Winter Habitat Associations of Juvenile Salmon in the Susitna and Talkeetna Rivers

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By:

Aquatic Restoration & Research Institute

Jeffrey C. Davis, Gay A. Davis, Leslie R. Jensen, Hannah N. Ramage and Eric Rothwell (NMFS)
Aquatic Restoration & Research Institute
P.O. Box 923, Talkeetna AK, 99676

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Abstract
Juvenile salmon distribution was investigated among habitat types present within the large glacial Susitna and Talkeetna Rivers located in Southcentral Alaska. Monthly and seasonal winter (October – March) habitat surveys and fish sampling events were conducted within main channel, tributary mouth, mainstem backwater, and upland slough habitat types. Fish sampling was conducted within 100-m sampling reaches using 10 baited minnow traps fished for 24 hours. Beach seining and videography were used to augment trapping efforts. Chinook and coho salmon were present at all sampling locations with the exception of an upland slough characterized by extremely low dissolved oxygen concentrations (35% saturation at 4°C). The relative abundance of juvenile Chinook and coho salmon varied significantly among sampling locations but not consistently among habitat types likely due to different habitat characteristics between habitats with the same classification. Chinook salmon tended to be more abundant in mainstem and side slough habitats while coho salmon tended to be more abundant in side slough and upland slough habitats, with equal use of tributary mouths. These trends were based on high abundance at one of two macrohabitats and not both sites with the same macrohabitat classification. The relative abundance of Chinook salmon was correlated with water depths, dissolved oxygen, and cobble substrates. Coho salmon abundance was correlated with water depths and water temperatures. Based on comparisons between similar classified habitats, dissolved oxygen, specific conductivity, turbidity, water depth, water velocity, and woody debris could be influencing the distribution and relative abundance of juvenile salmon within tributary mouths and upland sloughs. Changes in fork lengths throughout the winter suggested winter growth that varied amount habitat types and potential emigration under the ice during winter.

Introduction
Little is known about juvenile salmon winter distribution under ice in large northern river systems. Several studies have documented the shift in juvenile salmonid habitat preferences between summer and winter rearing, and the rarity of suitable winter habitat is often cited as the limitation on smolt production (Nickleston et al. 1992; Brown and McMahon 1998; Giannico and Hinch 2003). However, these studies generally focus on fish in small streams, and often in locations without significant ice cover.

Juvenile Pacific salmon have been shown to emigrate from summer rearing to overwintering habitats. Migration is associated with declining water temperatures but may be linked to changes in flow, or light levels (Bjorn 1971, McMahon and Hartman 1989). Migration from summer rearing habitat may be initiated by low fall flows, winter freshets, and the loss of open water as small tributaries freeze to the bottom (Prowse 1994). Juvenile salmon generally select overwintering habitats with low water velocity, cover, and relatively warmer water due to springs or upwelling groundwater (Giannico and Hinch 2003, Hillman et al. 1987, Cunjak 1996). Winter habitat selection is based on the need to minimize energy expenditure and to avoid adverse physical or chemical conditions (anchor ice, floods, low oxygen) (Cunjak 1996).
Chinook and coho salmon have different winter habitat preferences, while little is known about overwintering habitats used by stream-type sockeye salmon. Substrate with interstitial spaces that provide cover and lower water velocities may be important for overwintering Chinook salmon (Hillman et al. 1987, Bjorn 1971). Bjorn (1971) found fewer juvenile Chinook salmon migrated out of streams with large cobble substrate than those with gravel or finer substrate. Juvenile Chinook salmon were found in association with macrophytes and undercut banks during winter and the addition of cobble substrate increased overwinter abundance (Hillman et al. 1987) in the Lemhi River (Northern Idaho). Juvenile steelhead and Chinook were found overwintering in deep pools and the interstitial spaces of riprap cover in a large river in British Columbia (Swales et al. 1986). Bustard and Narver (1975) found juvenile coho salmon and steelhead trout in waters with velocity < 0.15 cm/s when water temperatures were below 8°C. While Hillman et al. (1987) found Chinook salmon in water velocities less than 20 cm/s during winter with larger fish using higher water velocities.

Overwintering juvenile coho salmon are found consistently in slow-water off channel habitats with abundant cover. Overwintering coho habitat in British Columbia is in side channels fed by ground water (Giannico and Hinch 2003). Ground water fed side channels and ponds provide stable water flows, higher temperatures and invertebrate production allowing fish to forage and continue to grow during winter (Peterson, 1982a,b; Brown, 1985 in Giannico and Hinch 2003). In coastal streams of Vancouver, juvenile coho salmon moved into side channels and into beaver ponds and were associated with cover provided by woody debris or overhanging vegetation (Bustard and Narver 1975). Juvenile coho salmon emigrated from streams as light levels decreased in the fall unless they were in locations with low water velocity and abundant cover from woody debris and overhanging vegetation. Use of cover decreased with continuous ice cover (McMahon and Hartman 1989). On the Olympic Peninsula coho salmon have been found to move large distances to off channel ponds with a large amount of cover for overwintering habitat (Petersen 1982). Similarly in British Columbia, side channel and off channel habitats with abundant cover provide overwintering habitat for juvenile coho salmon (Swales et al. 1986).

