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Inventory, monitoring, and the efficacy of minnow traps in capturing juvenile coho salmon in the Knik River Basin, Southcentral Alaska, 2011

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Inventory of Fish Distribution in the Matanuska-Sustitna Basin, Southcentral Alaska, 2011

Elizabeth B. Benolkin and Suresh A. Sethi

Abstract

Anthropogenic activities, particularly residential and commercial development, in the Matanuska-Susitna (Mat-Su) Borough, Alaska, are likely threats to fish habitat. Fish habitat protection authorities and planning processes in Alaska are constrained by the extent of current knowledge of fish distributions and their habitats. Some protections provided under the Anadromous Fish Act (AS 16.05.871) only apply to waters specified in the *Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes* (AWC). The Anchorage Fish and Wildlife Field Office initiated this project to increase coverage of the AWC for Mat-Su basin water bodies in support of Mat-Su Basin Salmon Habitat Partnership. Sampling during 2011 was focused in the Knik River Public Use Area based on consultations with Alaska Department of Fish and Game biologists. Fisheries and land managers have concerns that intense recreational use in these extensive wetlands could impact salmon production. Sampling for the AWC was initiated as a first step in gaining a better understanding of the use of these wetlands by juvenile salmon. Fish and aquatic habitat parameters were collected from 10 study areas within the Knik River drainage, resulting in 8 nominations to update the AWC in 2011. Approximately 225 hectares of lake/wetland complexes were surveyed in 2011. Juvenile coho salmon *Oncorhynchus kisutch* were the most common anadromous species captured in Knik River drainage sites using baited minnow traps (n =821; 47-153mm), followed by juvenile sockeye salmon (*O. nerka;* n = 14 ; 57-73 mm). Dolly Varden *Salvelinus malma*, Alaska blackfish *Dallia pectoralis*, threespine stickleback *Gasterosteus aculeatus*, ninespine stickleback *Pungitius pungitius*, and sculpin *Cottus spp*. were also captured in 2011. This project began in the Knik River drainage of the Mat-Su basin in 2010 and will continue to document the spatial distribution of anadromous fish and recreational trails during 2012.

Introduction

The human population of the Matanuska-Susitna (Mat-Su) Borough is one of the fastest growing in the U.S., with a decadal growth rate of 49% from 1990 to 2000 and 50% from 2000 to 2010[1]. Population growth and associated development continue to challenge the ability of fisheries and land managers to balance fish habitat conservation with these changes over time. Maintaining healthy fish habitat, including water quality and quantity, is critical to maintain healthy fish populations in the Mat-Su basin.

Concerns for how to effectively protect and restore salmon production in the face of rapid development led to the formation of the Mat-Su Basin Salmon Habitat Partnership (Partnership). The Partnership is one of 13 fish habitat partnerships approved nationwide under the National Fish Habitat Action Plan (NFHAP), a national effort to protect and restore the nation's waterways and fisheries through science-based partnerships of affected stakeholders. The

[1] United States 2010 Census. http://2010.census.gov/news/releases/operations/cb11-cn83.html. Retrieved 23 April 2011.

Authors: The primary author is a fishery biologist with the U. S. Fish and Wildlife Service and can be contacted at Anchorage Fish and Wildlife Field Office, 605 W. 4th Ave., Anchorage, AK 99501 or elizabeth_benolkin@fws.gov.

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.

Fish habitat protection authorities and planning processes in Alaska are constrained by the extent of current knowledge of fish distributions and their habitats. Some protections provided under the Anadromous Fish Act (AS 16.05.871) only apply to waters specified in the *Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes and Companion Atlas* collectively referred to as the AWC (Johnson and Blanche 2010). Currently, the AWC documents anadromous fish presence in less than 4,200 miles of the more than 23,900 miles of streams that have been mapped in the Mat-Su basin. Management and regulatory tools cannot be applied to their full extent until the remainder of likely anadromous fish habitat in the basin is surveyed.

The Anchorage Fish and Wildlife Field Office initiated this project in 2007 to support the Partnership's Strategic Action Plan and the NFHAP by increasing coverage of the AWC for Mat-Su basin water bodies. The overall goal of this project is to provide information needed for protection and management of the freshwater habitats that support Alaska's anadromous and freshwater fish. The specific objectives of the project are to: (1) maximize the spatial extent of mapped anadromous fish habitat depicted in the AWC within the Knik River basin, and (2) present a confidence statement as to whether juvenile salmon occupy a polygon or trap site given what is known about trap efficiency in detecting animals if they are present, and given the outcome of a trapping sampling effort. A suite of water quality and habitat measurements were also collected at each trap location to maintain consistency with previous USFWS AWC studies.

We use estimates of minnow trap detection efficiency to formulate probabilistic confidence statements about whether a monitored site or area contains juvenile coho salmon given an amount of sampling effort. Occupancy confidence statements provide objective guidance on the amount of sampling effort necessary to consider a site or area as devoid of juvenile salmon and provide information useful for designing inventory and monitoring programs for juvenile coho salmon. Monitoring for juvenile salmon under the AWC is often carried out with minimal knowledge of the population ecology of juvenile salmonids in local environments. If salmon are detected during a survey at a site then the water body in questions supports salmonids and could be included under the AWC, but under what conditions should a survey site or area be considered devoid of salmonids? No detections could be the result of time varying occupancy in a survey area, or could be the result of low sampling gear efficacy. Direction as to the amount of sampling effort necessary to inventory water bodies under the AWC (and specifically as they apply to lakes or wetland areas) is not currently available, however, we suggest that the probabilistic confidence statements about whether juvenile salmon are absent from a site or area given no detections in some amount of sampling effort outlined below may be useful for making recommendations under the policy.

Study Area

The Matanuska and Susitna river watersheds encompass about 24,500 square miles in Southcentral Alaska. The watersheds meet freshwater life history needs of all five species of Pacific salmon and support populations of other salmonids including Arctic grayling *Thymallus arcticus*, rainbow trout *O. mykiss*, and Dolly Varden *Salvelinus malma*, as well as many other species such as threespine *Gasterosteus aculeatus* and ninespine *Pungitius puntitius* stickleback, and sculpin *Cottus* spp. Sampling efforts were focused in streams, lakes, and wetlands in the

Knik River Public Use Area (KRPUA) of the Mat-Su, which is a legislatively designated area managed by the Department of Natural Resources (DNR), Division of Mining, Land, and Water The KRPUA encompasses approximately 1,050 km^2 of state, federal, and private land surrounded by the Chugach mountain range, and is characterized by a mix of temperate freshwater habitats including the large order glacial Knik River, smaller order high gradient streams, and a large wetland-lake complex. The KRPUA was established to "preserve, perpetuate, and enhance public recreation, enjoyment of fish and wildlife, and the traditional use of fish and wildlife resources" (KRPUA management website: http://dnr.alaska.gov/mlw/krpua/index.cfm), and is popular among recreationalists who enjoy activities ranging from salmon fishing to riding off-road vehicles to hunting, boating and bird-watching. It also provides habitat for rich and diverse fish and wildlife populations, including anadromous fish such as sockeye and coho salmon. However, the specific freshwater habitats which may be important to juvenile anadromous fish is not documented for much of this area. In addition to a lack of information about which areas may be important habitat for salmon, resource managers have expressed concerns that increased and intense recreational use in these extensive wetlands could impact water quality, riparian habitat, and salmon production. Data gaps and concerns about potential threats to fish habitat in the KRPUA prompted the focus of AWC sampling here.

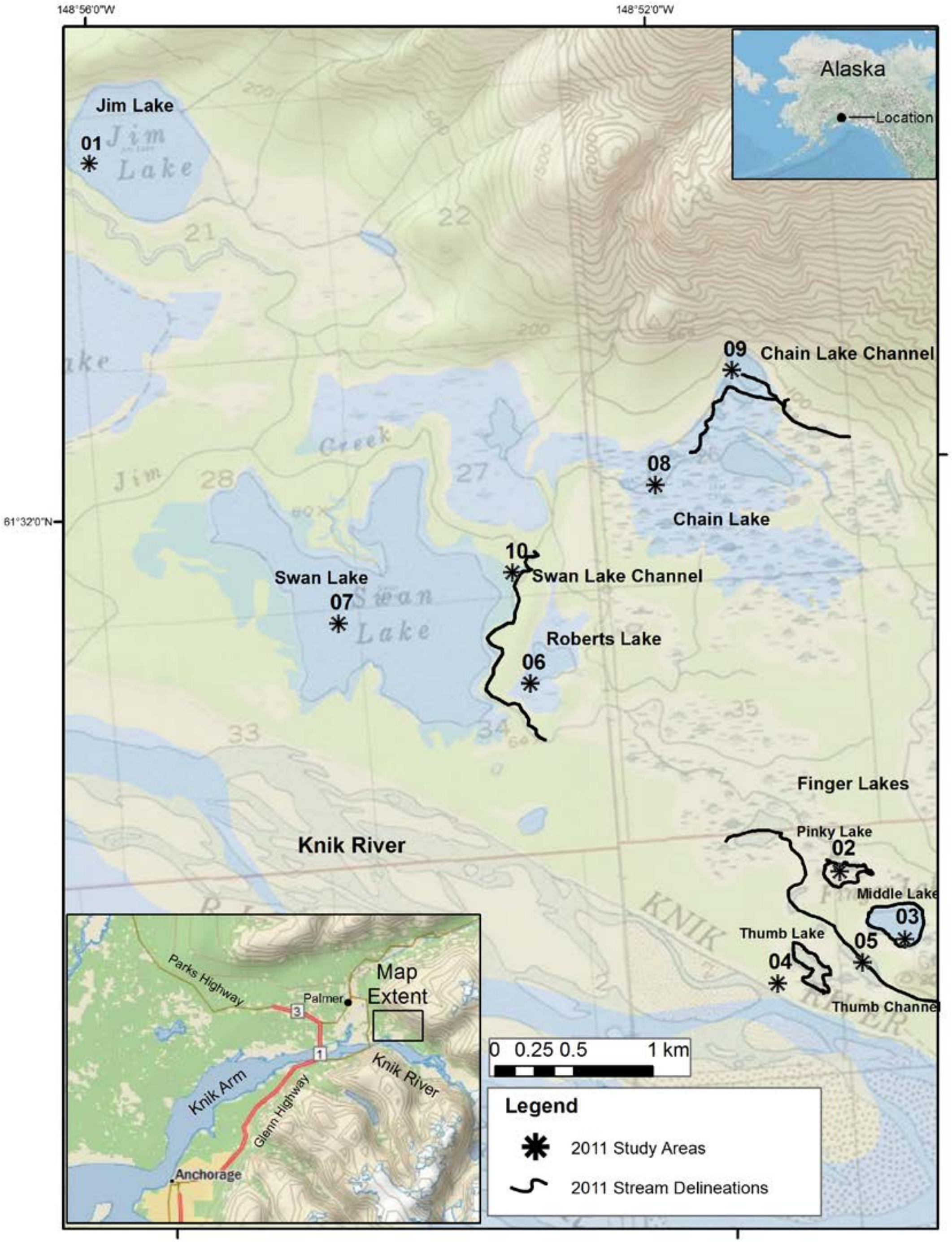

Figure 1. Study areas (01-10) and stream channel delineations within the Knik River Public Use Area, Alaska, 2011. The KRPUA is located within the map extent block in inset map. Finger Lakes study area was divided into four sampling subunits (Pinky (02), Middle (03), and Thumb Lakes (04), and Thumb Channel (05).

Methods

Study Design

Anadromous Waters Catalog sampling methods were adapted from Buckwalter (2010) and from the Alaska Department of Fish & Game's AWC polygon sampling guidelines (ADF&G 2010). Methods target rearing salmonids in streams, lakes, and wetland complexes considered important for anadromous fish. The study region was selected based on consultations with the Habitat-Restoration Branch of the U.S. Fish and Wildlife Service (USFWS) and the Alaska Department of Fish and Game (ADF&G; Sport Fish and Habitat Divisions, Palmer Alaska). Criteria for study region selection included on-going and expected recreational use, key data gaps, and potential threats to anadromous streams. Areas specified for priority sampling include streams, lakes, and wetland complexes north of the Knik River, which are part of the KRPUA and include Jim Lake, Swan Lake, Chain Lakes, Finger Lakes, and the ponds, wetlands, and tributary channels southeast of Swan Lake (Figure 1).

The sampling scheme outlined below was developed to be repeatable for future AWC polygon sampling. It is tailored towards fitting occupancy models (Mackenzie et al. 2006); however, at a minimum, it is designed to ensure good coverage over candidate AWC polygons for determinations as to whether or not an area should be included into the AWC, regardless of whether a formal occupancy model is estimated.

Sampling hierarchy

The overall sampling design can be viewed as a series of nested levels in a hierarchy (Figure 2). The coarsest level of interest is the AWC polygon, referred to as a "study area" for which a determination of whether juvenile salmon occupy the habitat or not is desired. The set of AWC polygons are referred to as the "study region". For the current research effort, the set of polygons are those areas within the Knik River Public Use Area which are candidates for AWC inclusion but have not been previously quantitatively surveyed for the presence of juvenile salmon.

Within AWC polygons, a number of minnow traps were deployed at trap "sites" to assess whether juvenile salmon occupy the polygon or not. Three repeated surveys (i.e. trap deployments) at fixed trap sites were conducted in order to provide data to estimate the probability of detecting juvenile salmon with minnow traps if present (p). A "sampling occasion" encompasses the length of time required to complete all K repeated surveys across all M trap sites. An important assumption of occupancy modeling is that trap sites are closed during a given sampling occasion, meaning no movement of animals onto or off of the trap site during a sampling occasion (though random movement into and out of sites is acceptable). In order to adhere to the closure assumption, repeat trap surveys at all study sites in a study area were conducted back to back. Three repeat surveys were conducted in a 96 hour period, such that a sampling occasion length is four days. Finally, in order to examine whether occupancy changes over time, the entire sampling regime was repeated once a month during the summer and early fall months. This allowed for inclusion of a "month" effect in the occupancy model when data are analyzed. Trap sites locations were fixed over the entire study season, i.e. both within and across sampling occasions.

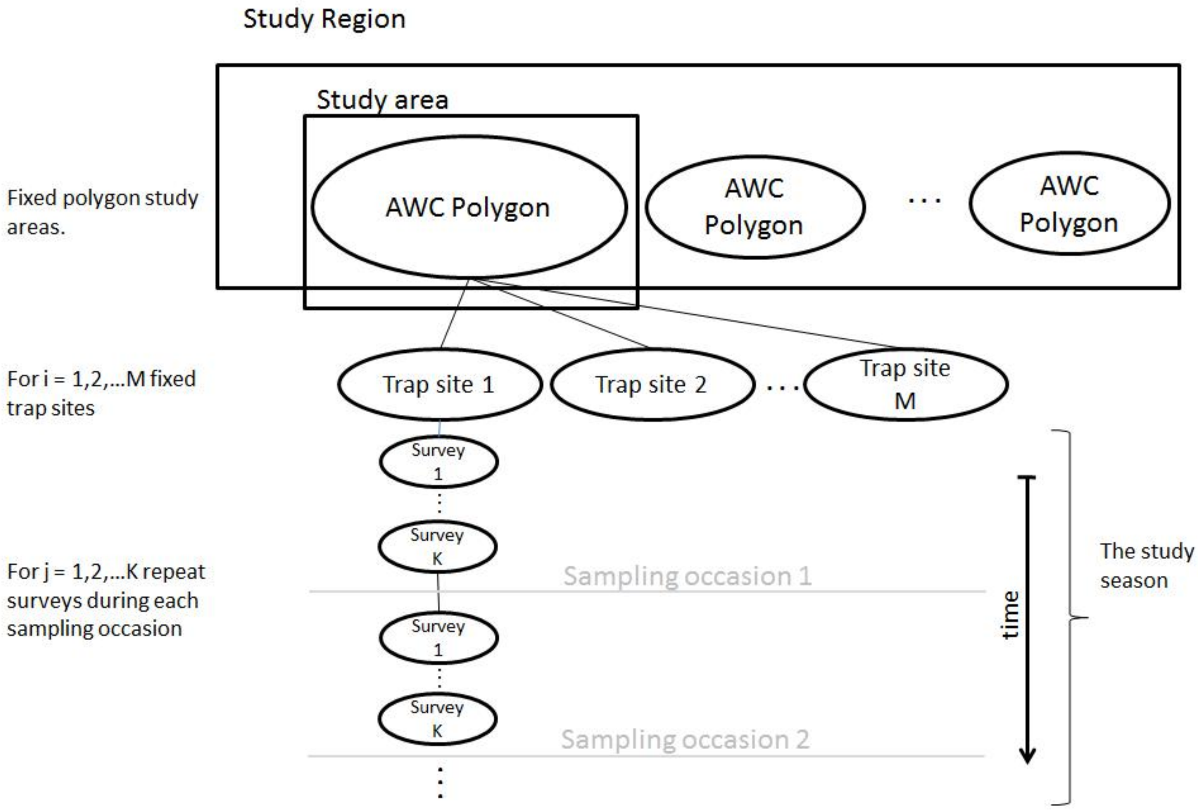

Figure 2. Sampling hierarchy for AWC polygon sampling in Southcentral Alaska.

Trap site placement

The goal of the occupancy modeling was to provide a probabilistic assessment of whether or not a polygon contains juvenile salmon, and to estimate the probability of detecting salmon given that they occupy a site. We employed a blend of systematic and random sampling as follows. A study area was divided into four quadrants and the total number of trap sites was divided evenly among quadrants. Within quadrants, traps were randomly placed. As detailed study area maps were not available before sampling began to conduct formal pure random trap site selection, trap placement was haphazard random. This design ensured that traps sites were distributed throughout each study area. Spatial autocorrelation is a sampling issue for occupancy modeling. If animals exhibit a patchy distribution throughout the environment (as schools of fish might), then it is likely that traps placed close together would have positively correlated catches. This could potentially introduce what is termed “pseudoreplication” into the data and result in estimated parameter precision estimates that are too narrow (e.g. Diniz-Filho et al. 2003). One simple way of dealing with spatial autocorrelation is to space trap sites far enough apart such that survey results are not correlated. We used pilot data on minnow trapping counts in the broader study region from 2010 AWC sampling in Southcentral Alaska (Benolkin 2011) to construct spatial correlograms for four sampled polygons to examine catch correlation as a function of trap spacing (Figure 3). In most cases, it appears that there is little spatial autocorrelation even with closely spaced traps, however, there is some suggestion that minimum trap spacings of 50 to 75m may help ensure a reduction in spatial autocorrelation. In light of this, when feasible, traps were spaced at distances greater than 50m in the field. Two-person crews operated 30 traps/day, and this trap spacing resulted in trap density of ~30 traps/75 ha of trappable area.

Finally, minnow traps are only effective in water depths exceeding 10 cm (Swales 1987). Thus, the study area (a candidate AWC polygon) was defined as trappable area. Water must sufficiently cover the entrance holes on both ends of the trap to allow fish capture, however complete submersion of the trap is ideal.

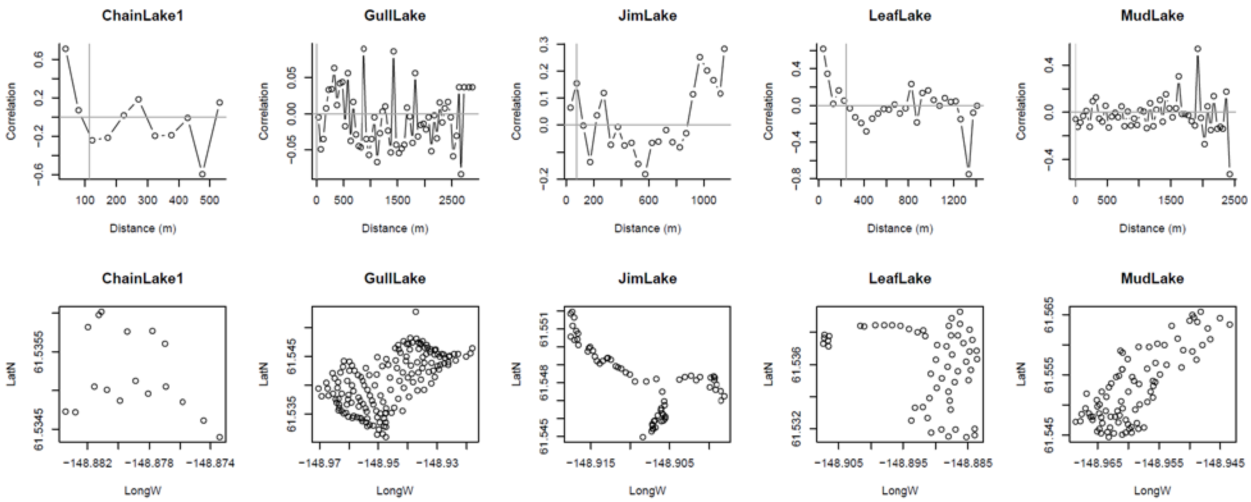

Figure 3. Correlograms for spatial autocorrelation of coho salmon counts in minnow traps deployed in 2010 AWC polygon sampling in South Central AK. The top row of plots presents spatial autocorrelation as a function of trap spacing; gray lines indicate the minimum trap spacing associated with zero autocorrelation. The bottom row of plots displays trap locations in latitude (N) and longitude (W).

Sampling effort allocation

Sampling effort can be allocated to either more trap sites or more repeated surveys within trap sites. MacKenzie et al. (2006) suggest that more survey sites (*M*, trap locations, see Figure 2) provides increased precision of the estimates of occupancy probabilities, whereas more repeat surveys (*K*, repeat surveys at each trap site, see Figure 2) provides increased precision of the estimate of probability of detection. MacKenzie et al. (2006) provide simulation results which indicate that if a species is "common" in the environment, which indicates a high probability of occupancy at sites , then 2 or 3 repeat surveys at sites provides the optimal number of repeat survey effort in terms of balancing precision between occupancy and detectability estimates. A high probability of occupancy at a site is =0.7 or greater, (or a >70% chance that juvenile salmon are present at a randomly selected trap site), and detectability is on the order of 0.6 (or a 60% chance of detecting a salmon at a trap site given it is present). Pilot AWC polygon sampling in in this area during 2010 (Benolkin 2011) suggest that juvenile salmon are common, and that trapping success was moderate to good in most candidate polygons. In light of this, we targeted 3 repeat surveys at each site, conducted back to back in order to protect the closure assumption of occupancy modeling outlined above.

