95.3, 109.7, 121.2	0.159, 0.219, 0.314	93.0, 97.5, 100.1	0.062, 0.096, 0.143	361
October	Main	75.4, 78.9, 81.4	53.5, 82.7, 107.3	0.605, 0.751, 0.870	99.8, 106.5, 112.4	53.5, 82.7, 107.3	0.130, 0.249, 0.395	90.0, 96.1, 101.0	0.016, 0.054, 0.981	54
June	Trib*	64.7, 70.6, 79.0	23.9, 92.5, 134.7	0.333, 0.560, 0.787	102.0, 114.1, 121.0	23.9, 92.5, 134.7	0.212, 0.440, 0.667	85.0, 92.9, 100.0	0, 0.011, 0.055	12
July	Trib	59.1, 60.4, 61.9	91.2, 107.2, 123.9	0.673, 0.724, 0.776	91.0, 93.6, 96.5	91.2, 107.2, 123.9	0.223, 0.275, 0.327	78.0, 79.83, 83.0	0.031, 0.047, 0.067	260
August	Trib	66.7, 68.4, 70.4	62.6, 80.0, 100.4	0.635, 0.710, 0.788	95.8, 98.5, 102.4	62.6, 80.0, 100.4	0.211, 0.290, 0.365	83.0, 85.83, 90.0	0.020, 0.041, 0.062	130
September	Trib	70.8, 74.0, 76.3	71.8, 95.5, 114.1	0.641, 0.795, 0.899	90.7, 97.1, 105.6	71.8, 95.5, 114.1	0.100, 0.205, 0.359	83.0, 91.3, 99.0	0.035, 0.087, 0.139	164
June	Pooled*	51.5, 57.9, 65.1	106.5, 181.1, 241.5	0.357, 0.523, 0.718	94.8, 102.7, 111.4	106.5, 181.1, 241.5	0.282, 0.477, 0.643	73.0, 80.53, 89.1	0.009, 0.047, 0.106	26
July	Pooled	62.1, 62.6, 63.2	74.8, 79.8, 85.1	0.649, 0.668, 0.691	97.0, 97.7, 98.5	74.8, 79.8, 85.1	0.308, 0.332, 0.351	81.0, 81.9, 83.0	0.019, 0.023, 0.28	1,375
August	Pooled	67.9, 68.7, 69.6	49.9, 57.8, 68.9	0.582, 0.660, 0.728	91.5, 95.5, 99.5	138.1, 188.5, 233.6	0.271, 0.340, 0.418	80.0, 82.7, 86.0	0.050, 0.082, 0.120	1,135
September	Pooled	82.0, 84.5, 86.8	150.3, 171.6, 193.1	0.641, 0.797, 0.908	101.3, 107.1, 115.5	150.3, 171.6, 193.1	0.092, 0.203, 0.359	97.0, 106.5, 116.1	0.062, 0.135, 0.213	986
October	Pooled	83.5, 84.7, 86.0	79.5, 93.3, 105.1	0.706, 0.777, 0.841	104.5, 107.1, 110.5	79.5, 93.3, 105.1	0.159, 0.223, 0.294	98.0, 101.4, 105	0.066, 0.096, 0.123	652

Table 10. Comparison of age as predicted by fork length (FL) between observers and mixed model on all captured juvenile coho salmon.

	Observer		Model		Misclassification	
FL range	Age-0	Age-1+	Age-0	Age-1+	Rate	*N*
40 - 49	7		7		0%	7
50 - 59	4		4		0%	4
60 -69	8		8		0%	8
70 -79	2		2		0%	2
80 - 89	6	1	6	1	0%	7
90 - 99	3	5	5	3	25%	8
100 - 109		6	1	5	17%	6
110 - 119		6		6	0%	6
120 -129		4		4	0%	4
130 - 139						0
140 - 149		1		1	0%	1