In colder side channels with a surface water source, woody debris increased coho salmon carrying capacity and smolt output, but in the relatively warmer side channel with a groundwater source, woody debris had no effect or a negative effect (Giannico and Hinch 2003). The authors believed that cover was more important in the cold water side channels as fish swimming ability decreased with lower temperatures. Warmer groundwater was determined to be a key characteristic of productive overwintering habitat for coho salmon (Giannico and Hinch 2003).

Overwinter survival of sockeye salmon, as with other salmon species, is believed to be limiting to overall production (Stienhart and Wurtsbaugh 2003). However, juvenile sockeye salmon generally overwinter in lakes, and little is known about overwinter survival of stream-type sockeye salmon. Sockeye salmon have been found to spawn in side channels of glacial rivers including the Matanuska and Susitna Rivers (Curran et al. 2011, Barrett et al. 1985), and there is indication of overwintering in side channels and sloughs (ADFG 1984).

Tributaries, tributary mouths, side channels and sloughs likely provide overwintering habitat for juvenile salmon in large glacial rivers. Side channels and sloughs provide slow-water habitats and are often fed by groundwater or tributary sources (Curran et al. 2011). Warmer wetland tributary streams provide overwintering habitats with high winter growth rates and their confluence with glacial rivers could serve as overwintering locations. Whiskers Creek (a wetland
tributary) Whiskers Slough (side slough) and Slough 6A (upland slough) within the upper Susitna River were used for overwintering by age 1+ and 2+ coho salmon (ADFG 1984). Significant overwintering of juvenile coho salmon in the Talkeetna-to-Devil’s Canyon reach of the Susitna River occurs in side sloughs and upland sloughs (ADF&G 1984b) and some coho may also use the mainstem and side channels for overwintering (ADF&G 1981b). Similarly, some age 1 sockeye have been found in Susitna River sloughs, which suggests overwintering in these locations (ADFG 1894). However, the distribution of juvenile salmon species among the potential overwintering habitats and factors that may influence juvenile fish use of these areas has not been investigated.

Interactions between ice formation, flow patterns, and fish movements are often complex and highly variable from year to year with differences in freeze-up patterns. Off-channel habitats may be important rearing areas within large rivers, but passage conditions between habitat types may be limited by main channel low flows or ice accumulation. These passage conditions may change throughout a season with backwater associated with freeze-up (Prowse 1994).

Although large mainstem rivers are often considered mostly migration corridors for juvenile salmon, some research has found that mainstem reaches near spawning areas can have a significant amount of winter rearing and feeding activity (Levings and Lauzier 1991). Winter base-flows may create microhabitats in the main channel similar to off-channel sites with pools, eddies, and meander margins suitable for juvenile rearing. As long as physical habitat and biotic variables remain within suitable limits for survival, these may also be important wintering locations.

Ice cover in all habitat types can lead to depleted oxygen concentrations through lowered diffusion, decreased photosynthesis, and increased percent contribution of poorly oxygenated groundwater (Schreier et al. 1980). Dissolved oxygen levels can decline to levels known to impair biological activity and are likely the most important change to water quality caused by winter ice over (Power et al. 1993).

Sites with more abundant cover and deeper waters provide refuge from velocities and predators and are expected to have the highest fish abundances (Peterson 1982). However, ice cover has also been shown to be avoided by salmon in some systems because anchor ice often inundates these areas (Brown et al 1994; Prowse 1994).

The objectives of this study were to (1) assess sampling methods for monitoring juvenile salmon under ice in various habitat types; (2) evaluate fish distribution and relative abundance among habitat types and physical/chemical characteristics, and (3) compare indicators of fish growth among different habitat types. These objectives will provide insight for future winter habitat studies and contribute toward the identification of different habitat types and their characteristics that are important for overwinter salmonids.