Occupancy Modeling

We assessed juvenile coho presence and the efficacy of minnow trapping to detect juvenile coho salmon at study areas using occupancy models (MacKenzie et al. 2002; MacKenzie et al. 2006). Occupancy models estimate the probability that an organism occupies a study site, taking into account that survey methods are not 100% effective in detecting organisms. The data that go into occupancy models are repeat surveys of study sites which indicate presence or absence of an organism, in this case repeated minnow trap deployments to capture juvenile coho salmon. The two key parameters of occupancy models are the probability an animal occupies a study site, or occupancy, ψ, and a probability of detecting an organism given it is present at a study site, or conditional (on occupancy) probability of detection, p. Occupancy models can be viewed as hierarchical models (Royle and Dorazio 2008), specifying a separate model for a state process, i.e. coho juvenile occupancy, and an observation process, i.e. minnow trap detections:

$$Z_i \sim Bernoulli(\psi)$$
$$Y_{ij}|Z_i \sim Bernoulli(Z_i p)$$

where the first statement is the state process and Z_i indicates an indicator variable equal to 0 if no animals occupy site *i* or 1 if the site is occupied. The second statement is the observation process, conditioned on occupancy, where Y_{ij} is the count of animals detected as site *i* on trap deployment *j* . Note, if the site is unoccupied, then the probability of detecting at least one animal is zero. Key assumptions of occupancy models are that trap sites are closed to additions and losses of animals throughout the survey period (here, across all repeated trappings within a time-area combination sampling occasion) and that outcomes of surveys across sites are independent. As outlined above, we attempted to accommodate the closure assumption by employing back to back trap deployments during a sampling occasion, and traps were spaced at least 50m apart to avoid any spatial dependence between trap outcomes that may result from patchily distributed or schooling juvenile coho.

The probability of detection estimates from occupancy models provide information on the efficacy of minnow traps to detect juvenile coho salmon which can be used to make probabilistic statements regarding the presence of salmon given trapping effort. Of primary interest is P(salmon are absent at a site | no detections across *J* repeated trap deployments). This quantity can be calculated using Baye's rule as:

P(salmon absent | none detected, ψ, p) = P(none detected | absent, ψ, p)*P(absent| ψ, p) / P(none detected| ψ, p)

$$= 1.0(1-\psi) \Big/ \left((1-\psi) + \psi \prod_{j=1}^{J}(1-p)\right)$$

$$= g(\psi, p)\ .$$

Note that this probability is a function of ψ and p requiring a value of the probability of occupancy and detection at a site be asserted to calculate the conditional probability. We did this in two ways. First, we assumed a probability of detection and occupancy and then calculated a probability of animals being absent from a study site given a number of repeated trap deployments with no detects. Second, we viewed the above probability as a joint probability of P(salmon absent, ψ| none detected, p), reflecting the ignorance about occupancy, and estimated the marginal distribution of P(salmon absent | none detected,ψ, p) by integrating out the probability of ψ. This can be viewed as placing a prior on different occupancy probabilities (e.g. all ψ are equally likely, or ψ ~Uniform(1,1)) and then integrate P(salmon absent | none detected,ψ, p) across all ψ values and their associated probabilities, P(salmon absent | no detects and p known) = $\int_{\psi=0}^{1} \mathrm{P}(salmon\ absent, \psi | sampling\ effort, p)\mathrm{P}(\psi)d\psi$

The above calculations specify the probability of absence at a specific site given an amount of sampling effort with no detections, however, for many wildlife inventory applications, the goal will be to characterize a collection of sites, i.e. a study area, as either containing or devoid of salmonids. Unfortunately, this calculation is not straightforward because it requires substantial information to be in hand including knowledge of the number of non-overlapping trap sites in the candidate area which itself requires knowledge of the area sampled by a trap, true occupancy probabilities at sites, and probabilities of detection. Barring these difficulties, suppose a candidate area can be divided into *S* non-overlapping trap sites, and each site has an associated true probability of occupancy ψ_i. Then before any monitoring has occurred and assuming sites are independent with respect to occupancy, the probability salmon are absent in the area is:

$$\mathrm{P}(\text{absent in area} \mid \boldsymbol{\psi}) = \prod_{i=1}^{S}(1-\psi_i)$$

where $\boldsymbol{\psi}$ represents a vector of site occupancies. After sampling effort yielding no detections, information is gained regarding whether specific sites contain salmon and the probability salmon occupy an area is updated. Suppressing notation for conditioning on the probability of detection and assuming sites are independent:

$$\mathrm{P}(\text{absent in area} \mid \boldsymbol{\psi}, \text{no detects in survey}) = \prod_{i=1}^{S}(1-\omega_i)$$

with

$$\omega_i = \begin{cases} \psi_i & \text{if site } i \text{ not trapped} \\ 1 - P(\text{ absent at site } i \mid \text{no detects in survey}) & \text{if site } i \text{ trapped} \end{cases},$$

where an estimate for P(absent at site i | no detects in survey) is generated as above. This calculation specifies a probability of presence that requires a priori knowledge of $\boldsymbol{\psi}$ at untrapped sites. Following the logic above, ψ_i could be marginalized out at each site if analysts were not able to assert specific occupancy probabilities, however this is equivalent to asserting an expected value of ψ_i at each untrapped site:

$$\omega_i = \begin{cases} \int_0^1 \psi_i f(\psi_i)d\psi_i = E[\psi_i] & \text{if site } i \text{ not trapped} \\ 1 - P(\text{absent at site } i \mid \text{no detects in survey}) & \text{if site } i \text{ trapped} \end{cases}.$$

As an example of the calculations necessary to make an assessment about presence of salmonids in a study area, suppose that an observer is attempting to characterize the probability salmon are absent in an area that contains 10 non-overlapping trap sites and they believe the true occupancy probability at all sites is 0.1. Then prior to any trapping effort, the estimated probability salmon are absent from the area is $\prod_1^{10}(1-0.1) = 0.35$. Five sites are trapped repeatedly three times with a known probability of detection of 0.6 and no detections are observed, yielding a probability salmon are absent at each trapped site of 0.99 . Then the probability salmon are truly absent in the area is: $\prod_1^5(1-0.1) \times \prod_1^5(1-(1-0.99)) = 0.56$. In this hypothetical example with imperfect detection, if all sites were trapped then the probability salmon are absent from the area is $\prod_1^{10}(1-(1-0.99)) = 0.90$.
Occupancy models were fit to Knik Public Use Area 2011 minnow trap data using maximum likelihood methods implemented with the *unmarked* package (Fiske and Chandler 2011) in the R statistical programming environment (R Development Core Team 2010). We fit a suite of models which stratify ψ and *p* by either time, area, both time and area, or models which fix ψ and *p* as constant across time, area, or both time and area. Occupancy models were fit to a subset

of study areas for which repeated trapping sampling effort was available and for which coho salmon were known to inhabit sites at some point in the study period: July, August, and October sampling in Chain, Jim, and Pinky Lake. In most cases, only one sampling occasion was available per month per area except for Chain lake in which case the August 1-3 sampling occasion was used to model occupancy. In all cases, occupancy and probability of detection were modeled as constant across sites within a time-study area combination. Model support was evaluated using AIC scores. The global model included both occupancy and probability of detection as a function of time, area, and an interaction between time and area, represented in the R statistical programming language formula notation as:

$$\psi \sim Study\ Area + Month + Study\ Area{:}Month$$
$$p \sim Study\ Area + Month + Study\ Area{:}Month$$

As a first step in model fitting and selection, we assessed whether the global model could adequately explain the data using a monte-carlo based goodness of fit test proposed by MacKenzie and Bailey (2004). A parametric bootstrap routine was implemented using functions provided in package *unmarked* and using a Chi-squared test statistic. Briefly, the parametric bootstrap procedure works as follows: i) fit the occupancy model with observed data and calculate the observed Chi-squared test statistic: $\sum_{site\ i=1}^{M} \sum_{surveys\ j=1}^{J} {(O_{ij} - E_i)^2}/{E_i}$, where O_{ij} and E_i are the observed and expected occupancy at site *i* during trap deployment j , ii) generate simulated site-level occupancy data and observation data given occupancy using parameter estimates of the ψ and p from the model fitted to observed data, iii) fit the model using bootstrapped data and calculate the chi-squared test statistic, iv) repeat *B* times to approximate the test-static distribution and calculate the proportion of times the statistic under simulated data is as extreme or more extreme than the statistic from the observed data which provides a parametric bootstrapped *p*-value indicating the probability of obtaining the observed test statistic by chance alone if the underlying data generating process specified by the fitted model were true.

Fish Assessment

Fish sampling in study polygons was conducted by minnow trapping. Gee® brand minnow traps (Cuba Specialty Manufacturing Company, G-40, ¼” mesh) were baited with cured salmon roe, and set from canoes within lakes or by foot in wetland areas, and soaked for 24 hours. Traps were marked with a small float and anchored when necessary. The location of each trap site was recorded as a GPS waypoint, and the start, end, and total soak time was recorded. Experimental methods such as seining and electrofishing were used opportunistically to target sockeye salmon in areas previously undocumented with this species when feasible.

Captured fish were placed in a 12-L bucket less than one half full with stream water. Fish were counted and identified to species (Pollard et al. 1997). Total forked length (mm) was recorded for all juvenile coho salmon, sockeye salmon, and Dolly Varden. All fish were released back to the sample area and allowed to recover.

Water Quality Measurements and Habitat Observations

Water depth (cm), water and air temperature (ºC), pH, conductivity (µS/cm), and dissolved oxygen (DO; mg/L) measurements were collected from each trap site at each trap deployment. Water temperature (°C), conductivity (µS/cm) and pH were measured using a YSI 63 water quality multimeter, and DO (mg/L) was collected using a YSI 550A at consistent subsurface depths of about 0.5m or within 0.1m of the lake bottom where water was < .05m deep. Sampling equipment was calibrated weekly according to manufacturer's manuals or more often if readings were suspect.

When feasible, several other broad habitat observations were visually estimated at each site including minimum distance to shore (m), dominant substrate category (boulder, cobble, pebble/gravel, sand/silt/clay, or organic; Buckwalter 2010), type of aquatic vegetation (emergent, floating, submerged), presence of woody debris, percent vegetation coverage, and water color (clear, ferric, glacial, humic, or muddy; Buckwalter 2010). Photos were taken at each site to document habitat characteristics.

In addition to the habitat covariates listed above, sampling date and location information were collected. A time covariate (e.g. a categorical month) was included into model estimations in order to test whether the relationship between juvenile salmon use changes throughout the summer. Similarly, occupancy and detection may also vary across study area. Location information will allow for tests of changes in the relationship between occupancy and/or detection among locations. Furthermore, sampling date and location information will allow for a hierarchical modeling structure of the data, should random effects models be indicated as fitting the data well when collected data were analyzed. Finally, if a candidate polygon study area is divided into multiple sampling subunits in order to achieve the desired standardized trap sites/area (see above), all subunits were sampled each month in order to test for changes in occupancy and detection by season.

Results

Approximately 225 hectares of lakes and channels were surveyed in the Knik River Public Use area from 15 June to 20 October 2011. Seven lakes and 3 stream channels were sampled for fish in 2011. Three repeated surveys (i.e. trap deployments) at fixed trap sites were conducted at 7 of these sites, while 2 sites (Robert's Lake and Swan Lake Channel) were opportunistically sampled for possible AWC inclusion.

Fish Surveys

Anadromous juvenile coho salmon (n =821) were captured in 6 of 9 sites surveyed in 2011 (Table 1). Four of the seven lakes (Sites 01, 02, 06, and 08) and three channels surveyed (Sites 05, 09, and 10) contained juvenile coho salmon (Table 1; Figure 1). No juvenile coho salmon were captured in Middle, Thumb or Swan Lake during any surveys (Table 1, Figures 3 and 5).

Anadromous juvenile sockeye salmon were captured in Jim Lake (n = 7), Chain Lake (n = 6) and a single sockeye salmon (length = 86 mm) was captured in Swan Lake during October surveys (Table 1, Figures 2, 5, and 6).

Schools of 100 to 300 juvenile coho salmon were observed near the Jim lake boat launch on June 24, and again in mid-August. A school of about 40 juvenile coho salmon were observed near the inlet to Swan Lake on June 24 (Figure 8); one was netted by hand and measured for length. A school of approximately 30 juvenile sockeye salmon was observed near the portage between Jim Lake & McRoberts Creek on June 22 (Figure 2). Four of these were captured by hand net to verify species. Schools of 25-50 adult sockeye salmon were observed on the east side of the Jim lake boat launch during mid-August (Aug 15-18). Numerous migrating adult coho and sockeye salmon were observed in Jim Creek and McRoberts Creek during travel to study sites throughout August. A school of unidentified whitefish species was observed on June 17 in Swan Lake Channel (Figure 9). Three size classes of whitefish were observed: schools of approximately 20-60 fish ranging from 100-150mm, schools of 20-40 fish ranging from 190mm to 260mm, and schools of approximately 1-15 fish from 300 -350mm.

Dolly Varden (n = 51) were captured in 4 sites surveyed (Sites 01, 02, 05, and 08; Table 1; Figure 1). Threespine stickleback (n = 8,013) and ninespine stickleback (n = 193) were captured in 6 of the same nine sites sampled (all but Sites 04, 05, and 09), and 643 unidentified stickleback species were captured at three sites (01, 02, and 08; Table 1; Figure 1). Alaska blackfish (n = 631) were captured in all sites surveyed, and one sculpin was captured in Pinky Lake (Table 1).

Of the 821 juvenile coho salmon captured, 736 were measured for length (mean = 106 mm; range = 47 to 153 mm; Table 1; Figures 11 and 12). Fish length showed a general increasing trend over sampling occasions in Jim Lake (Figure 11). Average fish size ranged from 83mm in Chain Lake Channel, to 114 mm in Jim Lake (Figure 12). Fourteen juvenile sockeye salmon were captured in 2011, and 10 of these were measured for length (mean = 67 mm; range = 57 to 86 mm). Of 51 Dolly Varden captured, 42 were measured for length (mean = 130 mm; range = 82 to 180 mm).

Table 1. Summary of study areas, sampling occasions, trap deployments, and total number of juvenile fish captured in minnow trap surveys in the Knik River Drainage, AK, 2011.

Study Area	Sampling occasions	# of Traps Deployed	Trap Names	Coho salmon	Sockeye salmon	Dolly Varden	3-spine stickleback	9-spine stickleback	Stickleback spp.	Alaska blackfish	Sculpin (spp.)
01 Jim Lake	June 15	14	C001-C014	0	0	0	532	0	0	1	0
	June 16	14	C001-C014	6	0	0	682	0	0	1	0
	June 22	0	N/A- Hand Net	NA	4	NA	NA	NA	NA	NA	NA
	June 28	28	C001-C014 & C043-C056	34	0	0	314	1	0	4	0
	July 18-20	28	C001-C014 & C043-C056	26	3	0	214	0	0	13	0
	Aug 15-17	28	C001-C014 & C043-C056	15	0	2	580	5	0	13	0
	Oct 11-13	28	C001-C014 * C043-C056	238	0	20	67	0	123	42	0
Total Jim Lake				318	7	22	2389	6	123	74	0
02 Pinky Lake	July 12-14	15	C087-C0101	25	0	2	354	2	0	38	1
	Aug 8-10	15	C087-C0101	61	0	7	206	20	0	59	0
	Oct18-19	15	C087-C0101	103	0	6	143	0	73	83	0
Total Pinky Lake				189	0	15	703	22	73	180	1
03 Middle Lake	July 12-14	14	S001-S014	0	0	0	244	13	0	33	0
	Aug 8-10	14	S001-S014	0	0	0	7	45	0	50	0
	Oct 17	9	TT21-TT29	0	0	0	0		0	10	0
Total Middle				0	0	0	251	58	0	93	0
04 Thumb Lake	July 12-14	9	S016-S024	0	0	0	0	0	0	68	0
	Aug 8-10	9	S016-S024	0	0	0	0	0	0	74	0
	Oct 17	10	TT11-TT20	0	0	0	0	0	0	27	0
Total Thumb Lake				0	0	0	0	0	0	169	0

Authors: The primary author is a fishery biologist with the U. S. Fish and Wildlife Service and can be contacted at Anchorage Fish and Wildlife Field Office, 605 W. 4th Ave., Anchorage, AK 99501 or elizabeth_benolkin@fws.gov.

Table 1 continued.

Study Area	Sampling occasions	# Traps Deployed	Trap Names	Coho salmon	Sockeye salmon	Dolly Varden	3-spine stickleback	9-spine stickleback	Stickleback spp.	Alaska blackfish	Sculpin (spp.)
05 Thumb Channel	July 12-14	1	S015	1	0	2	0	0	0	6	0
	Aug 8-10	1	S015	3	0	0	0	0	0	11	0
Total Thumb Channel				4	0	2	0	0	0	17	0
06 Roberts Lake	Aug 22-23	2	S025-S026	3	0	0	53	3	0	17	0
Total Roberts Lake				3	0	0	53	3	0	17	0
07 Swan Lake	June 21-23	28	C015-C042	0	0	0	359	2	0	1	0
	July 25-27	28	C015-C042	0	0	0	15	4	0	2	0
	Aug 22-24	4	C039-C042	0	0	0	1	0	0	0	0
	October 12	10	TT01-TT10	0	1	0	3	0	0	0	0
				0	1	0	378	6	0	3	0
08 Chain Lake	July 5-7	30	C057-C086	20	0	2	3796	0	*	8	0
	Aug 1-3	30	C057-C086	176	1	0	203	73	*	3	0
	Aug 22-24	30	C057-C086	4	3	5	15	19	*	1	0
	Oct 17, 20	24	C057-C061 & C067-C086	79	2	0	0	4	447	66	0
Total Chain Lake				279	6	7	4014	96	447	78	0
09 Chain Lake Channel	July 6-7	2	CH01-CH02	9	0	1	217	1	0	0	0
	August 1	7	CH01-CH07	18	0	4	8	1	0	0	0
Total Chain Lake Ch.				27	0	5	225	2	0	0	0
10 Swan Lake Channel	June 24	0	NA- Hand Net	1	NA	NA	NA	NA	NA	NA	NA
Total Swan Lake Ch.				1	0	0	0	0	0	0	0
Total Fish Captured				821	14	51	8013	193	643	631	1

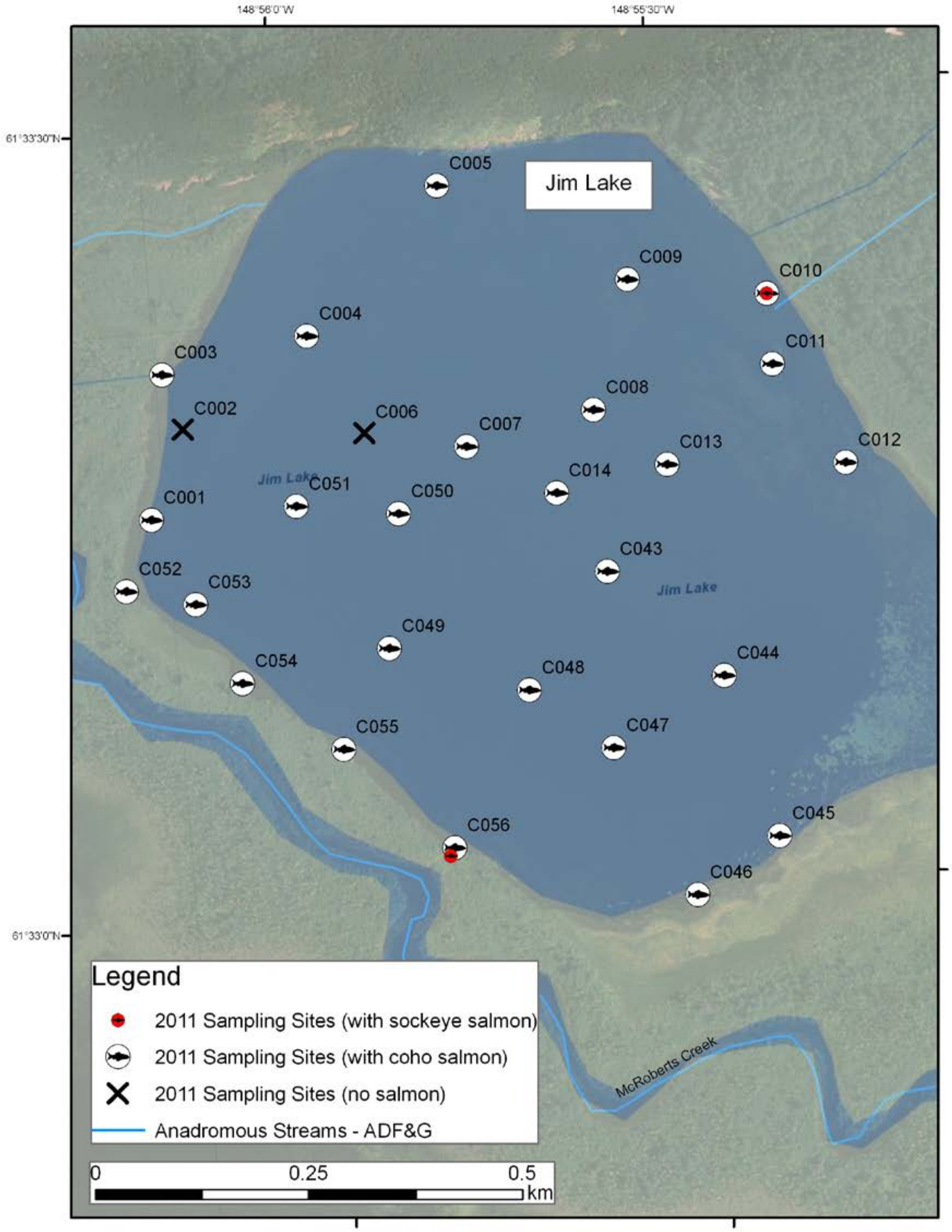

Figure 4. Minnow trap sites in Jim Lake, 2011. Black X's indicate locations where minnow traps were set and no anadromous fish were captured on any sampling event (June-October). Three hundred eighteen juvenile coho and 7 juvenile sockeye salmon were captured in Jim Lake during June, July, August, and October surveys, 2011. The majority of coho salmon (238 of 318) were captured in October.

Authors: The primary author is a fishery biologist with the U. S. Fish and Wildlife Service and can be contacted at Anchorage Fish and Wildlife Field Office, 605 W. 4th Ave., Anchorage, AK 99501 or elizabeth_benolkin@fws.gov.