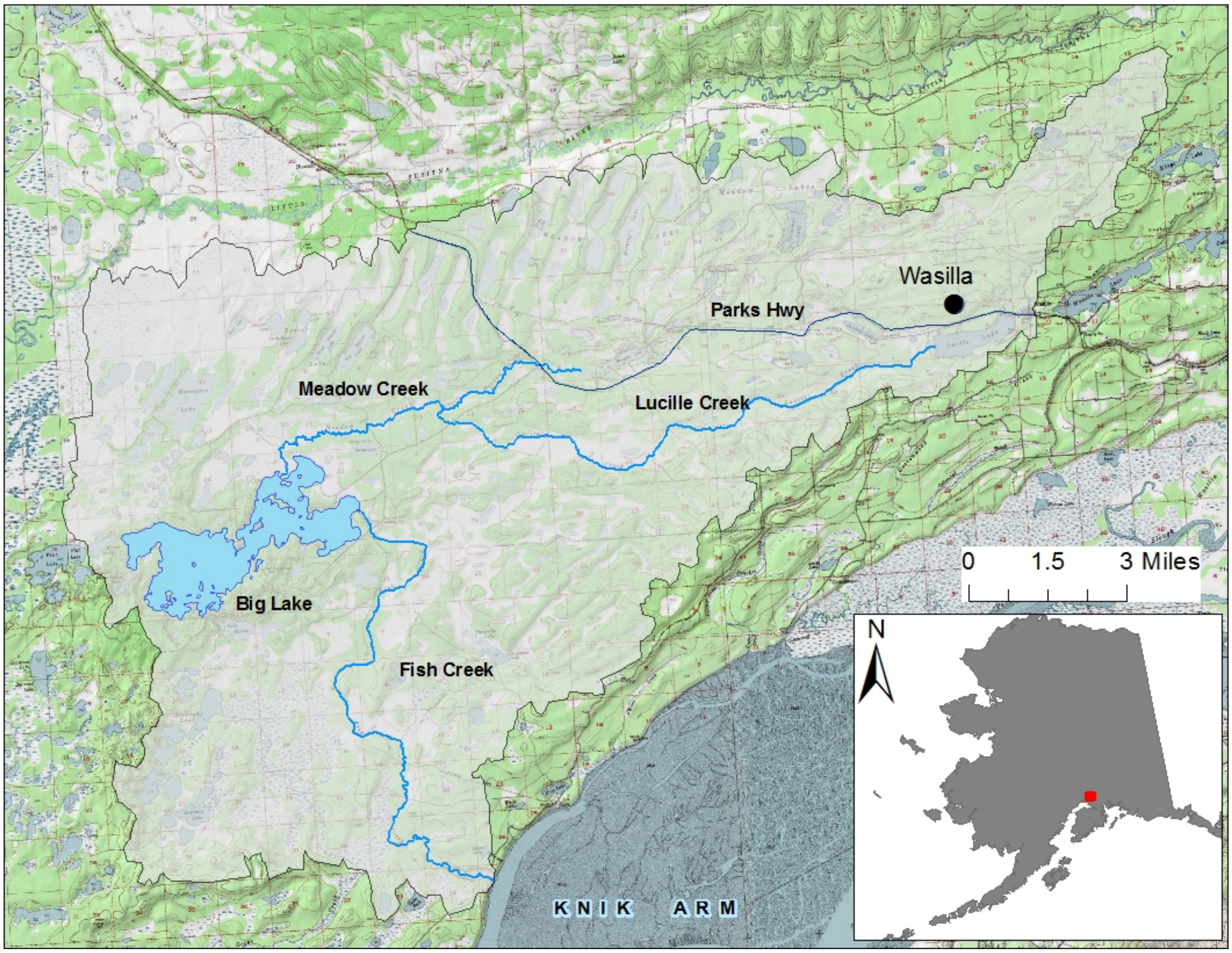

Figure 1. The major waterways found within the Big Lake drainage, Alaska.

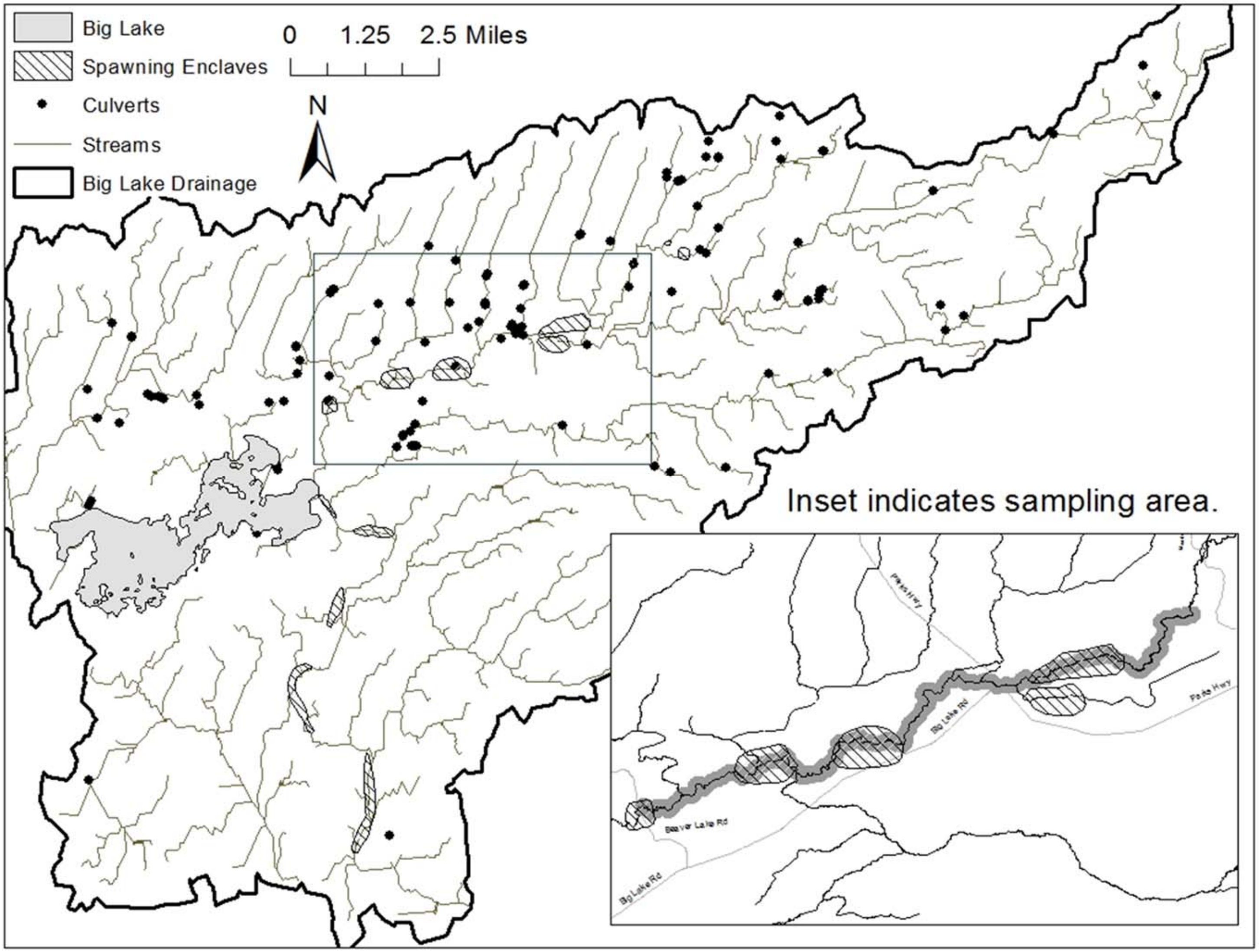

Figure 2. Map of the 2011 juvenile coho salmon sampling area located in the Big Lake drainage, Alaska.