**Methods**

**Field Sampling**

The relative abundance of juvenile salmon and physical habitat characteristics were measured at eight sampling locations on the Susitna and Talkeetna Rivers (Figure 1).
The Susitna and Talkeetna Rivers are large glacial rivers located in southcentral Alaska, with drainage areas of 6,288 mi² and 2,021 mi², respectively. Sampling locations were selected to represent the predominant macrohabitat types as identified in previous studies conducted in the early 1980s (ADFG 1981). These habitat types included mainstem (main channels and side channels), tributary mouth, side slough, and groundwater-fed upland sloughs. Mainstem side channels were defined as channels which are always fed by water from the mainstem but do not receive the majority of mainstem flow; a tributary mouth is the area within a tributary with mainstem hydrologic influence; side sloughs are overflow channels which are fed by the mainstem during high flows; and upland sloughs are similar to side sloughs but have a vegetated bar at the head that is rarely overtopped by mainstem flow.

All sites were sampled in October and February/March to look for changes in fish distribution among sampling sites during late fall and mid-winter. Three of these sites were additionally selected as “intensive sites” to represent side channel, tributary mouth, and upland slough habitat types. Intensive sites were sampled monthly to look at concurrent changes in physical and chemical characteristics within these habitats and fish distribution. The months sampled are listed in Table 1. Main channel 1 and Tributary Mouth 2 each missed a sampling event due to extreme ice cover (Main channel 1) or access problems and ice cover. Ice cover at the Upland Slough Head site extended to the streambed with no flowing water during the February sampling event. Tributary Mouth 1, Upland Slough 2, and the side slough sites were selected for sampling to compare with historical data that identified these sites as high-use overwintering area for juvenile Chinook salmon (ADFG 1981).
Table 1. Sampling locations and months sampled for each sampling site.

<table>
<thead>
<tr>
<th>Sites Sampled</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb/Mar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main channel 1</td>
<td>62.33220</td>
<td>-150.12900</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main channel 2</td>
<td>62.30787</td>
<td>-150.10747</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>61.93178</td>
<td>-150.09170</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upland Slough 1</td>
<td>62.35364</td>
<td>-150.13597</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Upland Slough 2</td>
<td>62.51432</td>
<td>-150.12202</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tributary Mouth 1</td>
<td>62.37452</td>
<td>-150.16906</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side Slough</td>
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<td>-150.16968</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tributary Mouth 2</td>
<td>62.34576</td>
<td>-150.10916</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The relative abundance of juvenile salmon and resident fish among sampling sites was determined primarily using baited minnow traps; however, sampling was augmented with seine hauls during open water conditions and during the ice covered period by videography. Ten baited minnow traps were fished for ~24 hours within each 100 m sampling reach. Minnow traps (1/4 inch mesh) were baited with salmon roe suspended from the top of the trap within a perforated whirl-pak bag. Traps were placed at approximately 10 m intervals in locations where water depth completely covered the trap. Traps were placed under cut banks or beneath woody debris when available. During periods of complete ice cover, areas of open water under the ice were determined by drilling a hole through the ice using an 18 inch long 3/8 inch bit. A hole was cut through the ice large enough to allow for trap deployment with a chain saw using vegetable oil as bar oil. The number of traps used at Tributary Mouth 2 was reduced to 5 during December sampling due to ice thickness. The number of traps used at both Main channel 1 and Main channel 2 was reduced due to ice cover to the streambed except in a few locations of open water along the stream margin which limited the number of available trapping locations.

Upon retrieval, fish were transferred from the trap to a 5 gallon bucket. All fish within each trap were identified to species and the fork length of all salmonids was measured. All fish were returned alive to the point of capture. For each site we calculated total salmon catch per unit trap (CPUT) and CPUT for each species individually. We estimated fish weight for juvenile Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) by using a condition factor of 0.10 (weight (g)/fork length (mm)^3 x 10000) developed previously for these species during summer sampling (unpublished report Miller et al. 2010). Total estimated biomass was calculated as the sum of estimated weights for all fish captured, standardized to 10 traps. We plotted frequency distribution by 3 mm fork length intervals for Chinook and coho salmon independently to estimate age class. However, in February/March at most sites there were not enough fish to estimate the mode of age-0/1 fish, so we used average fork length as a metric of fish length. There was only one age class of Chinook and at sites where age classes of coho could be estimated, the population was predominately age 0/1.

On the October sampling date, we tested for differences in CPUT for traps fished for 24 or 48 hours by comparing total salmon catch rates at each of the two time intervals. Ten baited minnow traps were set at each of three sites as described previously. After 24 hours the trap was removed from the water and all fish within each trap were counted either directly or by first emptying the trap into a bucket of stream water. The bait was replaced and the fish returned to
the trap and the trap redeployed at the same location. The traps were then removed 24 hours later and all fish were identified and fork lengths measured. Paired t-tests were used to test for differences in total salmonid CPUT between 24 and 48 hours (n = 28).