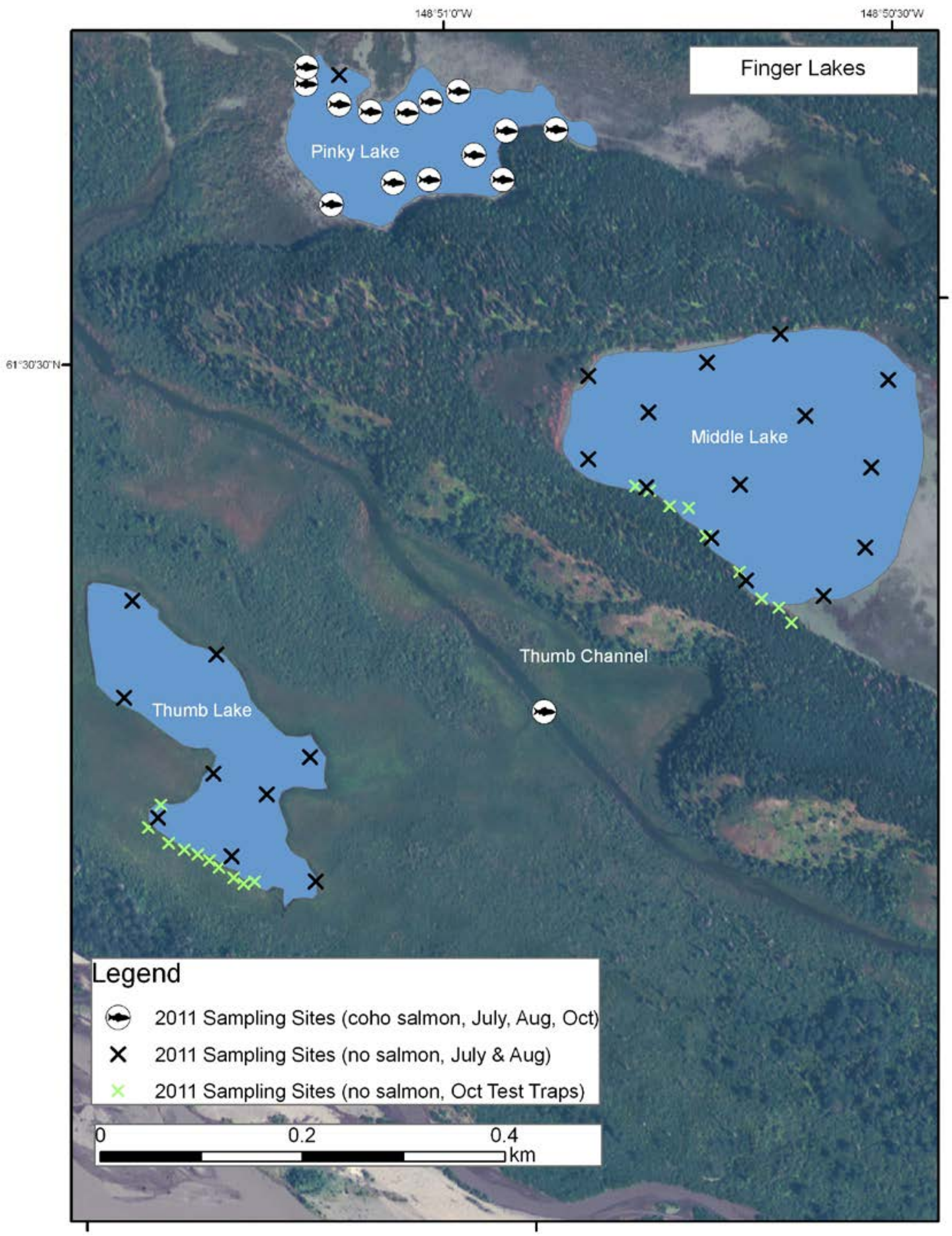

Figure 5. Minnow trap sites in Finger Lakes Study Area, 2011 (Sites 02, 03, 04, and 05). Three lakes (Pinky, Middle, and Thumb) were sampled for fish in July, August, and October, and a small stream channel (Thumb channel) was sampled for fish in July and August, 2011. Coho salmon (n = 189) were captured in Pinky Lake and Thumb channel (n = 4), but not in Middle or Thumb Lake. Sixty-minute Test Traps were placed in sites indicated by green X's in Middle and Thumb channel in October; no salmon were captured during these surveys.

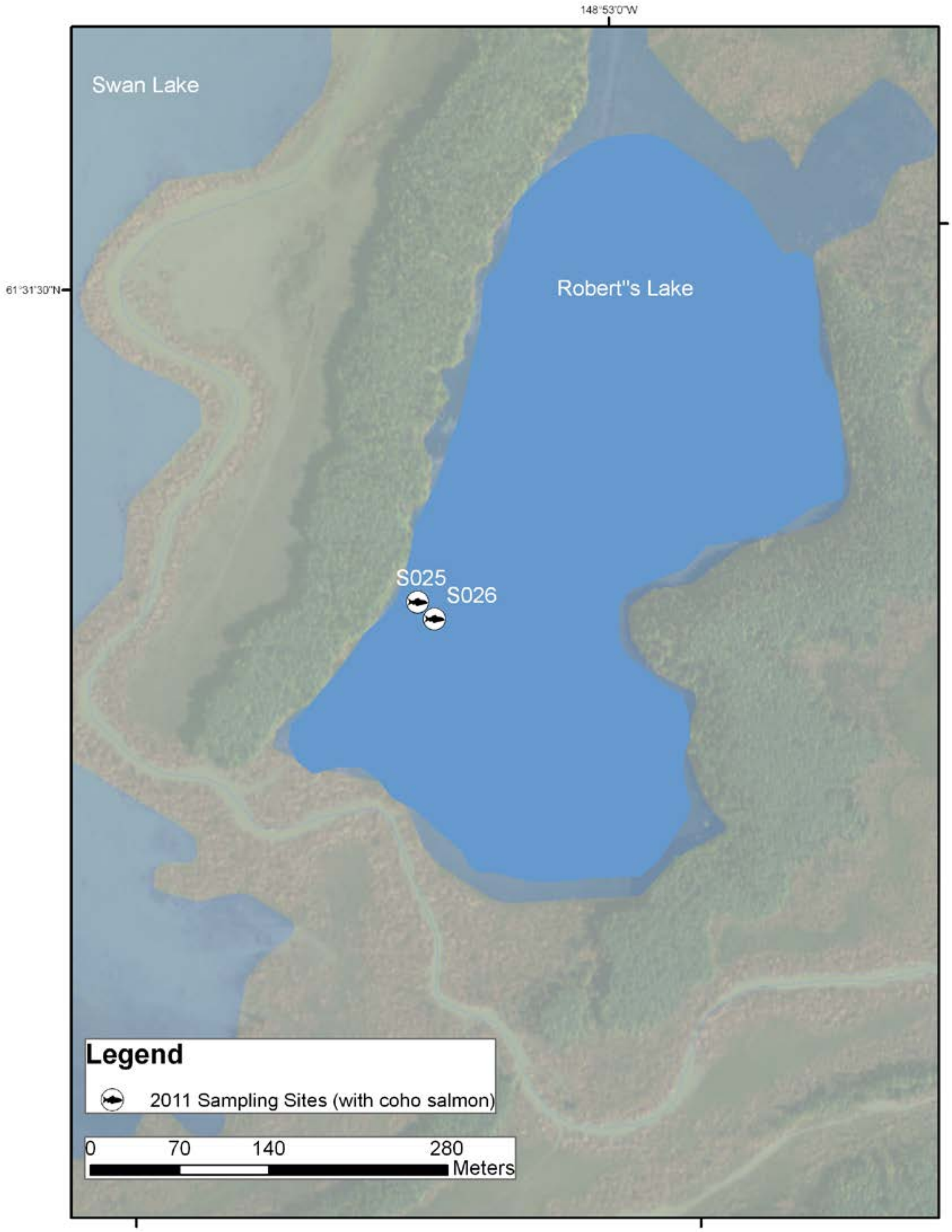

Figure 6. Minnow trap sites in Roberts Lake, August 2011. Roberts Lake was not repeatedly sampled, but three juvenile coho salmon were captured here in two minnow traps on August 22 and 23, 2011. Threespine and ninespine stickleback and Alaska blackfish were also captured in Robert’s Lake in these traps.

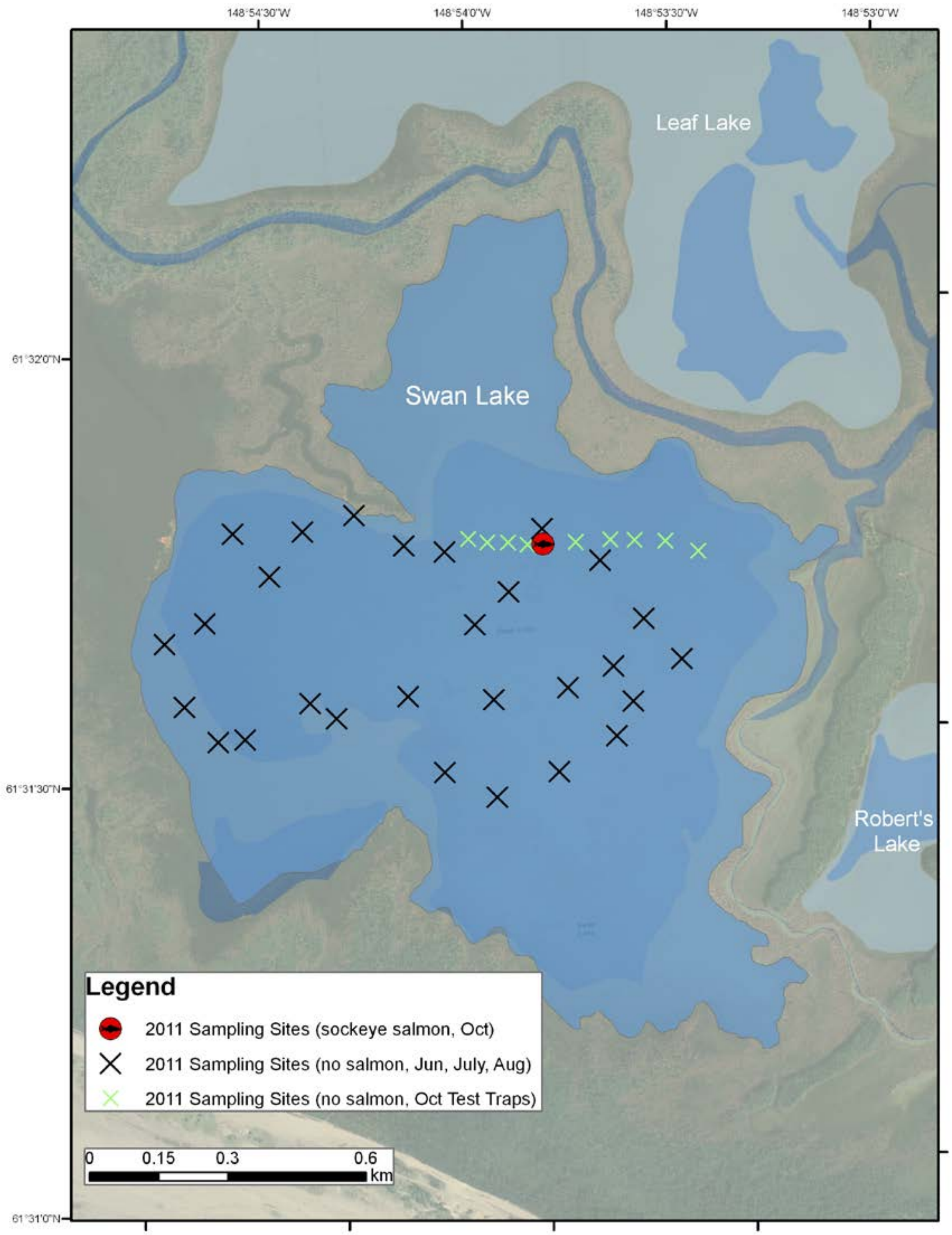

Figure 7. Minnow trap sites in Swan Lake, 2011. No juvenile coho salmon were captured in minnow traps in Swan Lake in June, July, or August, but a single juvenile sockeye salmon was captured in October in one of the test traps (60 min soak).

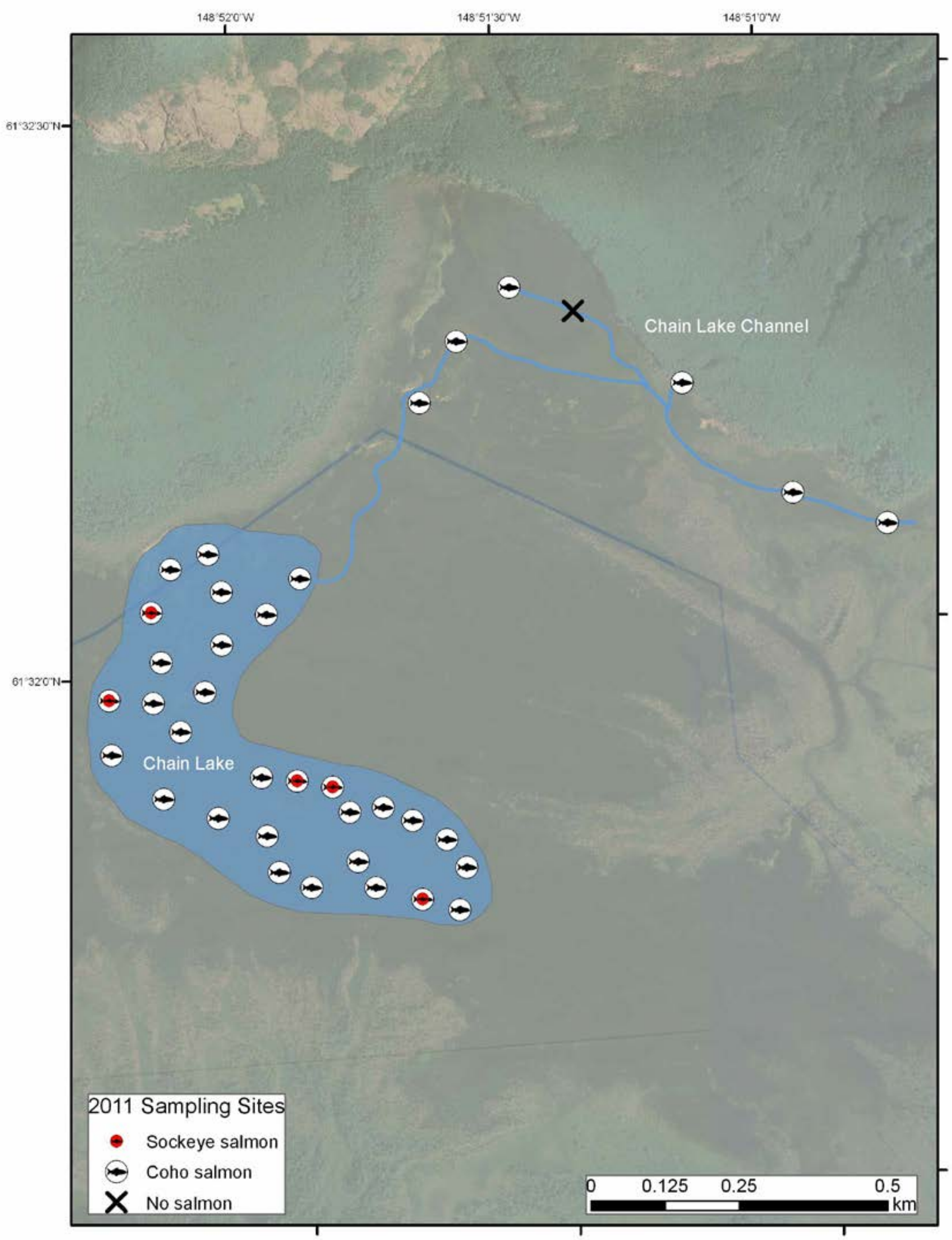

Figure 8. Minnow trap sites in Chain Lake and Chain Lake Channel, 2011. Chain Lake was sampled four times (July 5-7, August 1-3, and August 22-24. Coho salmon (n= 279) were captured at all sites, and six sockeye salmon were captured in Chain Lake. Chain Lake was sampled on July 6-7 and August 1. Twenty seven juvenile coho salmon were captured here.

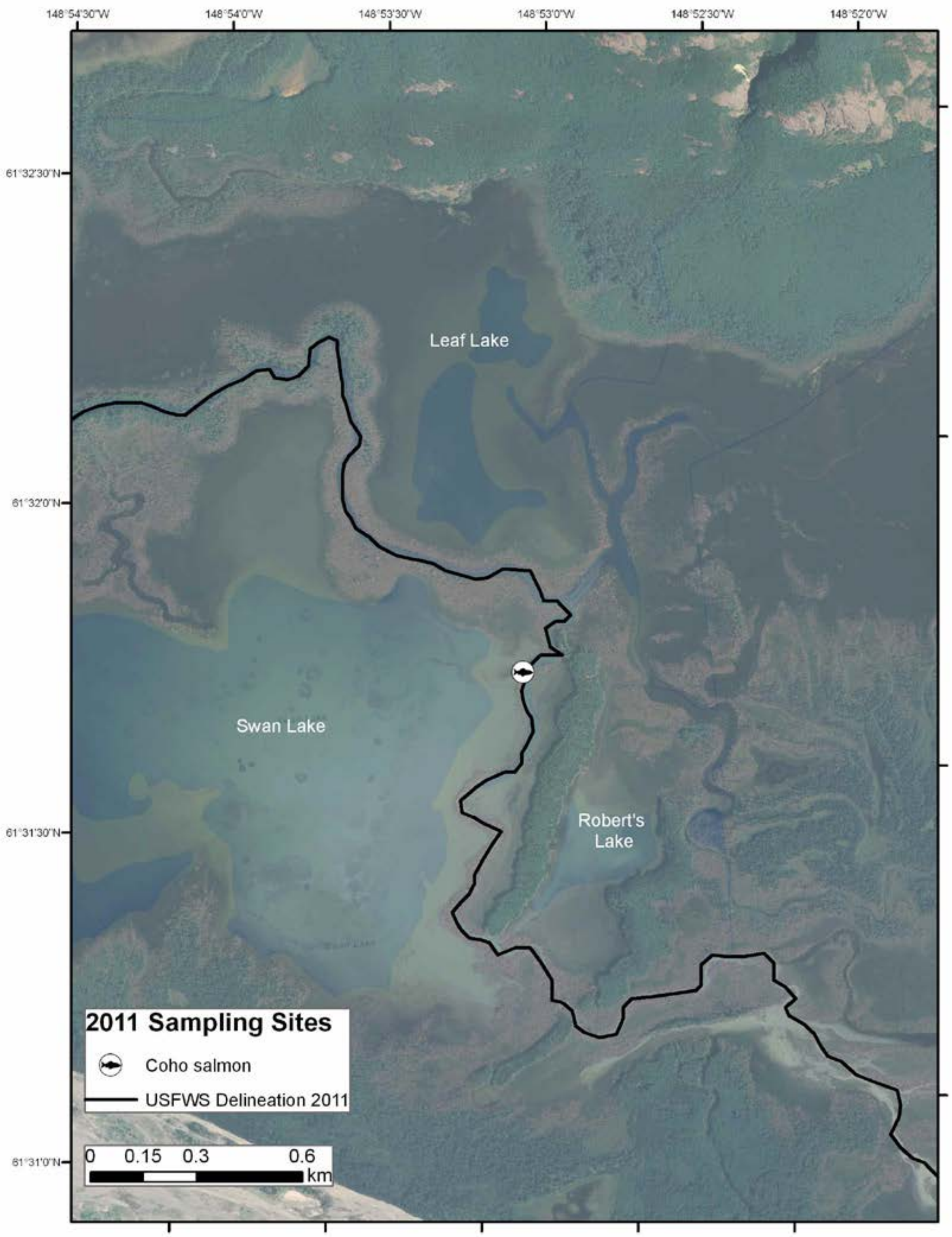

Figure 9. Location of juvenile coho salmon captured by hand net in Swan Lake channel, June 2011. A school of approximately 40 coho salmon were observed at this location in late June, and one was netted by hand for species verification. No minnow trapping or other sampling occurred at this site.

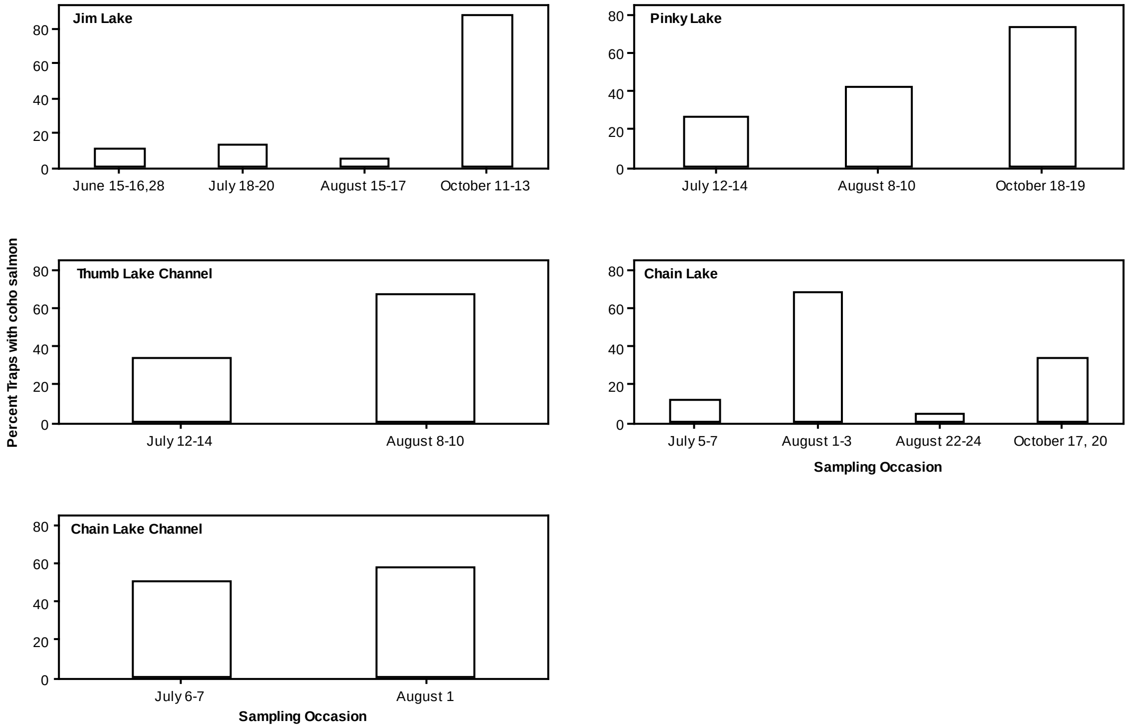

Figure 10. Percent of minnow traps occupied by juvenile coho salmon in each sampling occasion, for each study area in the Knik River Public Use area that were repeatedly sampled during summer and fall, 2011. Sampling occasion dates vary by study area.