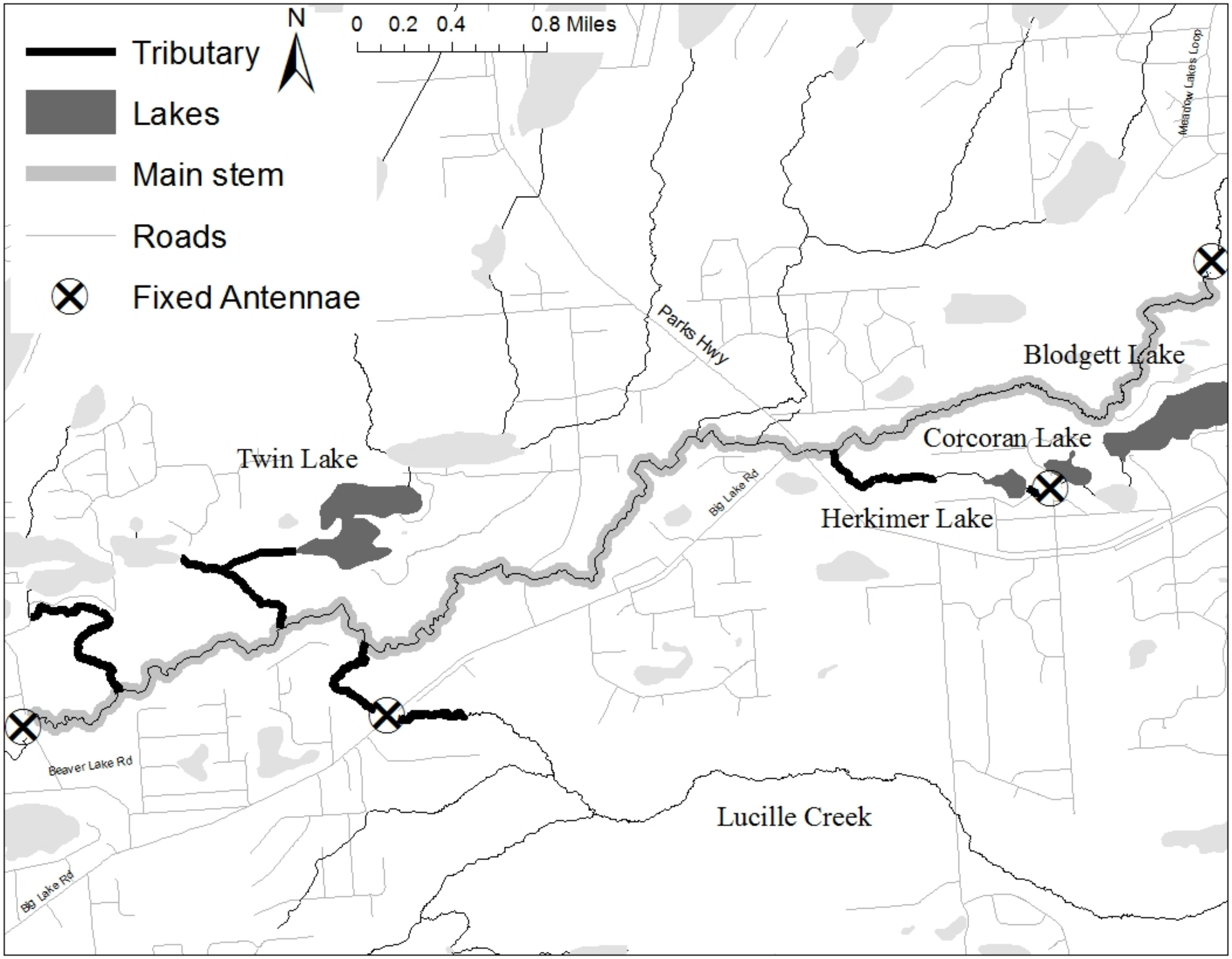

Figure 3. Location of environment types within Meadow Creek study area, Alaska.