Seines were used to sample fish during October sampling. Three seine hauls (40 m length, ¼ inch mesh) were conducted at each sampling site. All fish within each haul were processed using the same methods as minnow traps providing catch per haul values.

High definition videography was used as a second method for fish observations at each sampling site during the final sampling event. Twenty minutes of video was recorded at the upper, middle, and lower portions of five of the sampling reaches using a high definition underwater camera (SeaViewer). Recordings were captured after dark, when fish were expected to be the most active. Recordings were analyzed in the lab for fish presence and values of both the total number of fish sightings within a 20-minute timespan and maximum number of fish captured in a single frame were documented. Observed fish were identified to species when possible. These counts were compared with minnow trapping results at the same location to determine if either sampling method was more successful for capturing particular species. Comparisons between video observations and minnow trap CPUT also assessed whether or not values were similar enough for video to replace minnow trapping in locations that are too shallow or swift for trap deployment.

During October, channel width, water depth, and velocity were measured and dominant substrate visually estimated at three transects at each sampling reach. At the Tributary Mouths the Side Slough and Upland Slough 1 channel width, depth and velocity were measured along transects located at the downstream, middle, and upstream ends of each sampling reach. Channel width was measured from ordinary high water (vegetation line) and depth and water velocity was measured at both water’s edge, and at ¼, ½, and ¾ of the distance across the channel. Mean vertical water velocity was measured at these same locations at 0.6 x depth. Substrate size was visually estimated qualitatively as percent cover across each transect as silt/sand or large gravel to cobble. All large woody debris (5 cm diameter x 1 m length) within the 100 m sampling reach was counted. At mainstem sites and Upland Slough 2, water depth, velocity, and substrate size was measured at ~1 m intervals from the bank as far as possible (generally about 2 m into the channel) at the downstream, middle, and upstream ends of each sampling reach. When ice was present water depth, ice thickness, water velocity, and substrate size was measured at the downstream, middle, and upper most trap locations. Water velocity during February sampling was measured using a Flow Tracker (YSI Inc.).

Water chemical/physical properties were measured on all sampling events at transects (October) or trap sites. Measurements included pH, specific conductivity (YSI 63 meter and probe), turbidity (LaMotte TC-3000e), dissolved oxygen (YSI 550A), and temperature (specific conductivity and oxygen meters). When water temperatures were less than ~2°C, the YSI 63 could not correct for temperature and conductivity was recorded. All meters were calibrated prior to each field sampling date.

**Statistical Analyses**

One-way ANOVA and Tukey’s post hoc tests were used to test for significant differences in total salmonid, Chinook, and coho salmon CPUT among sampling locations for the October and
February/March sampling dates independently. Simple correlation and regression were used to test for relationships between fish metrics and physical and chemical characteristics at each site. Alpha was 0.05 for all tests.

Results

Sampling Locations and Physical Habitat Descriptions
Main channel 1 (Susitna River above Talkeetna). This site was classified as a backwater side channel of the Susitna River. During October and November, backwater from the Susitna River created a large pool. However, by December as mainstem flows declined, ice formed to the river bed along a submerged lateral bar with open water along the streambank. This channel remained open, at least in part, throughout the winter sampling period (Figure 2). During October and November sampling, substrate was 100% silt (Table 2) however, in February during lower flows substrate was mixed cobble and sand/silt (Table 3). There were 26 pieces of large woody debris (LWD) within the 100-m sampling reach and a large percentage of these were whole cottonwood or spruce trees.

![Figure 2. Main channel 1 during monthly sampling events, October-November. Clockwise from top left are site photographs looking downstream on 10/9/12, 11/13/12, 1/16/13, and 2/25/13.](image)

Water temperature at Main channel 1 averaged 5.4°C in October and below 1.0°C for all other sampling dates. Dissolved oxygen saturation showed a general increase downstream through the sampling reach. Mid-winter dissolved oxygen values (January and February) were approximately 75% of saturation at the upstream edge of the sampling reach and approximately 95% at the downstream end. The lowest average percent saturation was measured in November at 61.7%
and the highest average oxygen saturation measured was 92.43% in October. Specific conductivity also increased downstream through the reach during all sampling events, with all measurements after October below 20 \( \mu \text{S/cm} \) at the upstream end of the reach and above 100 \( \mu \text{S/cm} \) at the downstream end. Ice cover remained minimal along the left bank, where monthly sampling occurred, but extended to the substrate (> 1 m thick) approximately 2 m lateral to the bank. Water clarity increased after the October sampling event, with turbidity dropping from 32.1 NTU in October to 2.3 NTU in November and below 1.0 NTU in January and February. Apparent color was approximately 0 CU in January and February.