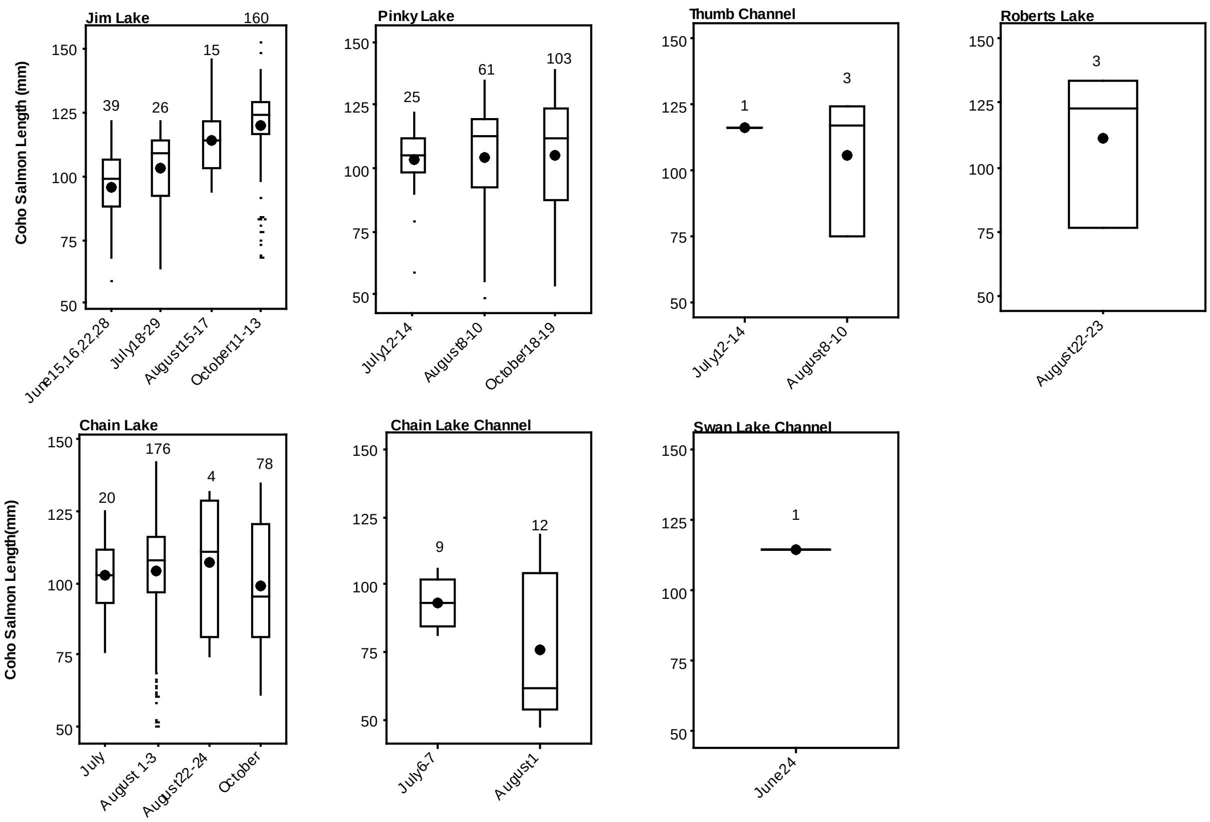

Figure 11. Boxplots of juvenile coho salmon total forked length (mm) for each study area in the Knik River Public Use Area, June, July, August, and October, 2011. Boxes represent the interquartile range, and the middle line is the median. Circles represent mean length, whiskers extend to minimum and maximum data points, and asterisks are suspected outliers. Sample size is indicated above each boxplot. Middle, Thumb, and Swan Lake are not displayed because no coho salmon were capture in these lakes in 2011. Sampling occasions differ among study areas.

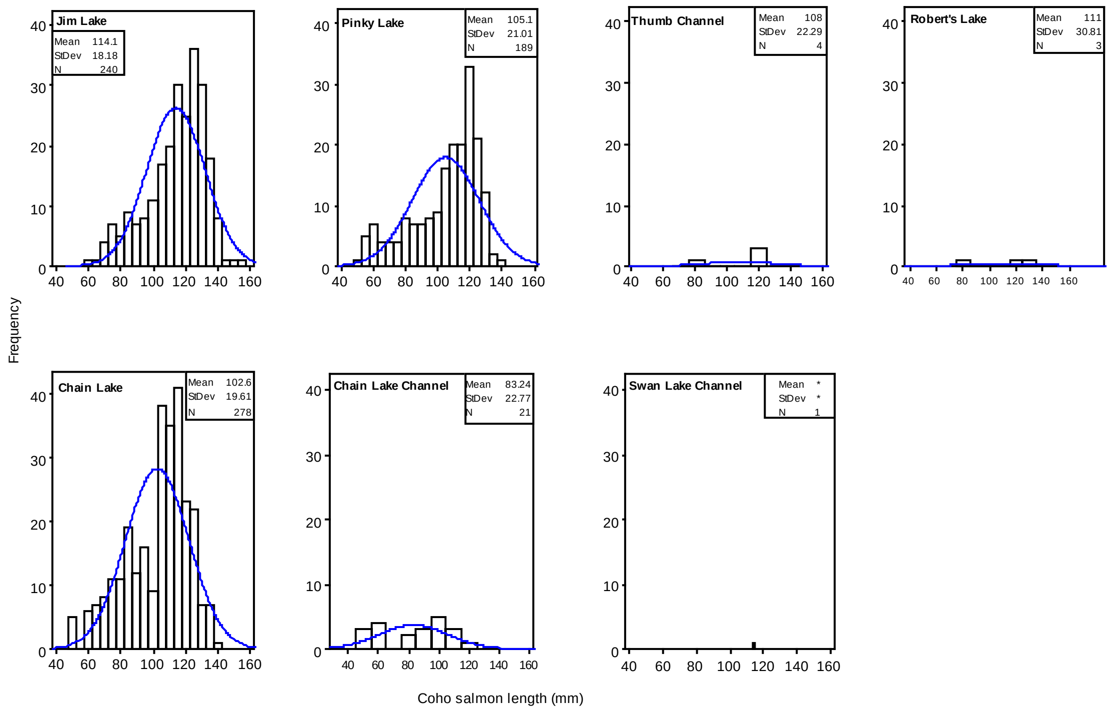

Figure 12. Histograms with fitted normal distribution of juvenile coho salmon total forked length (mm) for each study area in the Knik River Public Use Area. Data from all sampling occasions (June, July, August, and October, 2011) are combined for each location. Tables in each graph display the parameter estimates used to generate fitted normal curves.

AWC Nominations

Five nomination forms were submitted to update the AWC in 2011 and an additional nomination will be made in 2012 for a sockeye salmon captured in October (past the nomination deadline; Table 3). Most nominations were submitted to add or extend the distribution of rearing coho salmon. Juvenile coho salmon were captured in all but three sites (Middle, Thumb and Swan Lakes) in 2011 (Table 1). Three sites (Pinky Lake, Roberts Lake, and Thumb Channel) were nominated to add a new species (rearing coho salmon) and to add new lakes or stream sections that were not previously in the AWC. A nomination was submitted to add a new species (rearing sockeye salmon) to Chain Lake, and a nomination was submitted to add a new life stage (rearing sockeye salmon) in Jim Lake, and provide additional backup data on juvenile coho salmon presence. A single juvenile sockeye salmon was captured in Swan Lake channel, which was not likely sufficient for AWC nomination, but will be submitted with 2012 inventory data.

Table 2. Summary of nominations submitted for inclusion in the Anadromous Waters Catalog from the Knik River drainage in 2011. Swan Lake will be nominated with 2012 data because the sockeye salmon was captured in October, after the 2011 AWC nomination deadline. Species codes are CO = coho salmon, S = sockeye salmon. Life stage codes are: r = rearing, p = present, s = spawning.

Water body Name	USFWS Site ID	AWC Nomination Number	AWC Waterway # 247-50-10200-2081-	USGS Quad	New Species	Action
Jim Lake	AWC11-01	11-548	3025-4030-0030	Anchorage C6-SE	Sr	Added new life stage - sockeye rearing
Pinky Lake	AWC11-02	11-550	3033	Anchorage C5	COrp	Extending upper reach of stream
Pinky Lake	AWC11-02	11-550	3033-4031	Anchorage C5	COp	Added new stream with coho present
Pinky Lake	AWC11-02	11-550	3033-4031-0010	Anchorage C5	COr	Added new Lake with coho rearing
Robert's Lake	AWC11-03	11-551	3037	Anchorage C6	COr	Added new stream with coho rearing
Robert's Lake	AWC11-03	11-551	3037-4011	Anchorage C6	COr	Added new stream with coho rearing
Robert's Lake	AWC11-03	11-551	3037-0010	Anchorage C6	COr	Added new Lake with coho rearing
Swan Lake Channel	AWC11-04	11-552	3031	Anchorage C6	COp	Deleted stream
Swan Lake Channel	AWC11-04	11-552	3033	Anchorage C6	COrp	Added new stream with coho present and rearing
Swan Lake Channel	AWC11-04	11-552	3033-0010	Anchorage C6	-	Changed lake number from 3031 to 3033-0010
Swan Lake Channel	AWC11-04	11-552	3031-4002	Anchorage C6	COr	Added new short stream with coho rearing
Chain Lake	AWC11-05	11-555	938	Anchorage C5 and C6	COr, Sr	Added polygon with coho and sockeye rearing
Chain Lake	AWC11-05	11-555	0010	Anchorage C5 and C6	Sr	Added new species and life stage (sockeye rearing) to existing lake
Chain Lake	AWC11-05	11-555	3041	Anchorage C5 and C6	COr, Srp	Added new life stage (present) for sockeye salmon
Swan Lake	AWC11-06	TBD		Anchorage C6	Sr	Add new species –sockeye rearing

Occupancy Modeling

Goodness of fit testing failed to reject the global occupancy model as being adequate in explaining the data (parametric bootstrap χ^2 fit statistic p-value = 0.554). AIC model selection showed the global model (i.e. ~ StudyArea*Month) best explained the data, with an AIC weight (Burnham and Anderson 2002) of 54%, although the second best model, the "main effects" only version of the global model (i.e. ~ StudyArea + Month), had nearly the same AIC value and had a model weight of 45%. While the data provide support for heterogeneity in occupancy and probability of detection across areas and time (Table 3; Figure 13), examination of parameter estimates demonstrates that the variation in probability of detection is not great. For comparison, we also present results of the constant occupancy and constant probability of detection model (Table 3; Figure 13), which show that most area-time specific probability of detection estimates have 95% confidence intervals that overlap with a pooled (intercept only model) estimate of probability of detection. Patterns in occupancy are more pronounced (Figure 10; Figure 13). The lowest AIC model includes time-varying occupancy and shows an increasing gradient of occupancy as the season progressed, with low to no probability of occupancy (at a trap site) in July and high (or complete) occupancy in October (bottom panel Figure 13).

Tables 4 and 5 present calculations of P(juvenile coho salmon absent | no detects across J trappings), both by asserting a generic probability of occupancy of 0.50 (under the null model with constant occupancy and detection across all sites and area, $\widehat{\psi} = 0.546$ with a 95% confidence interval of (0.475, 0.616)), and with a Uniform prior on ψ (all values equally likely) and integrating across all ψ values. While the data suggest heterogeneity in probability of detection, detection probabilities estimated for individual time-area combinations are not appreciably different than an overall detection probability as estimated from the null model ($\hat{p}$= 0.684, 95% confidence interval = (0.618,0.734); top panel Figure 13). Under a rough approximation for minnow trap detection of 0.6 and assuming a generic occupancy probability of 0.5, three traps with no detections would indicate a >95% probability salmon were absent. Under a uniform prior for probability of occupancy and integrating across all ψ values, five traps with no detections would indicate a >95% probability salmon were absent from the study site.

Table 3. Occupancy model coefficient estimates for the lowest AICc model (global model: $\psi \sim Study\ Area + Month + Study\ Area\!:\!Month$ and $p \sim Study\ Area + Month + Study\ Area\!:\!Month$), and a constant only model ($\psi \sim 1$ and $p \sim 1$).

Global model				95 % Confidence Interval	
	Coefficient	Estimate[1]	SE	Lower limit	Upper limit
Occupancy	Intercept (Chain Lakes August)	2.561	0.708	1.174	3.948
	Jim Lake	-4.784	0.955	-6.656	-2.912
	Pinky Lake	-1.063	1.037	-3.096	0.971
	July	-3.719	0.924	-5.530	-1.908
	October	-2.029	1.010	-4.009	-0.049
	Jim Lake : July	4.090	1.257	1.627	6.554
	Pinky Lake : July	1.665	1.330	-0.942	4.271
	Jim Lake : October	6.222	1.341	3.594	8.851
	Pinky Lake : October	3.115	1.738	-0.292	6.522
Detection[1]	Intercept (Chain Lakes August)	1.146	0.251	0.655	1.637
	Jim Lake	0.082	1.089	-2.052	2.216
	Pinky Lake	-0.538	0.462	-1.443	0.366
	July	-1.707	0.673	-3.025	-0.388
	October	-1.014	0.636	-2.261	0.233
	Jim Lake : July	1.390	1.433	-1.419	4.198
	Pinky Lake : July	1.214	0.913	-0.575	3.002
	Jim Lake : October	0.919	1.268	-1.566	3.404
	Pinky Lake : October	2.121	0.957	0.246	3.996
Constant model					
Occupancy	Intercept only	0.185	0.146	-0.102	0.471
Detection[2]	Intercept only	0.752	0.139	0.481	1.024

[1]Parameter estimates are on logist scale. [2]Detection is in reference to minnow traps baited with cured salmon eggs and deployed for a 24 hour soak time.

Table 4. P(no salmon present | none detected) calculated under an asserted probability of occupancy at a site of $\psi = 0.50$ and a probability of detection of p = 0.6.

Trap deployments	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.526	0.556	0.588	0.625	0.667	0.714	0.769	0.833	0.909
2	0.552	0.61	0.671	0.735	0.8	0.862	0.917	0.962	0.999
3	0.578	0.661	0.745	0.822	0.889	0.94	0.974	0.992	0.999
4	0.604	0.709	0.806	0.885	0.941	0.975	0.992	0.998	0.999
5	0.629	0.753	0.856	0.928	0.97	0.99	0.998	0.999	0.999
6	0.653	0.792	0.895	0.955	0.985	0.996	0.999	0.999	0.999
7	0.676	0.827	0.924	0.973	0.992	0.998	0.999	0.999	0.999
8	0.699	0.856	0.945	0.983	0.996	0.999	0.999	0.999	0.999
9	0.721	0.882	0.961	0.99	0.998	0.999	0.999	0.999	0.999
10	0.741	0.903	0.973	0.994	0.999	0.999	0.999	0.999	0.999
11	0.761	0.921	0.981	0.996	0.999	0.999	0.999	0.999	0.999
12	0.78	0.936	0.986	0.998	0.999	0.999	0.999	0.999	0.999
13	0.797	0.948	0.99	0.999	0.999	0.999	0.999	0.999	0.999
14	0.814	0.958	0.993	0.999	0.999	0.999	0.999	0.999	0.999
15	0.829	0.966	0.995	0.999	0.999	0.999	0.999	0.999	0.999
20	0.892	0.989	0.999	0.999	0.999	0.999	0.999	0.999	0.999
25	0.933	0.996	0.999	0.999	0.999	0.999	0.999	0.999	0.999
30	0.959	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
35	0.976	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
40	0.985	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
50	0.995	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999

Table 5. P(no salmon present | none detected) calculated by assuming a Uniform (naïve) prior for the probability a site is occupied, ψ, and integrating across all ψ values, and a probability of detection of p = 0.6.

	Probability of detection								
Trap deployments	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.517	0.537	0.559	0.584	0.614	0.648	0.691	0.747	0.827
2	0.535	0.574	0.617	0.664	0.717	0.775	0.837	0.902	0.963
3	0.552	0.610	0.672	0.737	0.803	0.867	0.925	0.969	0.994
4	0.570	0.645	0.723	0.799	0.869	0.927	0.968	0.991	0.999
5	0.587	0.678	0.769	0.851	0.917	0.962	0.988	0.998	0.999
6	0.604	0.711	0.810	0.892	0.949	0.981	0.995	0.999	0.999
7	0.621	0.741	0.845	0.923	0.969	0.991	0.998	0.999	0.999
8	0.637	0.769	0.876	0.946	0.982	0.996	0.999	0.999	0.999
9	0.653	0.795	0.901	0.963	0.990	0.998	0.999	0.999	0.999
10	0.669	0.819	0.922	0.975	0.994	0.999	0.999	0.999	0.999
11	0.685	0.842	0.939	0.983	0.997	0.999	0.999	0.999	0.999
12	0.700	0.862	0.953	0.989	0.998	0.999	0.999	0.999	0.999
13	0.715	0.880	0.964	0.993	0.999	0.999	0.999	0.999	0.999
14	0.729	0.896	0.972	0.995	0.999	0.999	0.999	0.999	0.999
15	0.743	0.910	0.979	0.997	0.999	0.999	0.999	0.999	0.999
20	0.806	0.959	0.995	0.999	0.999	0.999	0.999	0.999	0.999
25	0.858	0.982	0.999	0.999	0.999	0.999	0.999	0.999	0.999
30	0.898	0.993	0.999	0.999	0.999	0.999	0.999	0.999	0.999
35	0.928	0.997	0.999	0.999	0.999	0.999	0.999	0.999	0.999
40	0.951	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
50	0.978	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999

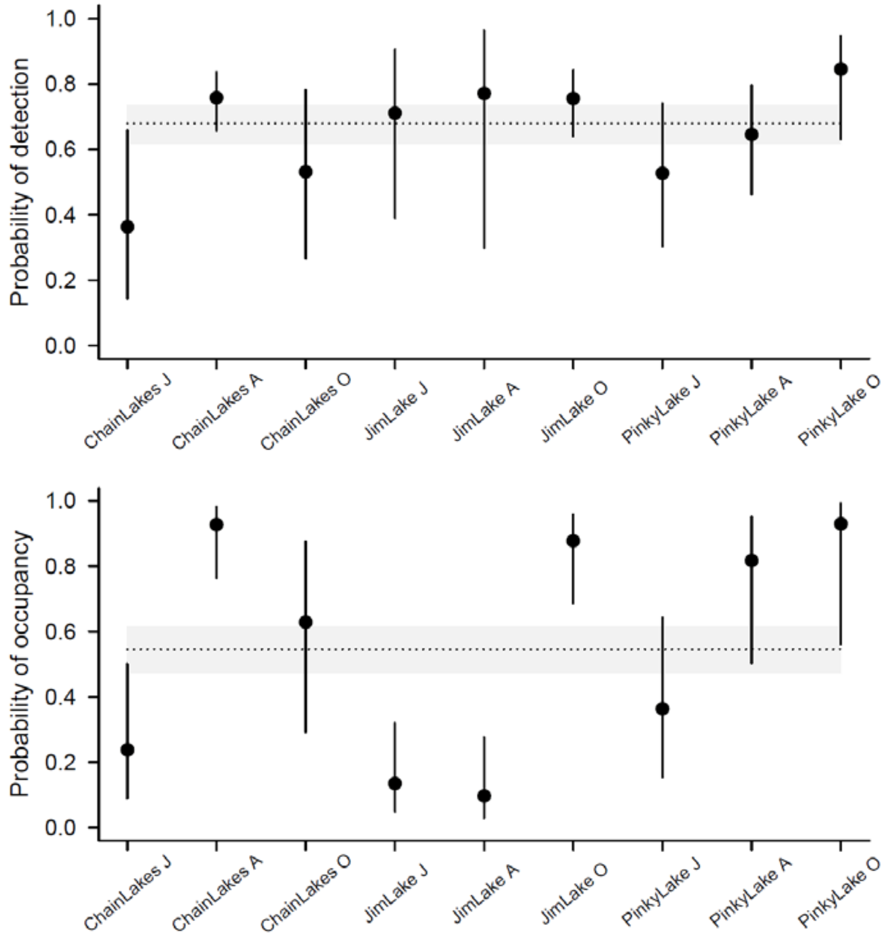

Figure 13. Estimated probability of detection and probability of occupancy of juvenile coho salmon during 2011 Knik Public Use Area minnow trap sampling. Black dots and segments indicate point estimates with 95% confidence intervals from the global model ($\psi \sim Study\ Area * Month$ and $p \sim Study\ Area * Month$). The horizontal gray box and dotted line present point estimates and 95% confidence intervals for the constant occupancy, constant probability of detection model ($\psi \sim 1$ and $p \sim 1$). Name labels indicate study area – time combinations with the following abbreviations for months: J=July, A=August, O=October. Detection is in reference to minnow traps baited with cured salmon eggs and deployed for a 24 hour soak time.

Water Quality Measurements

Water depth, water and air temperature, pH, conductivity, and DO measurements were collected from each trap site at each trap deployment (Table 6). Water depths in survey areas were in general shallow (range 0.2 to 1.5m; Table 6). Water temperatures in summer months ranged from 8°C in Chain Lake Channel on August 1 to 15°C in Chain Lake on July 5 (Table 6). October water temperatures ranged from 1 to 6°C in Chain Lake and Thumb Lake, respectively (Table 6). Summer air temperatures were generally slightly less than water temperatures at the same sites, and ranged from 8°C in Middle and Thumb Lakes on August 9 to 23°C in Chain Lake on July 5-6. October air temperatures ranged from -2°C in Chain Lake on October 20 and 6°C in Middle and Thumb Lake on October 17 (Table 6). The lowest pH measurement (5.4) was collected from Thumb Lake on October 17 and the highest (9.9) was collected from Swan Lake on July 26-27 (Table 6). Conductivity measurements ranged from 98.5 µS/cm in Swan Lake on October 12 to 381 µS/cm in Pinky Lake on July 14 (Table 6). Dissolved oxygen measurements ranged from 2.5 to 16.6 mg/L in Thumb Lake (October 17) and Pinky Lake (October 18; Table 6).

Table 6. Summary of water quality measurements collected from each study area in the KRPUA, 2011. Data are summarized for all trap sites within a study area by sampling occasion.

Study Area	Sampling occasion	Water Depth (m)			Water Temp (°C)			Air Temp (° C)			pH			Conductivity (µS/cm)			DO (mg/L)		
		n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max
01 Jim Lake	June 15	14	0.4	1.5	14	16	18	0	-	-	14	8.7	9.3	14	147	166	0	-	-
	June 16	14	0.3	1.5	14	12	18	0	-	-	14	7.2	8.9	14	139	166	0	-	-
	June 28	28	0.4	1.5	28	16	18	0	-	-	10	7.3	9.3	28	135	179	0	-	-
	July 18	28	0.3	1.5	28	9	19	28	14	15	14	8.6	9.3	28	129	188	14	8.4	10.6
	July 19	28	0.3	1.5	28	11	18	28	10	10	28	7.5	9.4	28	125	174	14	8.2	10.0
	July 20	28	0.3	1.5	27	12	19	28	16	16	28	7.5	9.4	27	120	174	13	9.1	10.6
	August 18	26	0.3	1.5	28	10	17	28	12	14	27	7.8	9.2	28	144	160	28	8.3	14.2
	August 19	26	0.3	1.5	28	10	17	28	10	15	27	7.7	9.2	28	143	162	28	8.3	13.9
	August 20	26	0.3	1.5	28	11	18	28	12	14	28	7.6	9.1	28	129	166	27	8.1	13.8
	October 11	28	0.2	1.5	28	3	5	28	2	4	28	7.3	9.1	28	123	155	28	9.4	15.4
	October 12	28	0.3	1.4	28	2	5	26	2	2.5	28	8.0	9.2	28	123	152	28	9.8	16.1
	October 13	28	0.3	1.4	28	3	4	28	1.5	3	28	7.2	9.0	28	112	154	28	10.2	14.8
02 Pinky Lake	July 12	14	0.3	0.6	15	14	16	0	-	-	15	7.1	7.8	15	293	333	0	-	-
	July 13	14	0.3	0.6	15	13	17	15	15	18	0			15	265	329	0	-	-
	July 14	14	0.3	0.6	14	14	15	15	13	16	13	7.1	7.7	14	143	381	0	-	-
	August 8	1	0.3	0.3	15	14	16	15	14	14	15	7.4	8.9	15	285	300	15	9.3	11.4
	August 9	1	0.3	0.3	15	11	13	15	11	11	14	7.1	7.5	15	259	288	15	7.0	10.6
	August 10	1	0.3	0.3	15	10	13	15	11	12	15	7.3	7.6	15	266	280	15	7.6	11.8
	October 18	14	0.2	0.5	15	2	3	15	1	1	15	7.8	8.4	15	227	242	15	8.4	16.6
	October 19	14	0.2	0.5	12	2	3	12	2	2	12	7.9	8.2	12	231	248	12	9.5	12.2
03 Middle Lake	July 12	14	0.2	0.9	14	16	18	14	14	16	14	8.0	9.8	14	147	227	0	-	-
	July 13	14	0.2	0.9	14	17	18	14	13	13	14	8.6	9.8	14	149	224	0	-	-
	July 14	14	0.2	0.9	14	16	17	14	11	11	14	8.1	9.8	14	146	237	0	-	-

Authors: The primary author is a fishery biologist with the U. S. Fish and Wildlife Service and can be contacted at Anchorage Fish and Wildlife Field Office, 605 W. 4th Ave., Anchorage, AK 99501 or elizabeth_benolkin@fws.gov.