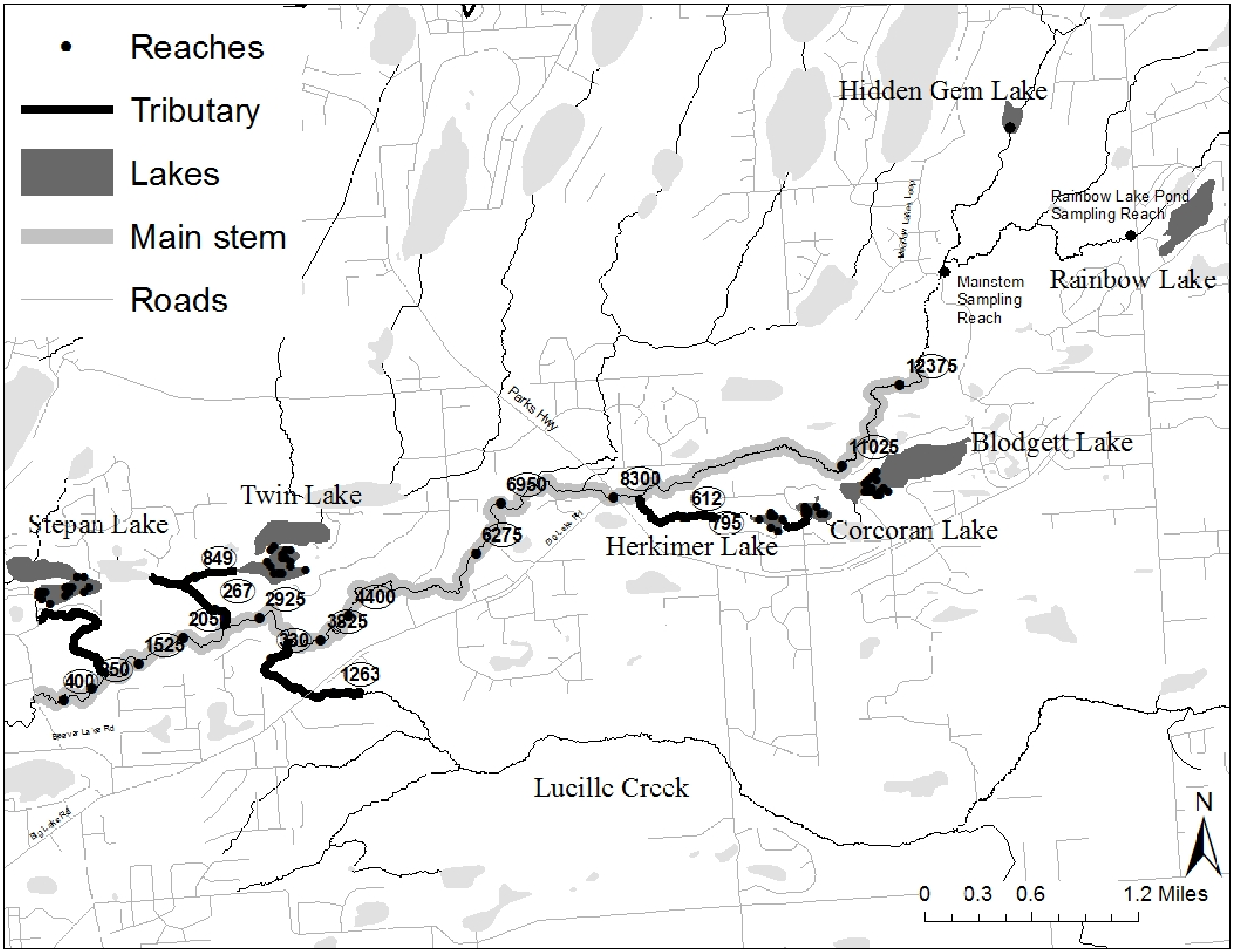

Figure 4. Location of the 2011 sampling reaches within the Meadow Creek study area, Alaska.

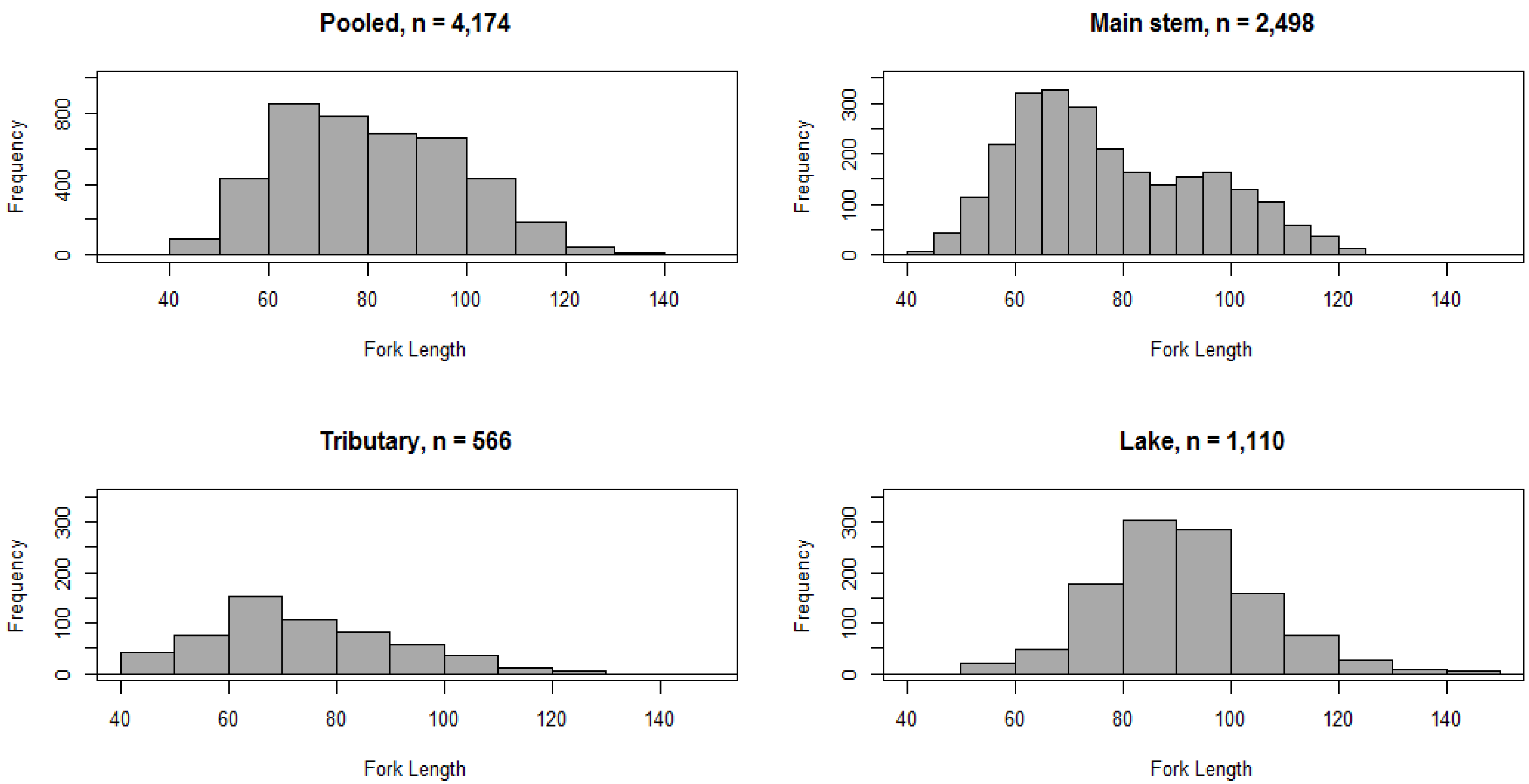

Figure 5. Length frequency distributions of all fish captured by environment in Meadow Creek study area, Alaska, 2011.