**Main channel 2 (Cravers).** This site is a backwater of an abandoned side channel of the Susitna River. The site is located in a braided portion of the river, downstream from the Talkeetna and Susitna rivers confluence. The channel narrowed between sampling events due to lateral ice formation, but maintained similar water depths and velocities and had minimal ice cover during both sampling events (Figure 3).

![Figure 3. Main channel 2 sampling site on 10/16/12 (left) and 3/5/13 (right).](image)

Water temperature averaged 1.47°C throughout the sampling reach in October and 0.55°C in early March, with a general cooling trend in the downstream direction. Dissolved oxygen was near saturation in October at 98.57% and averaged 78.67% in March, with a slight decreasing trend from upstream to downstream. The site had minimal ice cover in March, averaging about 0.01 m thickness throughout the reach, and the channel was significantly narrower with reduced flows. Water clarity improved between sampling periods, as apparent color dropped from 19.63 CU to approximately zero, and average turbidity dropped from 6.33 NTU to 0.26 NTU.

**Upland Slough Head (Harrison Slough).** This slough is located just downstream from the mouth of Caswell Creek. This upland slough was fed by groundwater throughout the reach as indicated by oxidized iron flocculent. It was the only location sampled with ice cover in October, and the site was ice covered to the streambed during the February sampling event (Figure 4). Sampling was conducted near the head of the slough, approximately 1.1 km upstream from the Susitna River confluence. Substrate was 75% cobble and 25% silt. Woody debris could not be accurately counted due to ice cover, but there was one debris dam observed within the sampling reach.
Because the site was completely iced through in March, physical and water chemistry values were only measured in October. Water temperature was 3.78°C with some ice cover averaging 0.01 m in depth. This was the only site with any ice cover during the October sampling events. Oxygen saturation averaged 20.63% within the sampling reach, lower than any other site during any of the sampling periods. Apparent color averaged 17.8 CU and average turbidity was 2.12 NTU.
backwater into the slough (Figure 5). The December sampling event was the only sampling period with substantial ice cover, and depths were greater at this time than during other sampling dates. Substrate was 100% silt.

Water temperature at the Slough 1 sampling site averaged 4.97°C in October, between 1-2°C in November and February, and below 1°C in December and January. Dissolved oxygen remained between 57.13% in December and 73.47% in January. Low saturation values during ice free periods may be an indicator of significant groundwater input throughout the year. This site remained relatively ice free among the sampling periods, with open water in October, November and January. Ice thickness was greatest in December at 0.19 m and was also present in February, averaging 0.05 m within the sampling reach.

Upland Slough 2 (Slough 6a). This site is an upland slough, which was mostly a backwater channel during the October sampling and appeared to be more of a stream mouth during the February sampling event.

Figure 6. Slough 2 sampling site on 10/10/12 (top) and 2/27/13 (bottom). February sampling found that only a small channel remained open, beginning at a tributary mouth near the upstream edge of the sampling reach.

The entire slough was completely iced over in February, except for a small channel through the sampling reach that drained a tributary at the upstream edge of the reach (Figure 6). This site was
100% silt with some emergent vegetation and organic matter with approximately 10 pieces of large woody debris within the 100 m sampling reach.

Water temperature at Upland Slough 2 averaged 5.75°C in October and 0.87°C in February. Oxygen saturation was very similar between sampling periods, at 79.97% in October and 81.73% in February. The site was completely ice free in October and had some ice cover along the channel margins in February, averaging 0.04 m. Apparent color dropped between sampling events from 31.23 CU to approximately zero and turbidity remained low on both sampling dates, at 3.75 NTU in October and 2.27 NTU in February.

Tributary Mouth 1. This sampling site is the mouth of Whiskers Creek, downstream of its confluence with Whiskers Slough. The location is mostly fed by tributary flow, except during high main channel discharges that overtop Whiskers Slough. In October, the sampling reach showed some backwater influence from the main channel Susitna River, and in February the site appeared to be mostly Whiskers Creek flow, with very little surface flow out of Whiskers Slough (Figure 7). The substrate was approximately 50/50 cobble and silt. There were 14 pieces of large woody debris counted.

Water temperature at this site averaged 6.23°C in October and 0.58°C in February. Dissolved oxygen was near saturation during both sampling events, at 96.70% in October and 86.47% in February. The site was ice free in October, and ice thickness in February was negligible, averaging 0.01 m. Apparent color dropped from 48.45 CU in October to negative values in February, and turbidity dropped from 2.91 NTU to approximately zero between sampling events.