Table 6 continued.

Study Area	Sampling occasion	Water Depth (m)			Water Temp(° C)			Air Temp(° C)			pH			Conductivity (µS/cm)			DO (mg/L)		
		n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max
03 Middle Lake	August 8	14	0.2	0.9	14	14	17	14	11	12	14	8.7	9.7	14	146	184	14	10.6	16.4
	August 9	14	0.2	0.9	14	14	15	14	8	8	14	8.4	9.4	14	145	191	14	8.9	12.3
	August 10	14	0.2	0.9	14	14	14	14	9	9	14	8.4	9.3	14	145	206	14	10.6	14.2
	October 17	9	0.2	0.6	9	4	4	9	6	6	9	8.3	8.9	9	178	180	9	11	12
04 Thumb Lake	July 12	9	0.7	1.3	9	17	18	9	14	15	9	7.5	7.9	9	120	225	0	-	-
	July 13	9	0.7	1.3	9	19	20	9	13	13	9	7.5	7.9	9	226	241	0	-	-
	July 14	9	0.7	1.3	9	17	18	9	11	11	9	7.7	8.0	9	220	226	0	-	-
	August 8	9	0.7	1.3	9	15	17	9	14	14	9	7.7	8.4	9	198	223	9	10.9	13.2
	August 9	9	0.7	1.3	9	13	14	9	8	8	9	7.5	8.1	9	189	211	9	10.1	12.8
	August 10	9	0.7	1.3	9	15	16	9	11	11	9	7.6	8.3	9	190	219	9	11.3	13.6
	October 17	10	0.4	0.7	10	3	6	10	6	6	5	5.4	7.5	10	107	146	10	2.5	11.1
05 Thumb Channel	July 12	1	0.4	0.4	1	15	15	1	14	14	1	7.4	7.4	1	302	302	0	-	-
	July 13	1	0.4	0.4	1	15	15	1	13	13	1	7.7	7.7	1	305	305	0	-	-
	July 14	1	0.4	0.4	1	14	14	1	11	11	1	7.5	7.5	1	300	300	0	-	-
	August 8	1	0.4	0.4	1	14	14	1	13	13	1	8.0	8.0	1	289	289	1	9.6	9.6
	August 9	1	0.4	0.4	1	12	12	1	8	8	1	7.2	7.2	1	278	278	1	7.0	7.0
	August 10	1	0.4	0.4	1	13	13	1	11	11	1	7.6	7.6	1	280	280	1	10.2	10.2
06 Roberts Lake	August 22	2	0.6	0.7	2	15	16	2	14	14	2	7.6	7.7	2	255	278	2	9.3	9.5
	August 23	2	0.6	0.7	2	16	16	2	14	14	2	7.1	7.8	2	255	272	2	7.4	8.7
07 Swan Lake	June 21	28	0.4	0.8	28	17	18	0	-	-	28	8.2	9.5	28	199	322	0	-	-
	June 22	28	0.4	0.8	28	18	20	0	-	-	28	8.1	9.6	28	201	321	0	-	-
	June 23	28	0.4	0.8	27	16	21	0	-	-	3	8.6	8.7	28	195	315	0	-	-

Table 6 continued.

Study Area	Sampling occasion	Water Depth (m)			Water Temp (° C)			Air Temp (° C)			pH			Conductivity (µS/cm)			DO (mg/L)		
		n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max	n	Min	Max
07 Swan Lake	July 25	28	0.7	1.2	28	15	16	28	10	13	28	8.2	9.8	28	153	248	27	8.1	11.2
	July 26	28	0.7	1.2	28	14	16	28	14	19	28	8.2	9.9	28	159	252	14	10.3	12.6
	July 27	28	0.7	1.2	28	16	18	28	13	18	28	8.6	9.9	28	165	238	28	9.2	12.5
	August 22	4	0.9	1.1	4	15	15	4	14	14	4	8.8	8.9	4	178	203	3	12.1	13.7
	August 23	4	0.9	1.1	4	15	15	4	14	14	4	8.9	9.1	4	179	192	4	12.3	14.0
	August 24	4	0.9	1.1	4	15	15	4	16	16	4	9.1	9.3	4	175	188	4	12.0	12.9
	October 12	9	0.3	0.7	10	3	4	10	2	2	10	7.5	8.1	10	98	205	10	6.6	12.6
08 Chain Lake	July 5	30	0.2	0.6	30	17	25	28	17	23	0	-	-	0	-	-	0	-	-
	July 6	30	0.2	0.6	30	19	22	28	17	23	0	-	-	0	-	-	0	-	-
	July 7	30	0.2	0.6	30	17	20	30	16	19	0	-	-	0	-	-	0	-	-
	August 1	30	0.3	0.7	30	14	16	30	12	14	30	8.1	8.9	30	256	360	30	8.2	11.3
	August 2	27	0.3	0.7	27	12	12	27	11	14	27	7.5	8.9	27	246	345	27	4.8	11.2
	August 3	30	0.3	0.7	30	11	14	30	13	14	30	7.8	8.6	30	226	360	30	10.5	12.4
	August 22	30	0.3	0.7	30	15	16	30	14	14	30	7.9	8.9	30	234	299	29	6.2	12.9
	August 23	30	0.3	0.7	30	15	16	30	13	14	30	7.6	8.7	30	229	298	30	8.4	12.8
	August 24	30	0.3	0.7	30	15	17	30	15	16	30	7.6	8.7	30	218	297	30	7.0	12.5
	October 20	24	0.2	0.6	23	1	4	15	-2	0	0	-	-	23	141	303	24	3.4	14.2
09 Chain Lakes Channel	July 6	2	0.3	0.4	2	21	21	2	22	22	0	-	-	0	-	-	0	-	-
	July 7	2	0.3	0.4	2	20	21	2	19	19	0	-	-	0	-	-	0	-	-
	August 1	7	0.3	0.5	7	8	16	7	14	16	7	7.6	8.9	7	276	327	7	8.3	16.2
10 Swan Lake Channel	June 24	1	0.5	0.5	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-

Discussion

Sampling in the KPUA demonstrated that minnow traps are an effective but imperfect gear for monitoring juvenile coho salmon in temperate shallow lake environments. Failure to account for detection efficiency can bias habitat preference studies, possibly leading to spurious ecological inference (MacKenzie 2005; MacKenzie et al. 2006). We found a sampling design of repeated trap deployments at sites was feasible to implement and provided necessary information to control for probability of detection, although three back to back deployments with lengthy soak times (24 hours) required considerable time in the field. We suggest that shorter soak times would still achieve a sampling design amenable to occupancy modeling and would reduce field time. Anecdotal field observations indicated that juvenile sockeye salmon periodically cohabited study sites with juvenile coho salmon, however, sockeye salmon were rarely captured in traps. This suggests that juvenile salmon behavior around minnow traps differs across species and we caution against extrapolating detection efficiency results presented here from coho salmon sampling to other species.

The KPUA presents a complex matrix of freshwater environments ranging from small to large order glacial streams as well as shallow water lakes. Little is known about the temporal dynamics of juvenile coho salmon throughout different freshwater rearing environments in the area, however we found evidence of juveniles moving into shallow ground-water fed lakes late in Summer and into the Fall, suggesting that these water bodies may provide overwintering habitat, consistent with earlier work in lake-type environments in the Pacific Northwest U.S. (Peterson 1982) and West Coast Canada (Swales et al. 1988). Occupancy during July and August was low, suggesting that shallow lake environments in the KPUA may be less important as summer rearing habitat.

Timed migrations of juvenile salmon into different freshwater rearing environments presents challenges in efforts to inventory salmonid-bearing habitat. If good information is available to suggest when juveniles might occupy a given habitat type, inventory efforts can be timed appropriately, however, lack of such information dictates that temporal replication will be necessary to assess whether at some point in a year candidate areas harbor salmonids. Furthermore, as demonstrated here, sampling gear is not 100% effective and survey replication is required to be confident that salmon are truly absent or potentially present at a given site. Fortunately, minnow traps appear to work well for detecting juvenile coho salmon, with an estimated probability of detecting coho salmon given they are present at a trap site on the order of 0.6-0.7. With this level of detection, two or three repeated trappings at a specific site yielding no detections would result in high confidence that salmon are absent at a trap site under moderate levels of the true underlying occupancy rate (e.g. Table 4 and 5).

Parameter estimates from occupancy modeling provide an objective framework for making confidence statements about whether an area contains juvenile salmonids or not (at least in a given point in time). For example, guidance could be given that to declare a candidate area as devoid of juvenile salmonids, sampling yielding no detections need be carried out in area until the probability salmon are truly absent at an area is ≥ 90%, following probability calculations as proposed above and given estimates (or educated guesses) of the probability of detection and occupancy that are applicable to the candidate area.

Five nominations were made in 2011 to update the AWC as a result of juvenile fish sampling efforts in the Knik River Public Use Area. Most nominations were submitted to add or extend

Authors: The primary author is a fishery biologist with the U. S. Fish and Wildlife Service and can be contacted at Anchorage Fish and Wildlife Field Office, 605 W. 4th Ave., Anchorage, AK 99501 or elizabeth_benolkin@fws.gov.

the distribution of juvenile coho salmon, which were captured in all sites except Middle, Thumb and Swan lakes. Few juvenile sockeye salmon were captured in the study region in 2011, but 3 nominations were made to add juvenile sockeye salmon in Jim, Lake, Chain Lake and Swan Lake.

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Detection efficiency and habitat use to inform inventory and monitoring efforts: juvenile coho salmon in the Knik River basin, Alaska

Suresh A. Sethi[1], Elizabeth Benolkin[2]

[1]US Fish and Wildlife Service, Biometrics, 1011 E Tudor Road, Anchorage, Alaska 99503, USA
[2]US Fish and Wildlife Service, Anchorage Field Office 605 W 4th Ave, Anchorage, AK 99501, USA

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Abstract – Imperfect detection associated with sampling gear presents challenges for wildlife inventory and monitoring efforts. We examined occupancy dynamics and habitat use of juvenile coho salmon, *Oncorhynchus kisutch*, in shallow lake environments over a summer and early fall season in the Knik River area of south central Alaska using models which control for and estimate sampling gear detection efficiency. In addition, we present statements for the probability that observed absences at a survey site or from a survey area (a collection of sites) are true absences given some amount of sampling effort and analysts' beliefs about site occupancy and sampling gear detection efficiency which can be used to guide inventory and monitoring efforts for juvenile salmon or other wildlife and plant species. Occupancy modelling results demonstrate that minnow traps were effective at sampling juvenile coho in shallow lake environments, with a mean probability of detection across the study period of 0.68 (i.e., probability of detecting the presence of juvenile coho given that they are present at a trap site; SE = 0.03). Juvenile coho salmon migrated into shallow water lakes in late summer and early fall, presumably to seek out overwinter habitat. *N*-mixture modelling examination of habitat use demonstrated that once in shallow lake environments, juvenile coho were widely distributed across a range of microhabitats, with some evidence for preference for shallower depths and warmer water temperatures.

Key words: Alaska; detection; juvenile salmon; occupancy; fish habitat

Introduction

Juvenile salmon are difficult to observe in the wild and field sampling gear is typically not 100% effective in detecting them. As a result, a challenge facing species distribution and habitat use monitoring programmes for Pacific salmon during their freshwater life stage is determining whether juveniles are truly absent from a study site if none were identified in sampling efforts, or whether juveniles were present but undetected (false absence). Over the past decade, substantial insight into the problem of false absences in species distribution and habitat use surveys has been gained (e.g., MacKenzie 2005; Royle & Dorazio 2008), driven by the development of a new class of hierarchical ecological models which explicitly control for imperfect detection, two of which are employed in this study: occupancy and *N*-mixture models.

Occupancy models (MacKenzie et al. 2002, 2006) use repeated presence-absence surveys to yield estimates of the probability that a site is truly occupied, as well as the probability of detecting at least one target organism at a sampling site given that the site is occupied. *N*-mixture models (Royle 2004) are similar in construction to occupancy models, but operate on repeated counts of animals, generating estimates of site-specific abundance and the probability of detecting a single individual given at least one subject is present at a site. Because *N*-mixture models use counts instead of presence-absence data, they can provide additional insight into habitat use by examining 'intensity' of use in the form of abundance estimates at survey sites. Typically, count data are more

Correspondence: S. A. Sethi, US Fish and Wildlife Service, Biometrics, 1011 E Tudor Road, Anchorage, Alaska 99503, USA. E-mail: sasethi@gmail.com

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costly to collect than presence-absence data, and a pragmatic strategy to implement a habitat use or species distribution study in a previously unsurveyed area is to first conduct presence-absence occupancy analysis to identify candidate sampling sites or time strata for subsequent fine-scale microhabitat use analysis with count data and *N*-mixture models (see below).

Although a primary goal of many applications of occupancy and *N*-mixture models is to generate estimates of the true distribution of subjects through landscapes after controlling for detection error (e.g., birds: Ferraz et al. 2007; fish: Wenger et al. 2008; mammals: Karanth et al. 2011), such models also provide valuable information on gear detection efficiency which can be used to design monitoring programmes and assess the confidence about observed distribution data. Below, we develop expressions for the probability that observed absences are true absences at individual study sites and at study areas (i.e., a collection of study sites). These expressions can be used to inform inventory and monitoring efforts as to the amount of sampling effort required to achieve a given level of confidence about observed absences, and to assess the confidence in observed absences from collected field data. For example, guidance is currently needed for inventory efforts under the State of Alaska's Anadromous Waters Catalog statute (Alaska Statute16.05.871; Johnson & Blanche 2011), which provides a legal platform to regulate development in salmon-bearing aquatic habitat.

To be included under the Anadromous Waters Catalog, evidence must be provided that a candidate water body contains salmon. As a result, considerable presence-absence inventory efforts have been conducted throughout the state (e.g., see the Alaska Department of Fish and Game Freshwater Fish Inventory database for sampling records available at www.adfg.alaska.gov, last accessed December 27, 2012); however, surveys have generally been implemented with a lack of knowledge about the population ecology of juvenile salmon in local environments. If salmon are detected during a survey at a site then clearly the water body in question harbours salmon and should be included under the Anadromous Waters Catalog, but under what conditions should a site be considered devoid of salmon? No detections could be the result of time varying occupancy in a survey area and/or low sampling gear efficiency. Protocols for the amount of sampling effort necessary to inventory water bodies under the Anadromous Waters Catalog are not currently available; however, we suggest that the expressions developed below for the probability that an observed absence is a true absence may be useful for making water body inclusion recommendations under the policy.

Information on juvenile Pacific salmon habitat use during their freshwater life stage is necessary to manage human development impacts on salmon-bearing watersheds (e.g., Hartman & Brown 1988; Wang et al. 2001; Smith & Anderson 2008). Characterisation of important juvenile rearing habitat can identify areas needing protection from the deleterious effects of housing, mining, or timber-related development on salmon habitat, and habitat use can provide an index for freshwater rearing habitat value that can be used in making optimal restoration decisions, such as identifying the best set of culverts or dams to mitigate to maximise benefits to salmon under a limited budget (Kemp & O'Hanley 2010).

In addition to formulating confidence statements about observed absences for salmon inventory and monitoring efforts, we examine seasonal occupancy dynamics of juvenile coho, *Oncorhynchus kisutch*, in ground-water fed shallow lakes in the Knik River Public Use Area (KRPUA) in the Matanuska-Susitna borough of south central Alaska over a summer and fall season, and subsequently use *N*-mixture models to examine coho microhabitat use during October sampling when juveniles were observed inhabiting lake environments in the KRPUA in established numbers. The Matanuska - Susitna Borough is the agricultural seat of Alaska and is relatively heavily populated, growing 50% per decade since 1990 with a 2010 census population of 89,000 people (~12.5% of the State's 2010 population; U.S. Census Bureau data available at www.census.gov). The Borough is an area of concern for urban and suburban development impacts on salmon habitat (e.g., Smith & Anderson 2008), however, information on juvenile coho ecology specific to lake habitats in south central Alaska is currently lacking.

In the subsequent Methods section, we provide introductions into occupancy models and *N*-mixture models. Details on model validation and AIC-based model selection (Burnham & Anderson 2002) are also provided. The Methods section concludes with derivations of the probability that an observed absence is a true absence after no detections in a given amount of imperfect survey effort. The Results section presents seasonal occupancy dynamics and microhabitat use for juvenile coho in the KRPUA, and applies occupancy and detection parameter estimates to inform true absence probability expressions for coho minnow trap sampling. Probabilities of true absence expressions are applied to juvenile coho sampling in the KRPUA; however, these results are general to other wildlife and plant survey efforts and we provide R code (R Development Core Team

2010) for true absence calculations in an online supplement. Finally, the Discussion section reviews occupancy dynamics and habitat use in the context of monitoring efforts for juvenile coho in the KRPUA and provides recommendations for future survey efforts.

Methods

Study region

Minnow trapping was conducted in a wetland-lake complex in the KRPUA (Fig. 1). The Alaska state-managed KRPUA is a $\approx$ 1,050 km^2 land and freshwater reserve area flanked by the Chugach mountain range, and is characterised by a mix of temperate freshwater habitats including the high order glacial Knik River, low order high gradient streams, and a large wetland-lake complex. The popular KRPUA is accessible by road, and human activity in the reserve includes hiking, camping, fishing, hunting, trail riding with pack animals, and all-terrain vehicles. The KRPUA supports spawning and rearing habitat for all five Pacific salmon species, and coho salmon runs returning to the area are an important commercial, subsistence and sport fishery resource for local residents (Oslund & Ivey 2010). Additional information is available at the KRPUA management website (http://dnr.alaska.gov/mlw/krpua/index.cfm; last accessed December 27, 2012).

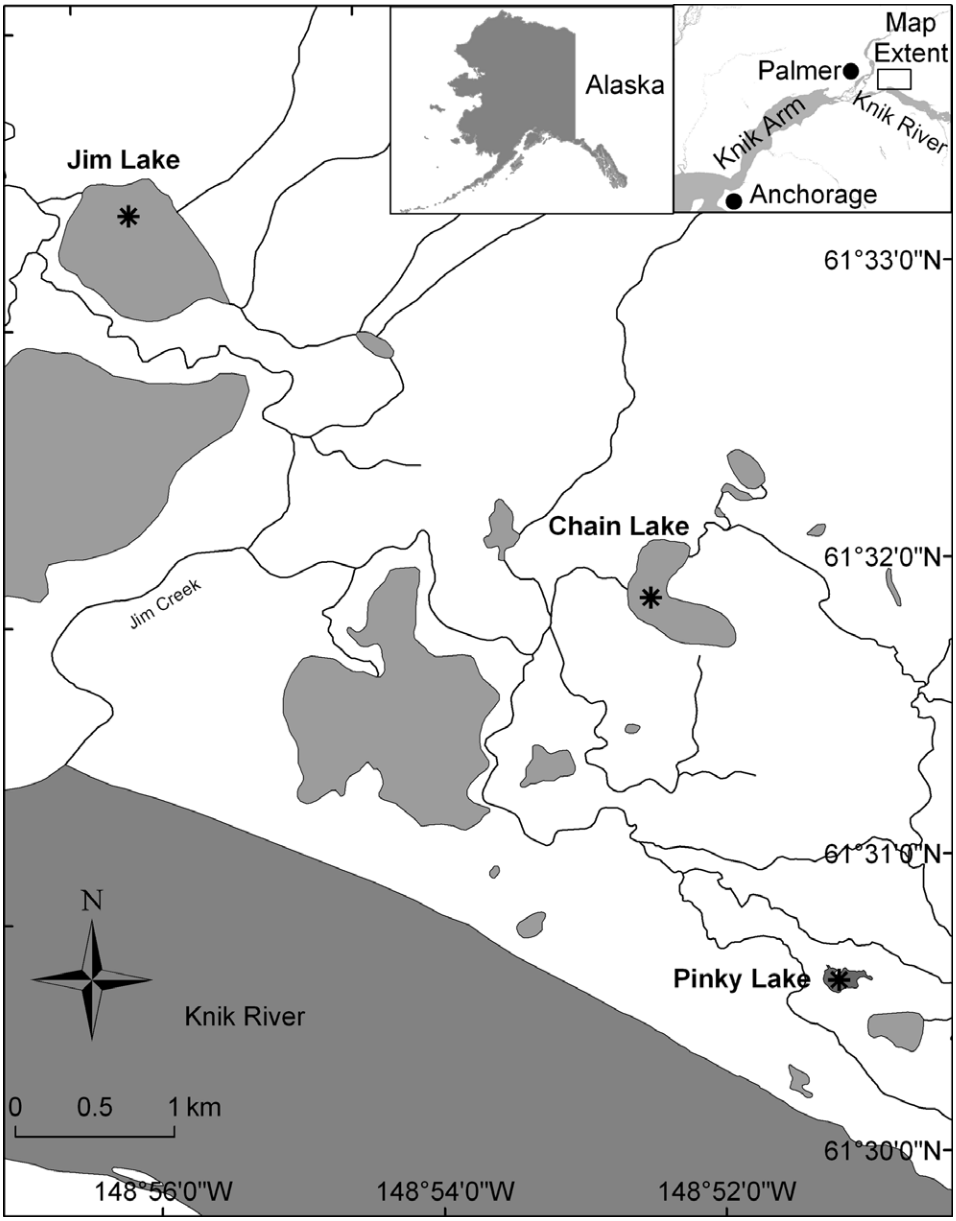

Fig. 1. Map of the study area.

Sampling effort

Fish sampling was conducted using Gee® brand minnow traps (Cuba Specialty Manufacturing Company, Fillmore, NY). Traps measure 42 cm by 22 cm and are composed of two interlocking galvanised wire mesh baskets with 22 mm wide openings on each end to allow juvenile fish to enter. Traps were baited with 4 g of cured salmon roe placed in plastic film canisters drilled with holes. Juvenile coho and adult three- and nine-spine stickleback, *Gasterosteus aculeatus* and *Pungitius pungitius*, counts were recorded after each trap deployment. Juvenile sockeye salmon, *O. nerka*, were also present in the study area; however, this species largely avoided minnow traps and was rarely captured during sampling. Captured fish were released back to the trap sites and traps rebaited before subsequent repeat deployments.

Sampling was conducted at three study areas within the wetland-lake complex in the KRPUA: Chain Lakes, Jim Lake and Pinky Lake (Table 1; Fig. 1). Study areas were shallow lake environments fed by a mix of ground-water and rain/snow precipitation, and ranged from 3 to 68 ha in size (Table 1). Within study areas, we randomly selected 15–30 trap sites, spacing traps a minimum of 50 m apart and deploying traps in water depths of 10 cm or greater, the minimum depth at which minnow traps can operate (e.g., Swales 1987). Trap site locations were recorded on a handheld GPS unit and remained fixed throughout the study. Trapping was conducted once a month during July, August and October of 2011, which we refer to as 'sampling dates'. Within sampling dates, three back-to-back 24 h trap deployments were conducted except for Pinky Lake during October sampling in which case two back-to-back deployments were conducted.