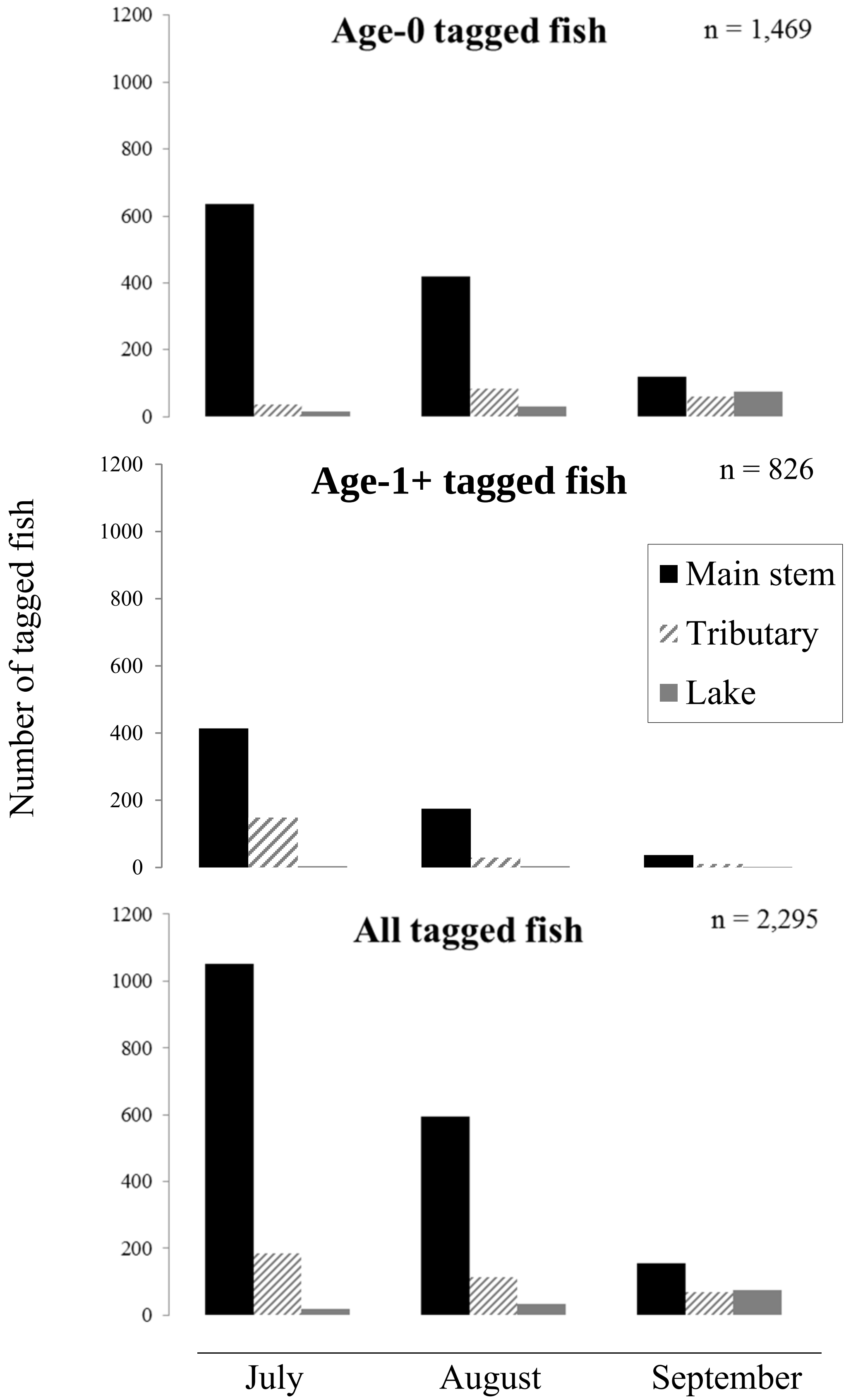

Figure 6. Number of juvenile coho salmon implanted with PIT tags by cohort and within each environment in Meadow Creek study area, Alaska, 2011.