Side Slough (Whiskers Slough). This sampling site did not have a headwater connection to a tributary or the Susitna River, except during high mainstem stage heights, so its main water source throughout the sampling period was groundwater flow. The head of the slough is non-vegetated and is overtopped at high flows, resulting in the side slough classification. The channel was very uniform between sampling periods, with only a thin ice layer during the February sampling event (Figure 8). Fish access into the site appeared to be limited during the February sampling period, indicating that rearing fish were probably trapped from a higher flow period, potentially during fall freeze-up. This site was 100% cobble/gravel within the channel, with silt and aquatic vegetation along the channel margins. This site had no large woody debris. Cobble substrate and the lack of woody debris suggest is consistent with annual mainstem flushing of side slough habitats.
Water temperature at the Whiskers Slough site averaged 5.80°C in October and 2.57°C in February. Oxygen saturation was 67.90% during the October sampling event and 40.47% in February, when ice thickness had increased from open water to an average of 0.10 m. Apparent color and turbidity at this site decreased from 16.8 color units and 10.6 NTU in October, to approximately 0 CU and 0 NTU in February.

Tributary Mouth 2 (Wiggle Creek). The Wiggle Creek sampling site is located at the stream mouth, just upstream of its confluence with the Talkeetna River. In October, the sampling site was over bank-full depth with backwater from the Talkeetna River, which dropped and maintained some depth and ice cover throughout the winter sampling events (Figure 9). The site was 100% silt substrate at cross-sections with at least 24 pieces of large woody debris within the sampling reach. Depth and water color make this number likely an underestimate.

Water temperature in October was an average of 5.86°C. In November, water temperature dropped below 1°C and remained below this temperature for subsequent sampling periods. Dissolved oxygen saturation remained relatively constant among sampling periods, averaging between 52.8% in December and 74.8% in October. Oxygen saturation was negatively correlated with ice thickness, which ranged from 0.00 m in October to 0.40 m in December. Apparent color in October was 51.3 color units, and color measurements after October were all around 15 color units, as the dominant water source transitioned from wetland drainage to groundwater upwelling. Turbidity was low during all sampling periods, ranging from 2-3 NTU, October through December, and averaging 8.14 in March.
Figure 9. Wiggle Creek sampling site clockwise from top left on 10/8/12, 11/13/12, 12/13/12, and 3/5/13.
Table 2. Physiochemical characteristics at all sampling locations in late October 2012. Sp. Cond is specific conductivity, DO is dissolved oxygen in percent saturation, D is depth, C is cobble, and SS is sand and silt.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Max Sp Cond (µS/cm)</th>
<th>Min Sp Cond (µS/cm)</th>
<th>Max Temp (C)</th>
<th>Min Temp (C)</th>
<th>Max DO % Sat</th>
<th>Min DO % Sat</th>
<th>Max Turb NTU</th>
<th>Min Turb NTU</th>
<th>Max D (m)</th>
<th>Ave D (m)</th>
<th>Ave V (m/s)</th>
<th>Max Ice Thickness (m)</th>
<th>% C</th>
<th>%SS</th>
<th>LWD</th>
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<tr>
<td>Main channel 1</td>
<td>136.8</td>
<td>85.2</td>
<td>5.6</td>
<td>5.7</td>
<td>102.6</td>
<td>97.00</td>
<td>36.1</td>
<td>34.2</td>
<td>1.10</td>
<td>0.55</td>
<td>0.01</td>
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<td>0</td>
<td>100</td>
<td>26</td>
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<td>1.5</td>
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<td>107.2</td>
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<td>6.5</td>
<td>6.2</td>
<td>72.5</td>
<td>60.3</td>
<td>11.5</td>
<td>10.5</td>
<td>0.79</td>
<td>0.29</td>
<td>0.00</td>
<td>0</td>
<td>40</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Tributary Mouth 1</td>
<td>24.5</td>
<td>23.2</td>
<td>6.5</td>
<td>6.3</td>
<td>97.3</td>
<td>96.7</td>
<td>5.01</td>
<td>0.7</td>
<td>0.90</td>
<td>0.44</td>
<td>0.08</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>14</td>
</tr>
<tr>
<td>Tributary Mouth 2</td>
<td>34.8</td>
<td>32.7</td>
<td>6.0</td>
<td>6.0</td>
<td>79.7</td>
<td>77.6</td>
<td>2.29</td>
<td>1.9</td>
<td>1.78</td>
<td>0.78</td>
<td>0.03</td>
<td>0</td>
<td>40</td>
<td>60</td>
<td>24</td>
</tr>
<tr>
<td>Upland Slough 1</td>
<td>143</td>
<td>126.4</td>
<td>5.1</td>
<td>5.0</td>
<td>68.0</td>
<td>63.7</td>
<td>17.47</td>
<td>7.8</td>
<td>0.95</td>
<td>0.40</td>
<td>0.01</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td>Upland Slough 2</td>
<td>111</td>
<td>53.1</td>
<td>6.1</td>
<td>5.3</td>
<td>86.9</td>
<td>75.0</td>
<td>6.58</td>
<td>1.9</td>
<td>1.10</td>
<td>0.51</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Upland Slough Head</td>
<td>270</td>
<td>267.3</td>
<td>4.0</td>
<td>3.5</td>
<td>35.3</td>
<td>28.5</td>
<td>2.96</td>
<td>2.1</td>
<td>0.82</td>
<td>0.40</td>
<td>0.00</td>
<td>0</td>
<td>80</td>
<td>20</td>
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</tr>
</tbody>
</table>