Habitat and water condition information was recorded during October sampling for Jim Lake and Pinky Lake (Table 2) for use in habitat use modelling (see '*N-mixture models*' below). Some covariates were invariant across trap deployments within a sampling date (i.e., site-level data) whereas others were recorded with each deployment (i.e., trap-level data; Table 2). Habitat covariates included per cent vegetative bottom cover, per cent vegetative cover in the water column measured from a bird's eye view, distance to shore, and presence of woody debris (present or not). Water condition covariates included depth, dissolved oxy-

Table 1. Sampling areas, dates and covariate coverage for minnow trapping in the Knik Public Use Area, AK, 2011.

Study Area	Water area (hectares)	Number trap sites	Trap deployments	Sampling date	Covariate coverage*
Chain Lakes	42	30	3	July	D,T
		30	3	August	D,T
		24	2	October	D,T
Jim Lake	68	28	3	July	D,T
		28	3	August	D,T
		28	3	October	SB,BC,MC,SD, W,D,DO,pH,SC,T
Pinky Lake	3	15	3	July	D,T
		15	3	August	T
		15	2	October	SB,BC,MC,SD,W, D,DO,pH,SC,T

*Covariate code definitions: bottom cover, depth, dissolved oxygen, midwater cover, pH, shore distance, specific conductance, stickleback count, temperature, woody debris. See Table 2 for covariate descriptions.

Table 2. Habitat and water condition covariates measured at Jim Lake and Pinky Lake, October, 2011.

Covariate	Code	Type	Sampling frequency	Description
Stickleback	SB	Integer	Trap-level	Count of sticklebacks (three-spine and nine-spine combined) captured in traps
Bottom cover	BC	Percentage	Site-level	Per cent of substrate with aquatic vegetation cover
Midwater cover	MC	Percentage	Site-level	Per cent of water column with aquatic vegetation cover, as measured from a bird's eye perspective
Shore distance (m)	SD	Continuous	Site-level	Straight-line distance to shore
Woody debris	W	Categorical	Site-level	Presence of woody debris in a trap site coded as 0 = none present, 1 = some present
Depth (cm)	D	Continuous	Site-level	Water depth at trap deployment location
Dissolved oxygen (mg/L)	DO	Continuous	Trap-level	Dissolved oxygen concentration measured 10 cm below the surface
pH	pH	Continuous	Trap-level	pH measured 10 cm below the surface
Specific conductance (μS/cm)	SC	Continuous	Trap-level	Specific conductance measured 10 cm below the surface
Temperature (°C)	T	Continuous	Trap-level	Water temperature 10 cm below the surface

gen, pH, specific conductance and temperature. Due to time constraints and difficulty in sampling survey sites during inclement weather, habitat and water condition covariates were not recorded with sufficient coverage to model occurrence or detection as functions of habitat/environmental covariates for sampling dates other than those during October.

Data analysis

We used occupancy models and presence-absence data to estimate minnow trap detection efficiency as measured as the probability of detecting at least one animal given that they occur at a sampled site and to examine seasonal occupancy dynamics through the summer and fall season. Although N-mixture models using count data (see below) could also be used to examine minnow trap detection efficiency and occupancy dynamics (e.g., Royle & Dorazio 2008), we chose to employ occupancy models to generate detection and distribution information that is directly applicable to presence-absence survey efforts typical of large scale inventory and monitoring programmes such as the Anadromous Waters Catalog programme discussed in this study. Subsequently, we examined fine-scale juvenile coho habitat use in shallow lake environments by relating trap site-specific counts to environmental and biological covariates using N-mixture models.

Occupancy modelling: seasonal habitat use and minnow trap detection efficiency

We assessed temporal trends in juvenile coho presence in the study area over the July–October sampling period and assessed the presence-absence detection efficiency of minnow traps using occupancy models (MacKenzie et al. 2002, 2006) implemented with the 'unmarked' package (Fiske & Chandler 2011) in the R statistical programming environment. Occupancy models are hierarchical, specifying a Bernoulli state process for presence at a site, and a Bernoulli observation process for detection conditional upon presence:

$$\text{state state process: } Z_i \sim Bernoulli(\psi_i)$$
$$\text{observation process: } X_i | Z_i \sim Bernoulli(Z_i, p_{ij}).$$

where Z_i is an indicator variable for the true occupancy state at site i equal to 0 (absent) or 1 (present), and X_{ij} is an indicator variable for observed presence (1) or absence (0) of salmon at site i on trap deployment j. The parameters of the model are the probability that a given site is occupied, ψ_i and the probability of detecting the presence of at least one organism given that a site is occupied, p_{ij}. Occupancy ψ_i can be parameterised to be constant or varying across sites, for example as a function of site-level covariates, whereas p_{ij} can be parameterised to vary across sites and trap deployments.

Under the assumptions of occupancy models, the true occupancy state at a trap site remains constant across repeat surveys within a sampling date, i.e., sites are 'closed' with respect to occupancy. We attempted to accommodate the closure assumption by repeatedly deploying traps over a relatively short period of time (24 h/trap deployment) and by deploying traps at a given site successively back-to-back. Trap sites were spaced at least 50 m apart to avoid any spatial dependence between trap outcomes that may result from patchily distributed or schooling juvenile coho.

Data available for this portion of the study were restricted to presence-absence data from all three study areas with repeated trap sampling conducted in July, August and October. A detailed examination of the association between biological and environmental covariates and juvenile coho abundance was carried out in a separate analysis with repeated count models using data from a subset of two study areas during the October sampling session (see below).

We fit a suite of occupancy models which stratify ψ and p by either time (sampling date) and/or study area, or models which fix ψ and p as constant. As a first step in model fitting and selection, we assessed whether the global model, with both ψ and p stratified by time and area, could adequately explain the data using a parametric bootstrap χ^2-test statistic goodness of fit test proposed by MacKenzie & Bailey (2004). Briefly, the parametric bootstrap procedure works as follows: (i) fit the global model with observed data and calculate the observed χ^2-test statistic:

$$T_{obs} = \sum_i \sum_j (O_{ij} - E_i)^2 / E_i$$

where O_{ij} and E_i are the observed and expected occupancy at trap site i during deployment j, (ii) generate simulated site-level true and observed occupancy data using parameter estimates of ψ and p from (i), (iii) fit the global model using bootstrapped data and calculate a bootstrapped χ^2-test statistic (T_{bs}), (iv) repeat B times to approximate the test statistic distribution and calculate the proportion of times the statistic under simulated data (T_{bs}) is as extreme or more extreme than the statistic from the observed data (T_{obs}). This proportion provides a parametric bootstrapped P-value indicating the probability of obtaining the observed test statistic by chance alone if the underlying data generating process specified by the global model were true. Failing to reject the global model as adequate in explaining the data, subsequent model fitting proceeded using AIC scores to evaluate relative model support (Burnham & Anderson 2002).

N-mixture models: association between coho abundance and microhabitat information

To investigate the relationship of juvenile coho abundance with habitat variables, water condition variables and stickleback counts, we implemented *N*-mixture repeated count models (Royle 2004) pooling data from two study areas (Jim Lake and Pinky Lake) during the October sampling date when juvenile coho salmon were known to inhabit the areas. *N*-mixture modelling was restricted to a subset of study areas due to logistical constraints in collecting detailed covariate information. Model fitting was carried out using the 'unmarked' package in R. Similarly to occupancy models, *N*-mixture models are hierarchical (Royle & Dorazio 2008), typically specified as:

$$\text{state state process:} N_i \sim Poisson(\lambda_i)$$
$$\text{observation process: } Y_i | N_i \sim Binomial(N_i, r_{ij}).$$

where N_i is the abundance of coho at trap deployment site i, λ_i is the mean (abundance) of the Poisson state process, Y_{ij} is the count of juvenile coho salmon detected at trap site i on deployment j and r_{ij} is the probability of detecting a single animal present at a site on deployment j, which differs from the detection parameter from occupancy modelling results, p that is the probability of detecting the presence of at least one animal at a trap site. Relationships between detection or abundance and covariates are introduced using a log link function for the mean parameter of the Poisson abundance process (λ_i) and a logit link function for the detection observation process (r_{ij}). As with occupancy models, sites are assumed to be closed with respect to abundance under *N*-mixture models.

Model fitting and selection occurred in three steps: variable screening, global model assessment and finally, multi-model inference. First, we screened the candidate covariates for highly correlated variables which can introduce collinearity problems into model fitting (e.g., Zuur et al. 2010). Pairwise correlation (ρ) was calculated using site-level data (i.e., using the mean for any variables with trap-level information, see Table 2). Most variables had correlations below 0.6; however, specific conductance was highly correlated with water temperature ($\rho = -0.93$), and shore distance with depth ($\rho = 0.88$). We chose to retain water temperature and depth because this information is easier to capture in the field should the results of this study be applied in future sampling efforts.

Following variable screening, we assessed whether the global model (full set of screened covariates included in both the detection and occurrence models) could adequately explain the data using the parametric bootstrap goodness of fit routine proposed by MacKenzie & Bailey (2004) outlined above, but specifying O_{ij} and E_i are the observed and expected counts at trap site i during deployment j (also see Kery et al. 2005).

The parametric bootstrap goodness of fit test for the global model specified with a Poisson state (abundance) process indicated overdispersion was present (bootstrap P-value <0.01). We attempted to accommodate overdipsersion in the count data by specifying a Negative Binomial state process (e.g., Kery et al. 2005); however, preliminary analyses found that these models were highly sensitive to choice of the upper limit of numerical integration for the state process in the integrated likelihood maximisation routine in the 'unmarked' package, K (a problem with the data and the specified state process, and not with the 'unmarked' analysis package). On the other hand, the Poisson model parameter estimates for the global model stabilised at choices of $K > 50$. We made the decision to model abundance as a Poisson process (with $K = 100$) because we believe the global model is adequate to approximate the mean abundance process behind the data, and we estimated a variance inflation factor with which to implement QAIC model selection (Burnham & Anderson 2002) to acknowledge Poisson overdispersion in assessing the uncertainty of parameter estimates and relative model support. MacKenzie & Bailey (2004), citing logic in White et al. (2002), suggest an estimator for a variance inflation factor, c, based upon the parametric bootstrap goodness of fit routine as: $\hat{c}_{bs} = T_{obs} \Big/ \overline{T_{bs}}$ where T_{obs} is the fit statistic based upon observed data, and $\overline{T_{bs}}$ is the mean of the fit statistics generated under the parametric bootstrap routine. Although there is no formal statistical justification for the use of this estimator of c for inference on *N*-mixture models, the logic put forth by White et al. (2002) is reasonable in the context of this study, and we employ $\hat{c}_{bs}$ as an attempt to account for abundance overdispersion as opposed to assuming it away. Under the global model and a Poisson state process, $\hat{c}_{bs} = 3.15$, indicating a moderate, but not extreme level of overdispersion (Burnham & Anderson 2002 page 69); this value was used as a constant variance inflation factor across all candidate models for subsequent multi-model inference.

With an estimate of $\hat{c}_{bs}$, we proceeded with QAIC multi-model inference (Burnham & Anderson 2002) and model averaging. Without prior knowledge of juvenile salmon occurrence or detection in the study area, we considered that all measured biological, habitat, and water condition covariates could conceivably affect both abundance (the state process) and detection (the observation process). Consistent with the site-closure assumption for *N*-mixture estimators, candidate models for the abundance process only included site-level covariates. When necessary, trap-level covariate information was converted to site-level data by taking arithmetic means over successive trap deployments during a sampling date, except for stickleback count in which case we assumed sites would be closed with respect to stickleback abundance and used the maximum observed count across trap deployments as a site-level covariate. In contrast, the outcomes of the observation process, zero or a count of detected animals, is not assumed to be fixed across trap deployments, and models for the probability of detection included a mix of site-level covariates (bottom cover, midwater cover, woody debris) and observation-level covariates (dissolved oxygen, pH, stickleback count, temperature).

Although the number of variables in this modelling effort is relatively small, the set of potential candidate models is large because both a state and detection process must be specified. We constrained the model fitting and model selection process by asserting a reduced set of plausible models for the state and observation processes and took a two-stage approach to model selection (MacKenzie et al. 2006; Hansen et al. 2011). The candidate model set used for both the state and observation process constituted 43 models, including a full and intercept-only model (Table S1), and was constructed to be balanced, such that each covariate entered approximately the same number of models, and to provide a range of complex to simple models with which to conduct multi-model inference (Burnham & Anderson 2002). Candidate models did not include interaction terms or higher order terms (e.g., covariate^2). In the first stage of model selection, we held the abundance process model fixed at the full model (all site-level covariates that were not purged during initial variable reduction) and selected the best model for the probability of detection based upon QAIC scores, which we denote as r(best). Then in stage two, we explored models for the abundance process parameter, λ, with r treated as a nuisance parameter and fixed at r(best), using QAIC weights to construct relative variable importance, model averaged parameter estimates ('shrinkage' method and using $\hat{c}_{bs}$-inflated standard errors), and model averaged confidence intervals using the unconditional standard error formula for model averaged parameter estimates suggested in equation of 6.12 of Burnham & Anderson (2002).

Probability of true absence given trapping effort

Detection estimates from occupancy models can be used to make probabilistic statements about the presence of salmon given trapping effort. One particular quantity of interest relevant when monitoring water bodies for the presence of salmon, for example as candidate water bodies for inclusion in the Alaska Anadromous Waters Catalog, is the probability that salmon are truly absent at a site given some amount of imperfect sampling effort yielding no detections. Information on the probability of true absences can inform monitoring effort design by suggesting how much sampling effort is required to minimise the chance of false absences to acceptable levels, and can also be used to evaluate the confidence about observed absences. The probability that salmon are truly absent at a site given some amount of imperfect sampling effort yielding no detections can be calculated using Baye's rule as:

P(absent at site i | none detected in J deployments, ψ_i, $\boldsymbol{p}_i$) = P(none detected in J deployments | absent at site i, ψ_i, $\boldsymbol{p}_i$) × P(absent at site i | ψ_i, $\boldsymbol{p}_i$)/P(none detected in J deployments | ψ_i, $\boldsymbol{p}_i$)

$$= 1.0(1-\psi_i)\Bigg/\left((1-\psi_i)+\psi_i\prod_{j=1}^{J}(1-p_{ij})\right) \tag{1}$$

where $\boldsymbol{p}_i$ denotes a vector of j deployment-level probabilities of detection.

If a target organism is observed at a site during a search effort, then the probability is 1.0 that it is present, whereas if the organism is not observed, Eq. 1 provides the probability that the organism is truly absent given an amount of imperfect detection effort. Alternatively, one minus this quantity gives P(present at site i | no detects in J deployments, ψ_i, $\boldsymbol{p}_i$) (also see MacKenzie et al. 2006 pages 97–98).

The statement in Eq. 1 requires values of the occupancy and detection parameters (possibly indexed by trap deployment) to be asserted. Analysts could specify point estimates of detection and occupancy using results from previous studies, such as those outlined above. Alternatively, one could avoid specifying point estimates for occupancy and/or detection by viewing the problem as estimating the marginal probability P(absent at site i | no detects in J deployments) from the joint probability P(absent at site i, ψ_i, $\boldsymbol{p}_i$ | no detects in J deployments) and integrating out p and/or ψ, using prior knowledge (or lack thereof) to specify a distribution for the marginalised parameters. For example, in this study, occupancy modelling results demonstrate that the probability of detection was stable across study areas and sampling dates; however, occupancy varied substantially (see below). In this case, one could calculate the probability that salmon are truly absent at a site after some amount of sampling effort by fixing p_i at a constant value p based upon empirical results and then incorporate uncertainty about specifying occupancy values by integrating out ψ_i:

P(salmon absent at i | none detected in J deployments and p known) =

$$\int_0^1 f(\text{salmon absent at } i|\text{no detects}, p \text{ known}, \psi_i) f(\psi_i) d\psi_i \quad (2)$$

with $f()$ indicating a probability density function and $f(\psi_i)$ summarising prior knowledge about occupancy, for instance Uniform (0,1) in the case of no prior knowledge. Similarly, both p and ψ_i could be marginalised out as: P(salmon absent at i | no detects) =

$$\int_0^1 \int_0^1 f(\text{salmon absent}|\text{no detects}, p, \psi_i) f(p) f(\psi_i) dp d\psi_i. \quad (3)$$

The online Supplementary Materials provide R code to make these calculations.

The above calculations specify the probability of true absence at a specific site given an amount of sampling effort with no detections; however, for many wildlife inventory applications, the goal will be to characterise a collection of sites, i.e., a study area, as either containing or devoid of target organisms. Unfortunately, this calculation is not straightforward because it requires substantial information to be in hand including knowledge of the number of non overlapping trap sites in the candidate area which itself requires knowledge of the area sampled by a trap, true occupancy probabilities at sites and probabilities of detection. Barring these difficulties, suppose a candidate area can be divided into S non overlapping trap sites, and each site has an associated true probability of occupancy ψ_i. Then before any monitoring has occurred and assuming sites are independent with respect to occupancy, the probability that salmon are absent in the area is as follows:

$$P(\text{absent in area}|\boldsymbol{\psi}) = \prod_{i=1}^{s} (1 - \psi_i) \quad (4)$$

where $\boldsymbol{\psi}$ represents a vector of site occupancies. After sampling effort yielding no detections, information is gained regarding whether specific sites contain salmon and the probability that salmon occupy an area is updated. Suppressing notation for conditioning on the probability of detection and assuming sites are independent:

$$\text{P(absent in area}|\boldsymbol{\psi}, \text{no detects in survey)} = \prod_{i=1}^{s} (1 - \omega_i) \text{ with}$$

$$\omega_i = \begin{cases} \psi_i & \text{if site } i \text{ not trapped} \\ 1 - P(\text{absent at site } i|\text{no detects in survey}) & \text{if site } i \text{ trapped} \end{cases} \quad (5)$$

where an estimate for P(absent at site i | no detects in survey) is generated as above. Eq. 5 specifies a probability of absence that requires a priori knowledge of $\boldsymbol{\psi}$ at untrapped sites. Following the logic above, ψ_i could be marginalised out at each site if analysts were not able to assert specific occupancy probabilities; however, this is equivalent to asserting an expected value of ψ_i at each untrapped site:

$$\omega_i = \begin{cases} \int_0^1 \psi_i f(\psi_i) d\psi_i = E[\psi_i] & \text{if site } i \text{ not trapped} \\ 1 - P(\text{absent at site } i|\text{no detects in survey}) & \text{if site } i \text{ trapped} \end{cases}.$$

Results

Occupancy modelling: seasonal habitat use and minnow trap detection efficiency

Goodness of fit testing failed to reject the global occupancy model as being adequate in explaining the data (parametric bootstrap χ^2-test statistic P-value = 0.554). AIC model selection showed the global model (both p and ψ ~ StudyArea × Month; AIC = 567.35) best explained the data, with an AIC weight of 54%, although the second best model, the 'main effects' only version of the global model (i.e., both p and ψ ~ StudyArea + Month; AIC = 567.65), had nearly equivalent support with a model weight of 45%. Although the data provide support for heterogeneity in occupancy and probability of detection across areas and time (Table 3; Fig. 2a), examination of parameter estimates indicates that the variation in probability of detection is not great. Most area-time specific probability of detection estimates from the global model have 95% confidence intervals that overlap with estimates from a constant (i.e., intercept only) probability of detection and occupancy model (Table 3; Fig. 2a). Patterns in occupancy are more pronounced, indicating an increasing gradient of occupancy as the season progressed, with low to no probability of occupancy (at a trap site) in July and high occupancy in October (Fig. 2b).

Table 3. Occupancy model results* for the global model (ψ ~ Study Area × Month and p ~Study Area × Month and a constant only model (ψ ~ 1 and p ~ 1).

				95% Confidence Interval	
Global model	Coefficient	Estimate	SE	Lower limit	Upper limit
Occupancy	Intercept (Chain Lakes August)	2.561	0.708	1.174	3.948
	Jim Lake	−4.784	0.955	−6.656	−2.912
	Pinky Lake	−1.063	1.037	−3.096	0.971
	July	−3.719	0.924	−5.530	−1.908
	October	−2.029	1.010	−4.009	−0.049
	Jim Lake: July	4.090	1.257	1.627	6.554
	Pinky Lake: July	1.665	1.330	−0.942	4.271
	Jim Lake: October	6.222	1.341	3.594	8.851
	Pinky Lake: October	3.115	1.738	−0.292	6.522
Detection†	Intercept (Chain Lakes August)	1.146	0.251	0.655	1.637
	Jim Lake	0.082	1.089	−2.052	2.216
	Pinky Lake	−0.538	0.462	−1.443	0.366
	July	−1.707	0.673	−3.025	−0.388
	October	−1.014	0.636	−2.261	0.233
	Jim Lake: July	1.390	1.433	−1.419	4.198
	Pinky Lake: July	1.214	0.913	−0.575	3.002
	Jim Lake: October	0.919	1.268	−1.566	3.404
	Pinky Lake: October	2.121	0.957	0.246	3.996
Constant model					
Occupancy	Intercept only	0.185	0.146	−0.102	0.471
Detection†	Intercept only	0.752	0.139	0.481	1.024

*Parameter estimates are on the logit scale.
†Detection is in reference to minnow traps baited with 4 g cured salmon eggs and deployed for a 24 h soak time.

N-mixture models: association between coho abundance and microhabitat information

Model selection for the detection process with the abundance process fixed at the full model indicates comparable support for a range of simple structures, with a total of 10 models within two QAIC units of the lowest QAIC model (Table 4; see Table S2 for complete QAIC results). The intercept-only detection model was the lowest QAIC choice, with a modest QAIC weight of only 11%. The intercept-only structure was used as the r(best) choice for all subsequent exploration of models for the abundance process.

Model selection for the abundance process with the detection process fixed at r(best) indicates preference for moderately complex models (Table 5; see Table S3 for complete QAIC results), with greatest support for model λ(W+D+T)r(best) with a QAIC weight of 23%. QAIC-based variable importance measures indicate water depth, presence of woody debris, and temperature had relatively greater support as being influential in the abundance process as compared to other covariates, although only water depth had a model averaged 95% confidence interval that did not contain zero (Table 6). Water depth had a significant negative effect on juvenile coho abundance in the study area during October sampling as indicated by marginal effect plots using model averaged abundance predictions (Fig. 3a). Water temperature had a less prominent positive effect on juvenile abundance (Fig. 3b). whereas the remaining covariates had no clear predicted effect on abundance (Fig. 3c-h).

Probability of true absence given trapping effort

Both detection and occupancy play a role in the probability that an observed absence at a site is a true absence. Holding detection constant, Eq. 1 indicates that sites with higher probability of occupancy, i.e., ‘good’ sites for target organisms, drive the probability of true absence downwards and require stronger sampling effort to confirm a true absence relative to ‘poor’ sites with lower occupancy probability (Table 7). Similarly, holding occupancy constant, increasing (decreasing) probability of detection leads to greater (less) confidence that an observed absence at a site is a true absence.