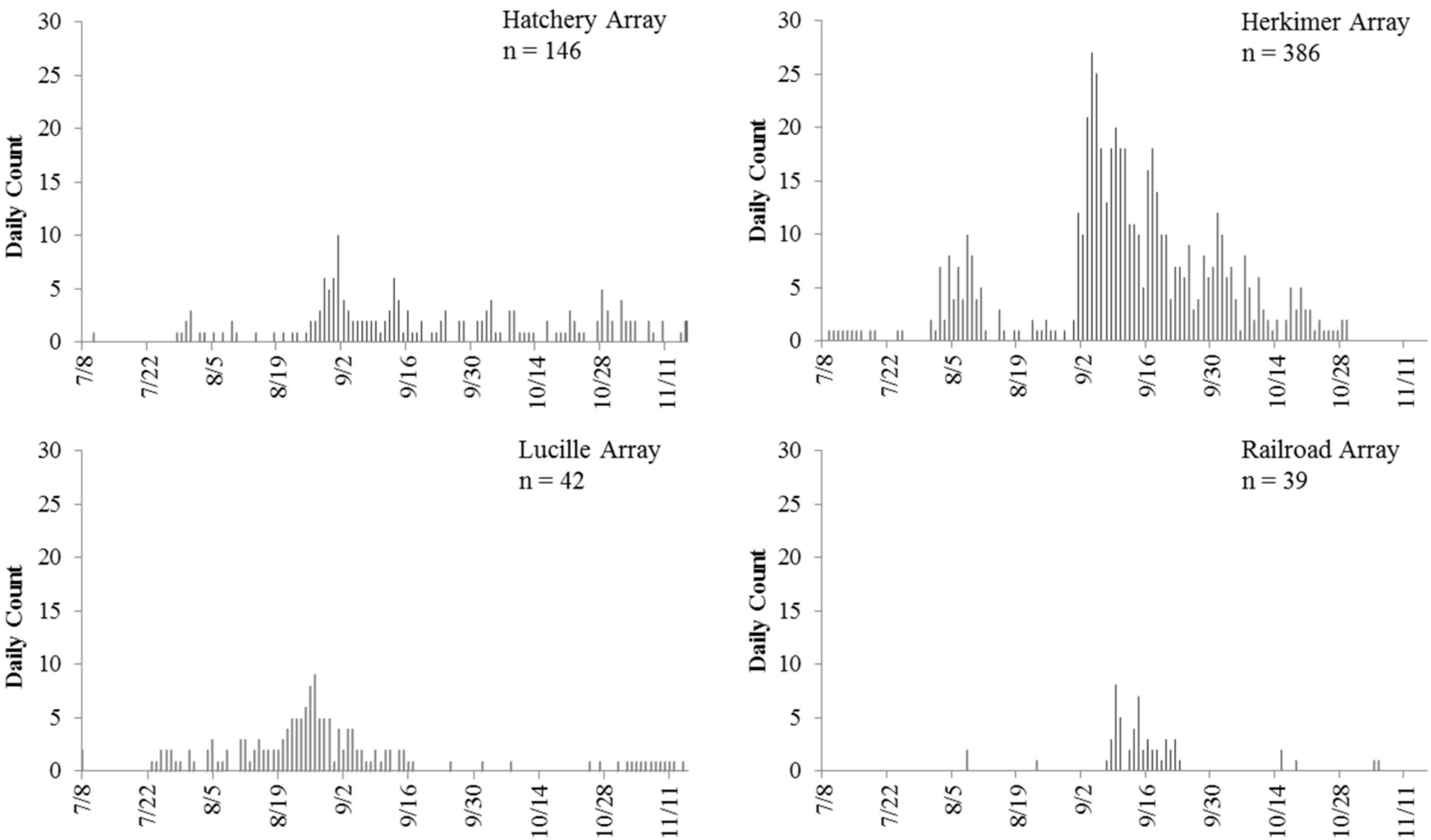

Figure 7. Number of unique PIT tags detected at each fixed array in Meadow Creek study area, Alaska, 2011.

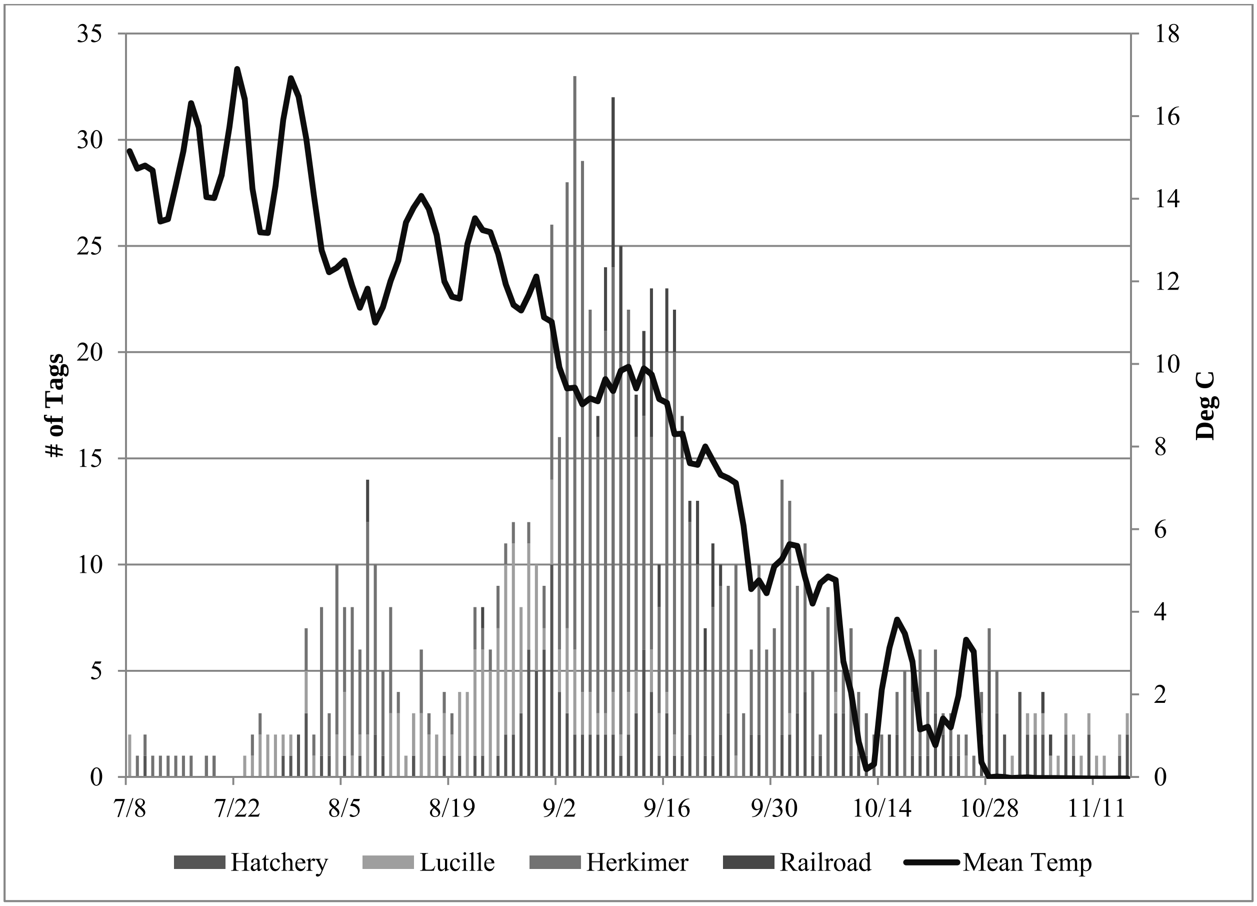

Figure 8. Combined tag detections at all fixed arrays in Meadow Creek study area as compared to daily mean water temperature values.