Table 3. Physiochemical characteristics at all sampling locations in February/March 2013. Sp. Cond is specific conductivity, DO is dissolved oxygen in percent saturation, D is depth, C is cobble, and SS is sand and silt.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>pH</th>
<th>Max Sp Cond (µS/cm)</th>
<th>Min Sp Cond (µS/cm)</th>
<th>Max Temp (C)</th>
<th>Min Temp (C)</th>
<th>Max DO % Sat</th>
<th>Min DO % Sat</th>
<th>Max Turb NTU</th>
<th>Min Turb NTU</th>
<th>Max D (m)</th>
<th>Ave D (m)</th>
<th>Ave V (m/s)</th>
<th>Max Ice Thickness (m)</th>
<th>% C</th>
<th>%SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main channel 1</td>
<td>7.36</td>
<td>109.0</td>
<td>101.0</td>
<td>1.1</td>
<td>0.0</td>
<td>97.5</td>
<td>78.9</td>
<td>1.48</td>
<td>0.41</td>
<td>0.83</td>
<td>0.78</td>
<td>0.020</td>
<td>0.04</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Main channel 2</td>
<td>7.38</td>
<td>92.7</td>
<td>16.9</td>
<td>1.0</td>
<td>0.0</td>
<td>81.4</td>
<td>75.5</td>
<td>0.64</td>
<td>0.12</td>
<td>1.09</td>
<td>0.5</td>
<td>0.073</td>
<td>0.01</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Side Slough</td>
<td>6.84</td>
<td>75.7</td>
<td>49.9</td>
<td>3.4</td>
<td>1.9</td>
<td>50.6</td>
<td>27.9</td>
<td>0.32</td>
<td>0</td>
<td>1.55</td>
<td>0.46</td>
<td>0.004</td>
<td>0.18</td>
<td>90</td>
<td>10</td>
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<td>Tributary Mouth 1</td>
<td>6.87</td>
<td>113.0</td>
<td>13.6</td>
<td>0.9</td>
<td>0.1</td>
<td>94.7</td>
<td>78.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.95</td>
<td>0.46</td>
<td>0.025</td>
<td>0.02</td>
<td>40</td>
</tr>
<tr>
<td>Tributary Mouth 2</td>
<td>6.75</td>
<td>71.4</td>
<td>46.9</td>
<td>0.9</td>
<td>0.1</td>
<td>75.5</td>
<td>58.9</td>
<td>12.9</td>
<td>2.75</td>
<td>0.85</td>
<td>0.47</td>
<td>0.006</td>
<td>0.06</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Upland Slough 1</td>
<td>7.29</td>
<td>136.4</td>
<td>43.2</td>
<td>2.4</td>
<td>1.0</td>
<td>65.1</td>
<td>62.5</td>
<td>3.41</td>
<td>1.3</td>
<td>0.38</td>
<td>0.24</td>
<td>0.020</td>
<td>0.02</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Upland Slough 2</td>
<td>6.67</td>
<td>39.3</td>
<td>32.0</td>
<td>1.1</td>
<td>0.7</td>
<td>87.2</td>
<td>77</td>
<td>5.58</td>
<td>0</td>
<td>0.39</td>
<td>0.29</td>
<td>0.088</td>
<td>0.1</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Upland Slough Head</td>
<td>Ice to Substrate</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Evaluation of Sampling Methods

Beach Seines
Beach seines were only used to capture fish during October sampling events as ice cover prevented their use in subsequent months. A total of three seine hauls were conducted at each site in October, with a maximum of four total fish captured at each sampling site (sum of all three seine hauls). This method captured small numbers of coho, Chinook, and sockeye salmon, as well as threespine stickleback, slimy sculpin, and longnose suckers. Some of these species are not attracted to bait and are thus not often captured by minnow traps, making this a potentially useful method to supplement minnow trapping results. The number of juvenile salmon captured with beach seines was much lower than those captured using minnow traps. The presence of large woody debris and cobble substrate at some sites prevented consistent application of this method at all sampling locations.