Occupancy modelling results suggest a reasonably high level of detection when using minnow traps to detect juvenile coho in shallow lake environments under the sampling protocol outlined above, with $\hat{p}$= 0.68 (95% confidence interval = (0.62,0.74)) under the pooled, constant only model. Assuming ignorance about the probability of occupancy at a given site by asserting ψ ~ Uniform (0,1) and specifying a conservative probability of detection of 0.5, six trap deployments with no detects at a site would be sufficient to state that juvenile coho are absent at a given trap location with 95% probability (Table 7).

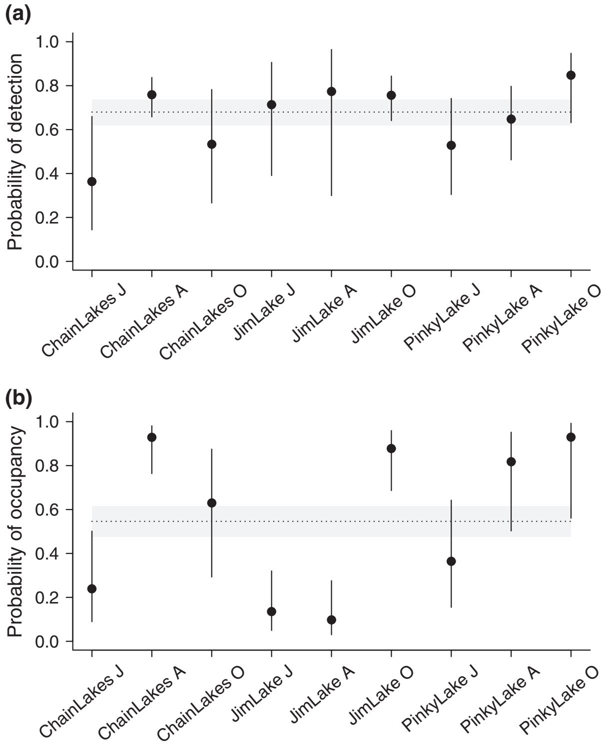

Fig. 2. Estimated (a) probability of detection and (b) probability of occupancy for juvenile coho during 2011 Knik River Public Use Area minnow trap sampling. Black dots and segments indicate point estimates with 95% confidence intervals from the global model (a: ψ ~ study Area × Month, b: p ~ Study Area × Month) The horizontal grey box and dotted line present point estimates and 95% confidence intervals for the constant occupancy (a: ψ ~ 1) and constant probability of detection (b: p~ 1) models. Name labels indicate study area – time combinations with the following abbreviations for months: J = July, A = August, O = October.

Table 4. QAIC results for *N*-mixture model specifications for the probability of detection process with the abundance process fixed at the full model*.

Model	Model terms†	QAIC	ΔQAIC	QAIC weight
λ(full)*r*(.)	11	198.81	0.00	0.11
λ(full)*r*(W+BC+MC)	14	199.50	0.69	0.08
λ(full)*r*(W)	12	199.51	0.70	0.08
λ(full)*r*(DO)	12	200.22	1.42	0.06
λ(full)*r*(SB)	12	200.31	1.50	0.05
λ(full)*r*(T)	12	200.35	1.54	0.05
λ(full)*r*(W+D)	13	200.53	1.72	0.05
λ(full)*r*(D)	12	200.57	1.76	0.05
λ(full)*r*(BC+MC)	13	200.65	1.84	0.04
λ(full)*r*(pH)	12	200.80	1.99	0.04
λ(full)*r*(SB+W)	13	201.16	2.35	0.03

*λ(full)=λ(SB+W+BC+MC+D+DO+pH+T);
†all component models contain an intercept term and an additional term to account for the $\hat{c}$estimate, e.g., λ(full) *r*(.) has eight covariates + intercept for the λ model, an intercept only for the *r* model, and one term for $\hat{c}$ for a total of 11 terms.

Six back-to-back deployments at a site would represent a considerable amount of sampling time; however, we suspect that trap soak times shorter than 24 h would not substantially reduce detection efficiency and could greatly reduce field time. Similar calculations asserting a fixed probability of occupancy value of ψ = 0.55 from the pooled, constant only model estimate (95% confidence interval = (0.47,0.62)) suggests that five trap deployments with no detects would be sufficient to state that salmon are absent with 95% probability (Table 7).

Table 5. QAIC table for *N*-mixture model specifications for the abundance process with the detection process fixed at *r*(best)*.

Model	Model terms†	QAIC	ΔQAIC	QAIC weight
λ(W+D+T)*r*(best)	6	192.67	0.00	0.23
λ(W+BC+MC+D+T)*r*(best)	8	194.92	2.25	0.07
λ(D+DO+pH+T)*r*(best)	7	195.03	2.36	0.07
λ(D)*r*(best)	4	195.10	2.43	0.07
λ(D+pH)*r*(best)	5	195.19	2.52	0.06
λ(SB+D+pH)*r*(best)	6	195.19	2.52	0.06
λ(SB+W+BC+MC+D+T)*r*(best)	9	195.38	2.71	0.06
λ(D+DO)*r*(best)	5	195.64	2.97	0.05
λ(SB+D+DO+pH)*r*(best)	7	196.24	3.57	0.04
λ(SB+W+D+DO+pH+T)*r*(best)	9	196.32	3.65	0.04

**r*(best)=intercept only, λ(full)=λ(SB+W+BC+MC+D+DO+pH+T);
†all component models contain an intercept term and an additional term to account for the $\hat{c}$ estimate.

As outlined above, to make a probability statement about presence or absence of coho in a sampling area, a vector of site occupancy probabilities must be specified, perhaps as informed by habitat use analyses using occupancy modelling or *N*-mixture models as presented above. For exposition purposes, suppose that an observer is attempting to characterise the probability that salmon are absent in an area that contains 10 non overlapping trap sites and they believe the true occupancy probability at all sites is 0.15 (e.g., as estimated for Jim Lake during the summer months; Fig. 2b). Then prior to any trapping effort, the estimated probability that salmon are absent from the area is as follows: $\prod_1^{10}(1-0.15)=0.20$. Five sites are trapped repeatedly three times with a known probability of detection of 0.6 and no detections are observed, yielding a probability that salmon are absent at each trapped site of 0.98 (Eq. 1). Then the probability that salmon are truly absent in the area is as follows: $\prod_1^5(1-0.15)\times\prod_1^5(1-(1-0.98))=0.40$. In this hypothetical example with imperfect detection, if all sites were trapped then the probability that salmon are absent from the area is given as $\prod_1^{10}(1-0.98)=0.82$.

Discussion

Sampling in the KRPUA demonstrated that minnow traps are an effective but imperfect gear for monitoring juvenile coho salmon in temperate shallow lake environments. Failure to account for detection

Table 6. QAIC model averaged coefficient estimates and variable importance for specifications of the abundance process with the detection process fixed at *r*(best)*.

Variable	Coefficient estimate	SE	95% Confidence limit Lower	95% Confidence limit Upper	Variable importance
λ(Intercept)	0.979	2.827	−4.561	6.519	.
λ(SB)	0.004	0.007	−0.009	0.018	0.36
λ(W)	−0.195	0.252	−0.690	0.299	0.54
λ(BC)	−0.001	0.002	−0.005	0.003	0.30
λ(MC)	−0.002	0.004	−0.009	0.006	0.30
λ(D)	−1.308	0.619	−2.520	−0.095	0.91
λ(DO)	0.023	0.054	−0.084	0.129	0.29
λ(pH)	0.166	0.355	−0.530	0.862	0.37
λ(T)	0.238	0.238	−0.229	0.705	0.58
p(Intercept)	−1.099	0.408	−1.898	−0.300	.

*Estimates are on the logit scale.

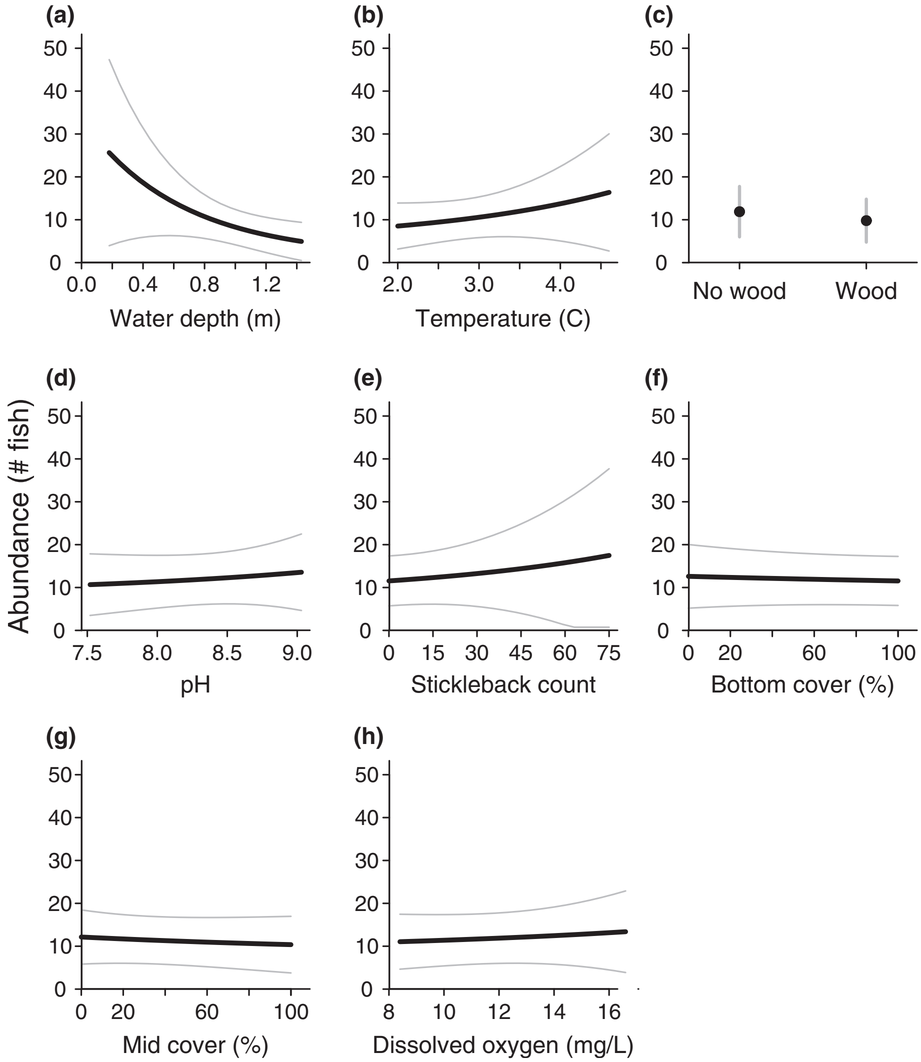

Fig. 3. Marginal effect plots showing QAIC-based model averaged abundance predictions across the observed range of values for a given covariate: (a) water depth, (b) water temperature, (c) presence of woody debris, (d) water pH, (e) stickleback count, (f) per cent vegetative bottom cover, (g) per cent midwater column vegetative cover, and (h) dissolved oxygen. Model averaged estimates use the full candidate model set (Table S1) for λ with the detection model fixed at *r*(best). Plots are arranged in descending order by QAIC-based variable importance. Predictions for a given covariate are made holding all other covariates constant at their mean observed value and with woody debris fixed at none present. Black lines or dots are predicted responses and light grey lines are asymptotic Normal 95% confidence intervals using the model averaged unconditional standard error formula provided in Burnham & Anderson (2002).

Table 7. Probability that salmon are absent at a site given no detects in trap deployments under different probability of detection and occupancy values*

	$\psi \sim$ U(0,1)			ψ = 0.35			ψ = 0.55			ψ = 0.75		
Trap deployments	*P* = 0.2	0.5	0.8	*P* = 0.2	0.5	0.8	*P* = 0.2	0.5	0.8	*P* = 0.2	0.5	0.8
1	0.54	0.61	0.75	0.70	0.79	0.90	0.51	0.62	0.80	0.29	0.40	0.63
2	0.57	0.72	0.90	0.74	0.88	**0.98**	0.56	0.77	**0.95**	0.34	0.57	0.89
3	0.61	0.80	**0.97**	0.78	0.94	**0.99**	0.62	0.87	**0.99**	0.39	0.73	**0.98**
4	0.65	0.87	**0.99**	0.82	**0.97**	**0.99**	0.67	0.93	**0.99**	0.45	0.84	**0.99**
5	0.68	0.92	**0.99**	0.85	**0.98**	**0.99**	0.71	**0.96**	**0.99**	0.50	0.91	**0.99**
6	0.71	**0.95**	**0.99**	0.88	**0.99**	**0.99**	0.76	**0.98**	**0.99**	0.56	**0.96**	**0.99**
7	0.74	**0.97**	**0.99**	0.90	**0.99**	**0.99**	0.80	**0.99**	**0.99**	0.61	**0.98**	**0.99**
8	0.77	**0.98**	**0.99**	0.92	**0.99**	**0.99**	0.83	**0.99**	**0.99**	0.67	**0.99**	**0.99**
9	0.80	**0.99**	**0.99**	0.93	**0.99**	**0.99**	0.86	**0.99**	**0.99**	0.71	**0.99**	**0.99**
10	0.82	**0.99**	**0.99**	**0.95**	**0.99**	**0.99**	0.88	**0.99**	**0.99**	0.76	**0.99**	**0.99**

*Columns under the heading $\psi \sim$ U(0,1) were calculated using Eq. 2 with $f(\psi) \sim$ U(0,1); all other calculations use Eq. 1. Values in bold indicate probabilities >0.95.

efficiency can bias habitat use studies, possibly leading to spurious ecological inference (MacKenzie 2005; MacKenzie et al. 2006). We found that a sampling design of repeated trap deployments at sites was feasible to implement and provided necessary information to control for probability of detection, although three back-to-back deployments with lengthy soak times (24 h) required considerable time in the field. We suggest that shorter soak times would still achieve a sampling design amenable to occupancy modelling and would reduce field time. Preliminary studies in south central Alaska suggest 1–2 h minnow trap soak times are effective in detecting juvenile coho (personal communication with J. Gerken, U.S. Fish and Wildlife Service). Anecdotal field observations indicated that juvenile sockeye salmon periodically cohabited study sites with juvenile coho; however, sockeye were rarely captured in traps. This suggests that juvenile salmon behaviour around minnow traps differs across species and we caution against extrapolating detection efficiency results presented here from coho sampling to other species.

The KRPUA presents a complex mosaic of freshwater environments ranging from small to large order glacial streams as well as shallow water lakes. Little is known about the temporal dynamics of juvenile coho throughout different freshwater rearing environments in the area; however, we found evidence of juveniles moving into shallow ground-water fed lakes late in late summer and into the fall, suggesting that these water bodies may provide overwintering habitat. These seasonal dynamics are consistent with earlier work in the Pacific northwest U.S. (Peterson 1982; Henning et al. 2006) and west coast Canada (Swales et al. 1988; Irvine & Ward 1989), which demonstrated advantages of higher growth and survival rates for juvenile coho salmon that overwintered in lake- or pond-type overwinter habitats. Juvenile coho occupancy in the study area during July and August was low, suggesting that shallow lake environments in the KRPUA may be less important as summer rearing habitat, although Davis & Davis (2009) found that streams in wetland-lake complexes were important habitat for juvenile coho in the Fish Creek and Big Lake drainages near the KRPUA during late spring, summer and early fall.

Once in shallow water lake environments during the fall, inference from *N*-mixture models suggests that juvenile coho were widely distributed throughout different microhabitats in shallow lakes, but did exhibit preference for shallower and warmer sites. We caution that the study design employed here was observational in nature, and thus we cannot make inferences about the driving forces behind coho habitat selection in shallow lakes such as water condition or thermal requirements (e.g., Richter & Kolmes 2005), predator avoidance (e.g., Dill & Fraser 1984), energy savings by leaving moving water (e.g., McMahon & Hartman 1989), and/or food availability (e.g., Grand & Dill 1996). Furthermore, with only a single sampling date, we were unable to assess whether coho habitat use patterns in shallow lake environments changed as the winter season progressed.

Timed migrations of juvenile salmon into different freshwater rearing environments present challenges for efforts to inventory salmon-bearing habitat. If good information is available to suggest when juveniles might occupy a given habitat type, inventory efforts can be timed appropriately; however, lack of such information dictates that temporal replication will be necessary to assess whether at some point in a year, candidate areas harbour salmon. Furthermore, as demonstrated here, sampling gear is not 100% effective and survey replication is required to be confident that salmon are truly absent or potentially present at a given site. Fortunately, minnow traps appear to work well for detecting juvenile coho, with an estimated probability of detecting coho given they are present at a trap site on the order of 0.6–0.7. With this level of detection, two or three repeated trappings at a specific site yielding no detections would result in high confidence that salmon are absent under moderate levels of the true underlying occupancy rate (e.g., Table 7).

Parameter estimates from occupancy modelling provide an objective framework for making confidence statements about whether an area contains juvenile salmon or not (at least in a given point in time). For example, guidance could be given that to declare a candidate area as devoid of juvenile salmon, sampling yielding no detections need be carried out in area until the probability that salmon are truly absent at an area is $\geq 90\%$, following probability calculations as proposed above and given estimates (or educated guesses) of the probability of detection and occupancy that are applicable to the candidate area.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Candidate model set used in specifying the state (abundance) and observation (detection) process models in *N*-mixture models.

Table S2. QAIC results for *N*-mixture model specifications for the probability of detection process with the abundance process fixed at the full model.

Table S3. QAIC results for *N*-mixture model specifications for the abundance process with the detection process fixed at *r*(best).

Data S1. R code to calculate P(absent | no detects in *J* trap deployments).

Data S2. Occupancy modelling data.

Data S3. *N*-mixture modelling data.

Investigation Plan

Title: Inventory of Fish Distribution and in the Knik River Basin, 2011

Principal Investigator: Elizabeth Benolkin, USFWS, Anchorage Fish and Wildlife Field Office

Co-Investigator: Suresh Sethi, USFWS, Anchorage Regional Office

Goals:

1. Present a confidence statement as to whether juvenile salmon occupy a polygon or trap site given what is known about trap efficiency in detecting animals if they are present, and given the outcome of a trapping sampling effort.

2. Develop standard sampling protocols specific to lake and wetland habitats (polygon sampling) to be used for inclusion in the Anadromous Waters Catalog.

3. Record gross characteristics of aquatic habitats at each sampling location to determine which habitat covariates are associated with juvenile salmon occupancy in order to infer habitat preference for juvenile salmon in summer rearing habitat, as well as to inform future search efforts for juvenile salmon in previously unsurveyed habitats in the study region.

Objectives:

1. Estimate an occupancy model (*sensu* Mackenzie et al. 2006) that will provide an estimate of the probability of detection of juvenile salmon given presence at a trap site.

2. Estimate an occupancy model that relates the probability of occurrence of juvenile coho salmon to habitat covariates measured in the field.

3. Design a repeat survey sampling protocol that will allow for a valid occupancy model to be estimated such that data are used efficiently (i.e. result in the most precise estimates of both probability of detection and occupancy) given a maximum survey effort of 30 minnow traps/day.

Introduction

The human population of the Matanuska-Susitna (Mat-Su) Borough is one of the fastest growing in the U.S., with a growth rate of 49% from 1990 to 2000. Population growth and associated development continue to challenge the ability of fisheries and land managers to balance fish habitat conservation with these changes over time. Maintaining healthy fish habitat, including water quality and quantity, is critical to maintain healthy fish populations in the Mat-Su basin.

Concerns for how to effectively protect and restore salmon production in the face of rapid development led to the formation of the Mat-Su Basin Salmon Conservation Partnership (Partnership). The Partnership is one of only four fish habitat partnerships approved nationwide under the National Fish Habitat Action Plan (NFHAP). The NFHAP 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.

Fish habitat protection authorities and planning processes in Alaska are constrained by the extent of current knowledge of fish distributions and their habitats. Some protections provided under AS 41.14.871 only apply to waters specified in the *Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes* (Anadromous Waters Catalog, AWC; Johnson and Blanche 2010). Currently, the AWC contains only 4,200 miles of the more than 23,900 miles of streams that have been mapped in the Mat-Su basin. Management and regulatory tools cannot be applied to their full extent until the remainder of likely anadromous fish habitat in the basin is surveyed.

The Anchorage Fish and Wildlife Field Office initiated this project in 2007 to support the Partnership's Strategic Action Plan and the NFHAP by increasing coverage of the AWC for Mat-Su basin water bodies. The overall goal of this project is to provide information needed for protection and management of the freshwater habitats that support Alaska's anadromous and freshwater fish. Efforts from this project in 2007 resulted in eight nominations for the AWC. Eighty-three reaches in 36 streams were sampled in 2008 resulting in 20 nominations to update the AWC, and 154 reaches in 73 streams were sampled in 2009, resulting in 86 nominations to update the AWC. Sampling during 2010 was focused in the Knik River Public Use Area based on consultations with Alaska Department of Fish and Game biologists. Fisheries and land managers have concerns that intense recreational use in these extensive wetlands could impact salmon production. Sampling for the AWC was initiated as a first step in gaining a better understanding of the use of these wetlands by juvenile salmon. Fish and aquatic habitat parameters were collected from 10 sites within the Knik River drainage in 2010, resulting in 9 nominations to update the AWC. Approximately 1,600 acres of lake/wetland complexes and 6 miles of streams were surveyed in 2010.

Background

The Matanuska and Susitna river watersheds encompass about 24,500 square miles in southcentral Alaska. The watersheds meet freshwater life history needs of all five species of Pacific salmon and support populations of other salmonids including Arctic grayling *Thymallus arcticus*, rainbow trout *O. mykiss*, and Dolly Varden *Salvelinus malma*, as well as many other species such as threespine *Gasterosteus aculeatus* and ninespine *Pungitius puntitius* stickleback, and sculpin *Cottus* spp. Sampling efforts were focused in streams, lakes, and wetlands in the Knik River Public Use Area (KRPUA) of the Mat-Su, which is a legislatively designated area managed by the Department of Natural Resources (DNR), Division of Mining, Land, and Water (Figure 1).

The KRPUA was established to preserve, perpetuate, and enhance public recreation, enjoyment of fish and wildlife, and the traditional use of fish and wildlife resources, and is popular among recreationalists who enjoy activities ranging from salmon fishing to riding off-road vehicles to hunting, boating and bird-watching. It also provides habitat for rich and diverse fish and wildlife populations, including anadromous fish such as sockeye and coho salmon. However the specific habitats which may be important to these anadromous fish is still not documented for much of this area. In addition to a lack of information about which areas may be important habitat for salmon, resource managers have expressed concerns that increased and intense recreational use in these extensive wetlands could impact water quality, riparian habitat, and salmon production. Data gaps and concerns about potential threats to fish habitat in the KRPUA prompted the focus of AWC sampling here.

Procedures

Study Design

Anadromous Waters Catalog sampling methods are adapted from Buckwalter (2010) and from the Alaska Department of Fish & Game's AWC polygon sampling guidelines (ADFG 2011). Methods target rearing salmonids in streams, lakes, and wetland complexes considered important for anadromous fish in mid to late summer. Sampling sites were selected based on consultations with the Habitat-Restoration Branch of the U. S. Fish and Wildlife Service (USFWS) and the Alaska Department of Fish and Game (ADF&G; Sport Fish and Habitat Divisions, Palmer Alaska). Criteria for study site selection included on-going and expected recreational use, key data gaps, and potential threats to anadromous streams. Areas specified for priority sampling include streams, lakes, and wetland complexes north of the Knik River, which are part of the KRPUA and include Jim Lake, Gull Lake, Swan Lake, Chain Lakes, Finger Lakes, and the ponds, wetlands, and tributary channels southeast of Swan Lake.