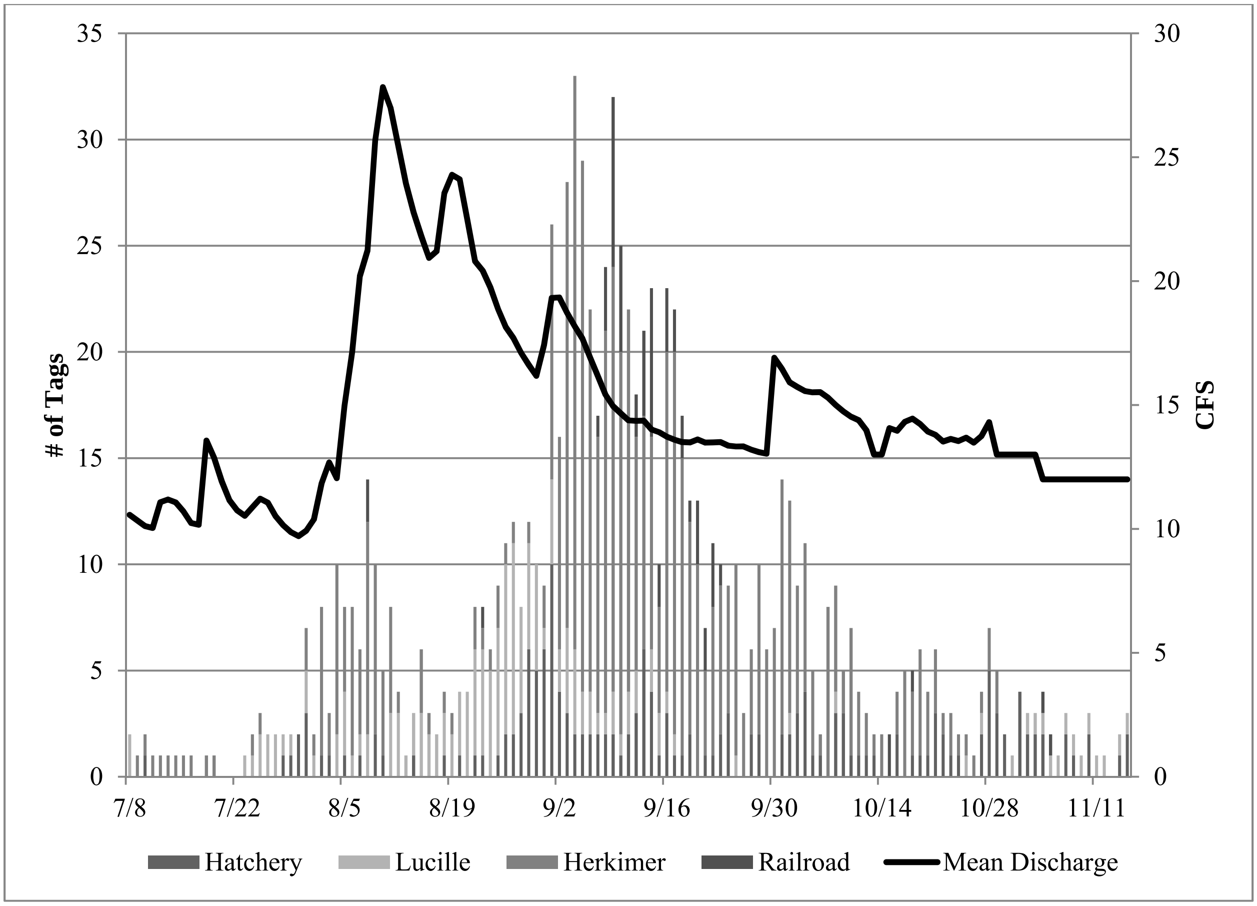

Figure 9. Combined tag detections at all fixed arrays in Meadow Creek study area as compared to mean daily discharge.