Data Collection

Sample sites will be chosen based on observations of size, water flow, and apparent limits of anadromous fish distribution. Sites will be accessed using the most direct route possible and permission from landowners will be secured in advance when accessing private property. Sampling at each study area will involve collection of fish and aquatic habitat parameters. Data will be immediately recorded on sampling forms printed on Rite in the Rain paper, then transferred to a laptop each week.

Below we outline a sampling scheme that we believe is easy to conduct in the field, and will be repeatable for future AWC polygon sampling. This sampling design is tailored towards fitting occupancy models (*sensu* Mackenzie et al. 2006); however, at a minimum, it is designed to ensure good coverage over candidate AWC polygons for determinations as to whether or not an area should be included into the Catalog, regardless of whether a formal occupancy model is estimated.

Sampling hierarchy

The overall sampling design can be viewed as a series of nested levels in a hierarchy (Figure 2). The coarsest level of interest is the AWC polygon, referred to as a "study area" for which a determination of whether juvenile salmon occupy the habitat or not is desired. The set of AWC polygons will be referred to as the "study region". For the current research effort, the set of polygons will be those areas within the Knik River Public Use Area which are candidates for AWC inclusion but have not been previously quantitatively surveyed for the presence of juvenile salmon. These areas will include a mix of lake and wetland habitats.

Within AWC polygons, a number of minnow trap will be deployed at trap "sites" to assess whether juvenile salmon occupy the polygon or not. Three repeated surveys (i.e. trap deployments) at fixed trap sites will be conducted in order to provide data to estimate the probability of detecting juvenile salmon with minnow traps if present (p). The survey "season" is the length of time required to complete all K repeated surveys across all M trap sites. An important assumption of occupancy modeling is that trap sites are closed during the repeated surveys season, meaning no movement of animals onto or off of the trap site (though random movement into and out of sites is acceptable). In order to adhere to the closure assumption, repeat trap surveys at all study sites in a study area will be conducted back to back. We expect all three repeat surveys to be feasible in a 96 hour period, such that survey season length is four days. Finally, in order to examine whether occupancy changes over time, the entire sampling regime will be repeated once a month during the summer and early fall months. This will allow for inclusion of a "month" effect in the occupancy model when data are analyzed. Trap sites will remain fixed both within survey seasons, and across repeat sampling months.

Trap site placement

The occupancy modeling goals of this study are twofold: provide a probabilistic assessment of whether or not a polygon contains juvenile salmon, and determine the relationship between habitat covariates and occupancy and/or detection that may help inform future research efforts. To accommodate the first goal, we would like to employ a sampling scheme that gets good trap coverage throughout a study area. In order to accommodate the second objective, we would like to have samples from the full range of habitat covariates present in a study area. Finally, to ensure that sampling does not introduce bias into modeling estimates, we would like to employ some form of random trap site allocation. Taking these factors into consideration, we will employ a blend of systematic and random sampling as follows. A study area will be divided into four quadrants and the total number of trap sites will be divided evenly amongst quadrants. Within quadrants, traps will be randomly placed. As detailed study area maps will likely not be available before sampling begins with which to conduct formal pure random trap site selection, trap placement will be haphazard random. This design will ensure that traps sites are distributed throughout a study area, maintaining good coverage of the study area, yet still attempt to maintain a random sampling component. Alternative targeted sampling designs were considered such as deploying traps in areas of likely salmon presence which may increase the chances of positively detecting salmon in a polygon, however, such design could bias the estimated relationship between habitat covariates and occupancy, as well as probability of detection; with a sampling using trap deployments in areas of likely salmon presence, the definition of the statistical population about which inference is being made would be changed such that the estimated parameters would be the effect of habitat variables on occupancy and the probability of detection *for likely salmon habitat* but not for lake and marsh habitats in general.

Spatial autocorrelation is a sampling issue for occupancy modeling. If animals are patchily distributed throughout the environment, for example as schools of fish might be, then it is likely that traps placed close together would have positively correlated catch counts. This could potentially introduce what is termed "pseudoreplication" into the data and result in estimated parameter precision estimates that are too narrow (e.g. Diniz-Filho et al. 2003). One simple way of dealing with spatial autocorrelation is to space trap sites far enough apart such that survey results are not correlated. Fortunately, pilot data on minnow trapping counts in the broader study region are available from 2010 AWC sampling in South Central Alaska. We used these data to construct spatial correlograms for four sampled polygons to examine catch correlation as a function of trap spacing (Figure 3). In most cases, it appears that there is little spatial autocorrelation even with closely spaced traps, however, there is some suggestion that minimum trap spacings of 50 to 75m may help ensure a reduction in spatial autocorrelation. In light of this, when feasible, traps will be spaced at distances greater than 50m in the field.

Finally, minnow traps are only effective in water depths exceeding 10 cm (Swales 1987). Thus, the study area (a candidate AWC polygon) will be defined as trappable area. Water must sufficiently cover the entrance holes on both ends of the trap to allow fish capture, however complete submersion of the trap is ideal.

Sampling effort allocation

Sampling effort can be allocated to either more trap sites or more repeated surveys within trap sites. MacKenzie et al. (2006) suggest that more survey sites (M , trap locations, see Figure 2) provides increased precision of the estimates of occupancy probabilities, whereas more repeat surveys (K, repeat surveys at each trap site, see Figure 2) provides increases precision of the estimate of probability of decection. MacKenzie et al. (2006; pg. 168) provide simulation results which indicate that if a species is “common” in the environment, indicating a high probability of occupancy at sites (e.g. probability of occupancy at a site =0.7 or greater, indicating that there is a >70% chance that juvenile salmon are present at a randomly selected trap site), and detectability is on the order of 0.6 (60% chance of detecting a salmon at a trap site given it is present) then 2 or 3 repeat surveys at sites provides the optimal number of repeat survey effort in terms of balancing precision between occupancy and detectability estimates. Pilot AWC polygon sampling in South Central AK in 2010 (Benolkin 2010, unpublished data) suggest that juvenile salmon are common, and that trapping success was moderate to good in most candidate polygons. In light of this, we will target 3 repeat surveys at each site, conducted back to back in order to protect the closure assumption of occupancy modeling outlined above.

Pilot sampling in 2010 suggests that two field crews of two people each can together deploy and survey 30 traps in a study area per day. As noted earlier, in order to protect the closure assumption, repeat surveys will be conducted back to back, such that a “unit” of sampling effort will be 30 traps per study area per sampling season where a season is likely to be 4 days long for 3 repeat surveys. This indicates that at least 4 days engaging the entire available sampling crew are required per 30 trap sites. No formal guidance is available on the number of traps required to get precise estimates of the relationship between habitat covariates and the probability of occupancy or detection as occupancy models have not been used in AWC sampling before. Furthermore, it is likely that the probability of detection and occupancy will vary across study regions. For example, it is plausible that a large study area with a low density of salmon would require more trap deployments to get acceptable precision for estimates of the probability of detection or occupancy than at a smaller site with high density of salmon. Furthermore, candidate AWC polygons (study areas) span a wide range in sizes, with larger areas several times the size of smaller areas such that it may be desirable to standardize the amount of effort deployed across study areas. Without further a priori sampling guidance, we will seek a balance between intensive sampling effort at a study area with the goal of sampling multiple study areas.

To achieve this, we will target 30 study sites/standardized area at each candidate AWC polygon, targeting approximately 30 trap sites/75hectares of trappable area. Study areas will be defined at a scale observable with GIS analysis and identifiable with GPS technology in the field environment. Polygon areas may change throughout the Summer and Fall due to varying water levels, where pilot sampling in the study region suggests lower water in early Summer. Because the sampling regime will be repeated once each month over the Summer and Fall, we define polygon area as area that meets the trap requirements (i.e. minimum depth requirement) throughout Summer to Fall and will delineate polygon areas in early summer at low water. Study areas (<75 ha of trappable area) will be combined with nearby interconnected small areas if possible and treated as one contiguous area where all traps will be deployed at a distance of at least 50m apart. If small study areas are isolated (e.g. ponds), they will be treated as a single polygon where all traps will be deployed with an effort to not overlap traps sites with a 50m minimum trap spacing constraint. Spatial autocorrelation will be tested post-hoc to verify survey sites are not correlated.

Habitat Assessment

The extent of the lake or wetland complex will be identified using satellite imagery and with on-the-ground observations, and spatial coordinates will be delineated as a polygon around the trappable area with GPS tracks. Spatial coordinates of the upstream terminus of each stream reach or the delineated polygon will be recorded in decimal degrees with a handheld global positioning system device using the North American Datum of 1983 (NAD 83) geographic coordinate system. Photos will be used to document habitat characteristics at each site.

At each trap site, habitat covariates will be measured. These will be used to estimate the relationship between habitat characteristics and the occupancy of juvenile salmon. The following habitat covariates will be measured:
1. Water Depth (cm)
2. Water and Air Temperature (ºC)
3. pH
4. Conductivity (µS/cm)
5. Dissolved oxygen (mg/L)
6. Minimum distance to shore (m)
7. Dominant substrate category
The dominant substrate will be visually estimated (Buckwalter 2010).

Substrate Category	Size	Code
Boulder	>256mm	BLD
Cobble	64-256 mm	CBL
Pebble/gravel	2-63mm	GRV
Sand/silt/clay	.059-1mm	SSC
Organic	incompletely decomposed organic material	ORG

8. Aquatic Vegetation and Woody Debris

The type of aquatic vegetation will be categorized at each site into one or more broad categories defined as emergent, floating, or submerged. Aquatic plant species will be identified to genus or species when possible. Woody debris (none, large, or small) will also be noted, based on visual observation. Percent vegetation coverage will be estimated at each the top, middle, and bottom of the water where a trap is set.

9. Water Color
Water color will be visually estimated using the following definitions from Buckwalter 2010.

Code	Description	Definition
CLR	Clear	Transparent water, or nearly so.
FER	Ferric	Rust- (orange) stained.
GHT	Glacial, High Turbidity	High turbidity waters (visibility ≤ 30 cm (12 in) typical of streams originating directly from glaciers (e.g., Matanuska River).
GLT	Glacial, Low Turbidity	Low turbidity waters (visibility > 30 cm) typical of systems with large lakes (settling basins) below glacial discharge (e.g., Kenai River). These waters are frequently turquoise-colored.
HUM	Humic	Tea-colored water (tannic)
MUD	Muddy	Dark water with high suspended particulate load.

Water temperature (°C), conductivity (μS/cm) and pH will be measured using a YSI 63 water quality multimeter, and DO (mg/L) will be collected using a YSI 550A at consistent subsurface depths of about 0.5m or within 0.1m of the lake bottom where water is < .05m deep. Sampling equipment will be calibrated weekly according to manufacturer's manuals or more often if readings are suspect. Substrate category will be determined as the majority type over the trap site which is defined to be the area for which the minnow trap is considered effective (at a minimum, a circular area with radius of 2 m; Bryant 2000).

In addition to the habitat covariates listed above, sampling date and location information will be collected. A time covariate (e.g. a categorical month) will be included into model estimations in order to test whether the relationship between juvenile salmon use and their environment changes throughout the summer. Similarly, occupancy and detection may also vary across study area. Location information will allow for tests of changes in the relationship between occupancy and/or detection and habitat covariates between locations. Furthermore, sampling date and location information will allow for a hierarchical modeling structure of the data, should random effects models be indicated as fitting the data well when collected data are analyzed. Finally, if a candidate polygon study area is divided into multiple sampling subunits in order to achieve the desired standardized trap sites/area (see above), all subunits will be sampled eacht month in order to test for changes in occupancy and detection by season.

Fish Assessment – Fish sampling in study polygons will be conducted by minnow trapping. Gee® brand minnow traps (Cuba Specialty Manufacturing Company) will be deployed. Minnow traps are composed of two galvanized wire mesh baskets (6mm mesh), which interlock and are fastened with wire clips to form a trap measuring 42cm x 22 cm. Openings on each end funnel on each end of the trap (22 mm) allow juvenile fish to enter. Traps will be baited with cured salmon roe (4g), placed in a predrilled film canister or whirlpack, and soaked for 24 hours. Each trap site will be recorded as GPS waypoint, and the start, end, and total soak time will be recorded. Experimental methods such as seining and electrofishing will be used opportunistically to target sockeye salmon in areas previously undocumented with this species when feasible.

Captured fish will be placed in a 12-L bucket less than one half full with stream water. Fish will be counted and identified to species (Pollard et al. 1997). Total forked length (mm) will be recorded for all juvenile sockeye salmon, coho salmon, and Dolly Varden. All fish will be released into a slack-water area within the sample site and allowed to recover.

Analysis and Reporting

AWC Nominations-- Project data will be used to nominate water bodies for inclusion in the AWC and thereby provide protections under AS 41.14.871. Nominations to the AWC may include (1) adding new streams or polygons, (2) adding species to cataloged streams, (3) extending species distribution in cataloged streams, (4) deleting streams or parts of them, (5) updating survey data on cataloged streams, or (6) revising stream channels, labeling errors, or identifying barriers to fish passage. For each nomination, copies of the actual sampling forms, maps, and photos will be provided. The data will also be used by ADF&G Habitat Division to address development pressures in the Mat-Su Basin. The information will allow managers to better understand the importance of wetland complexes and off-channel habitats for fish populations in the Mat-Su basin, and will provide data needed to help prioritize fish passage barrier removal and habitat restoration projects. A USFWS Fisheries Data Series Report will summarize efforts in 2011 and make recommendations for future work.

Project Timeline

Activity	Time Frame
Identify priority areas for sampling	1 – 31 April 2011
Pre-season logistics	1 – 30 May 2011
Crew training & preparation	16 May– 3 June 2011
Camp set up/ATV scoping/Jim Lake	6 – 10 June 2011
Sampling- Gull Lake/Delineations	13 – 17 June 2011
Sampling- Swan Lake/Delineations	20-24 June 2011
Sampling- Chain Lake	1 –15 July 2011
Sampling -Gull Lake, Leaf Lake	16 - 30 – July 2011

Sampling -Chain Lakes, ponds	1 – 15 August 2011
Sampling- Finger lakes	26 - 30 August 2011
Camp breakdown, gear inventory	1 -9 September
AWC nomination forms submitted	29 September 2011
Data summary and analysis	15 October – 30 January 2012
Draft report for review	1 February 2012
Final Data Series report published	31 March 2012

Funding

This project is supported by multiple funding sources. NFHAP funds in the amount of $32,000 will provide for Chickaloon Native Village personnel to collect field data. The USFWS Anchorage Fish and Wildlife Field Office will provide funds in the amount of $147,000 in personnel salary, housing, equipment, and supplies.

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Responsibility

Elizabeth Benolkin will be the Project Biologist, and will be responsible for the planning; day-to-day operations, scheduling, and supervision of the field crews; and analysis and reporting of project data.

Doug McBride, Fisheries Branch Chief, will be responsible for project oversight and assistance.

Figures

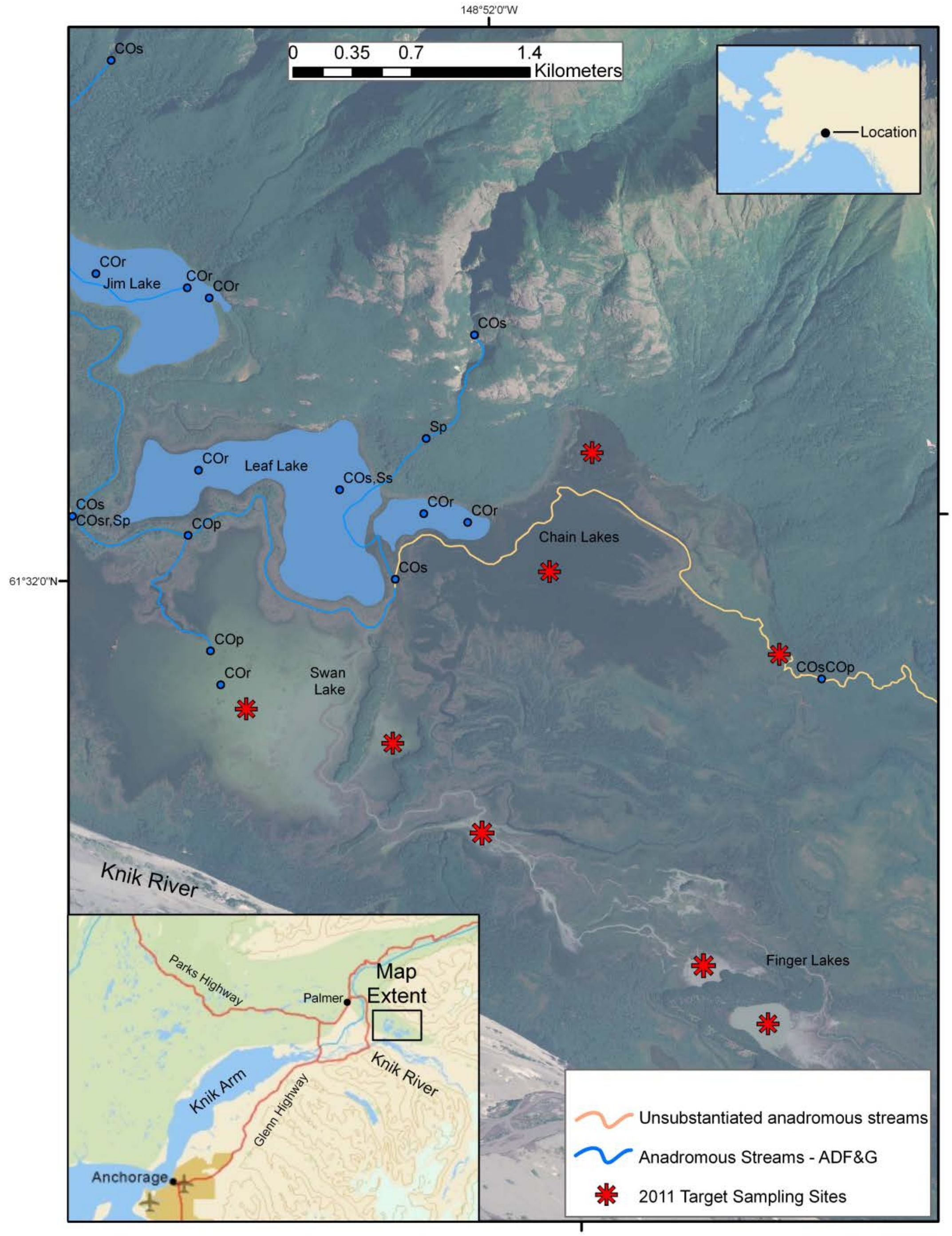

Figure 1. 2011 target study sites in the Knik River Public Use Area.

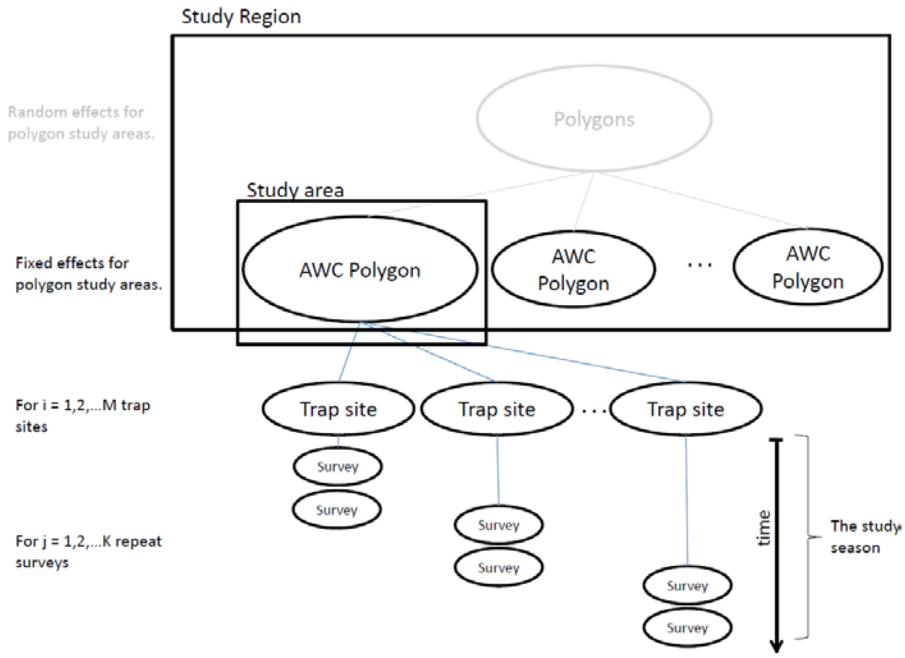

Figure 2. Sampling hierarchy for AWC polygon sampling in South Central Alaska.

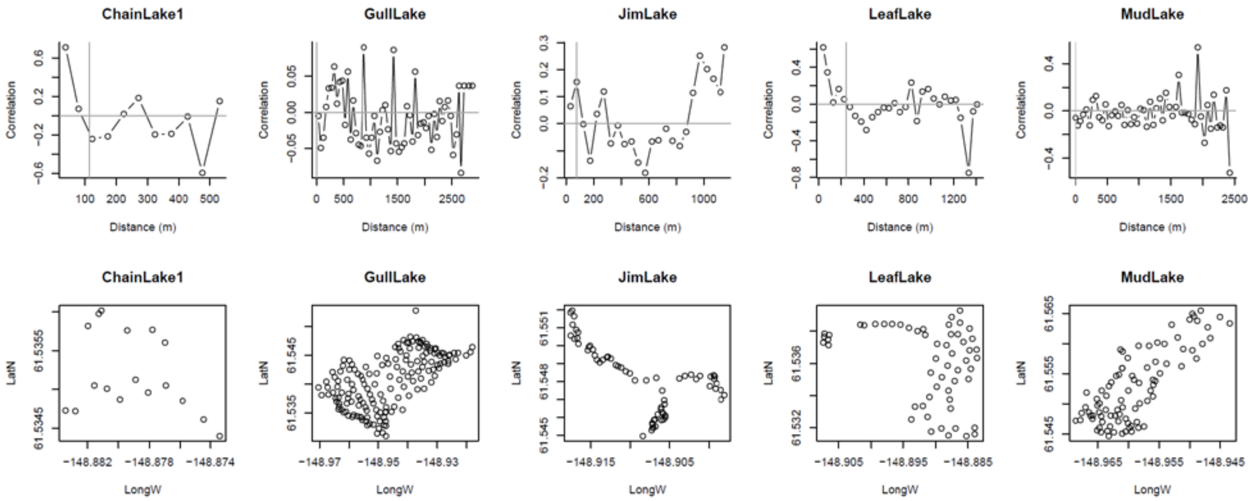

Figure 3. Correlograms for spatial autocorrelation of Coho counts in minnow traps deployed in 2010 AWC polygon sampling in South Central AK. The top row of plots presents spatial autocorrelation as a function of trap spacing; gray lines indicate the minimum trap spacing associated with zero autocorrelation. The bottom row of plots displays trap locations in latitude (N) and longitude (W).