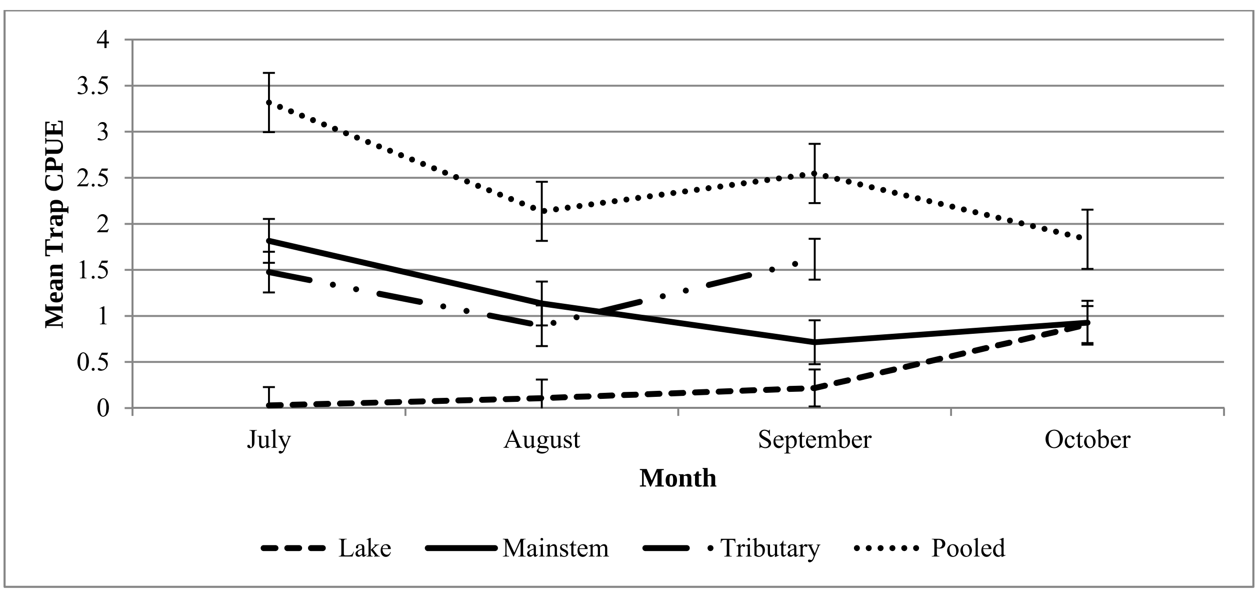

Figure 10. Mean monthly CPUE (number of fish captured/trap soak time) of juvenile coho salmon in each environment. Error bars represent standard error.

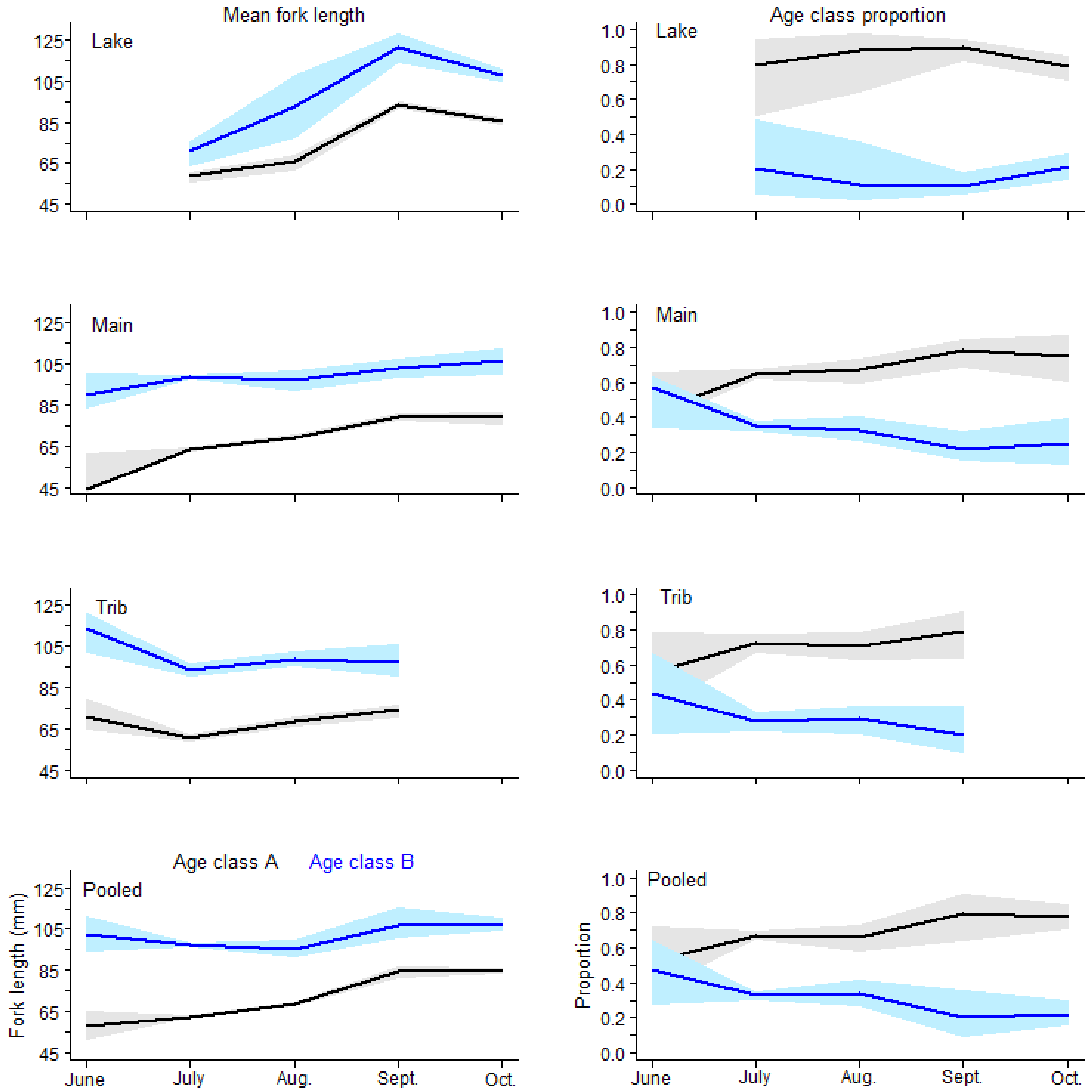

Figure 11. Time series of mean fork lengths (n = 4,174) and proportions of abundance estimated by Gaussian mixture distribution analysis on juvenile coho data. Shaded areas present 95% confidence regions. Age class A is age-0 fish whereas age class B is age-1+ fish. "Pooled" indicates samples from all environment types were combined.

Appendix A. Hatchery fixed array.

Appendix B. Lucille fixed array.

Appendix C. Herkimer fixed array.

Appendix D. Railroad fixed array.

Appendix E. Baffles affixed in bottomless culvert located upstream of the Lucille fixed array.