Soak Times
Minnow trapping was successful at capturing juvenile salmonids throughout the winter months, with similar capture rates at 24 and 48 hours (2.6 and 2.5 CPUT, respectively). This is in contrast to previous studies documenting depressed feeding activity during winter months that required extended trapping periods for adequate capture rates (ADFG 1981, 1983).

Video Surveys
Underwater high resolution videography enabled us to identify schooling behavior and presence/absence of salmonids during both daytime and nighttime. This was an unexpected result as activity was expected to be greatest at night. Ice cover may have resulted in an increase in the level of daytime activity (Hiscock et al. 2002; Linnansaari et al. 2008). Conditions were generally very clear, and we were able to capture a relatively large viewing area. In most cases, however, we were unable to distinguish between coho and Chinook salmon captured by the video (Figure 10) and abundance estimates were unreliable with this method due to the likelihood of resampling the same individuals. No other fish species were captured with this method. Additionally, capture success with one hour of video was not related to capture success with minnow traps. The sites with the greatest capture success using videography were among the lowest in capture success with minnow traps and vice versa (Figure 11). We additionally used variable recording lengths to determine the minimum length of time required to observe a reliable proportion of fish. With only 20.9 minutes of recording at Wiggle Creek, spread across four locations, we did not capture any fish, even though we captured 118 salmonids with minnow traps the day before. With an average of 60 minutes at all other sites, spread across a maximum of three locations, videos were able to capture at least some fish at all other locations. With these limitations, we could not determine a recording time that would provide comparable data to minnow trapping results; however, 20 minutes per site was clearly insufficient.
October and February Fish Distribution and Habitat Associations
A total of 556 fish of five different species were captured in minnow traps among the eight sampling sites in October. Juvenile Chinook and coho salmon dominated the catch (Table 2) making up 92% of the fish captured. Chinook salmon juveniles were present in samples from all habitat types except for the site located at the upstream end of an upland slough (Upland Slough Head); where stickleback were the only species captured. Coho salmon juveniles were captured at all other sampling locations except for one mainstem location. Approximately 43% of
Chinook salmon and 49% of coho salmon in October were captured in the two tributary mouths (Table 4). Chinook salmon juveniles tended to be more abundant than coho salmon in main channel habitats and coho more abundant in upland slough habitats in October. For example, 43% of Chinook salmon and 13% of coho salmon were captured in mainstem and side slough habitats. Whereas, 38% of coho salmon were captured in upland slough habitats. Sockeye salmon were captured in upland slough and tributary mouth habitats and burbot (*Lota lota*) in main channel and side slough habitats.

Average October Chinook and coho salmon CPUT differed between sites of the same habitat classification and among sites of different habitat classification (p < 0.001, Figure 12). Juvenile Chinook salmon CPUT was significantly higher in Tributary Mouth 2 than all other locations except the Main Channel 1 sampling location, where abundance was greater than Upland Sough Head and Upland Slough 1. Coho salmon CPUT in October also was significantly higher in Tributary Mouth 2 that all other sites except Upland Slough 2. Coho CPUT in Upland Slough 2 was significantly higher than Upland Slough 1, Main Channel 2, and Upland Slough Head.

Chinook and coho salmon relative abundance in October were positively correlated with maximum and average water depths ($R^2 0.73$, $p < 0.001$; and $R^2 0.60$, $p < 0.05$). There were no other significant correlations between habitat variables measured and Chinook and coho salmon relative abundance. Stickleback were the only fish species captured at the upstream end of the upland slough (Upland Slough Head). The absence of salmonids could be due to the low amount of dissolved oxygen, which was less than 35% saturation or 4.5 mg/L. The relative abundance of burbot was positively correlated with turbidity.

Indicators of fish growth (average fork length and biomass) by habitat and sampling site are provided in Table 5. Only one age class of Chinook salmon juveniles were present based upon size frequency distributions. In October, average Chinook salmon fork length ranged from 62.5 to 64.8 mm. At the Main channel 1 site Chinook salmon fork lengths ranged from 48 to 80 mm. Similarly in Tributary Mouth 2, Chinook salmon fork lengths ranged from 49 to 86 mm. Average coho salmon fork lengths ranged from 69.6 to 109 mm. At least 2 age classes of coho salmon were present at most sites. At the Upland Slough 2 site, 91% of the coho captured appeared to be age-0 with fork lengths ranging from 46 to 76 mm, with the remaining fork lengths ranging from 94 to 140 mm. Similarly in Tributary 2, 98% of the coho salmon fork lengths ranged from 46 to 88 mm in October. Three coho salmon were captured at the Main channel 1 site all of which were > 100 mm in fork length.

Chinook salmon fork lengths were negatively correlated with specific conductivity in October ($R = -0.84$) and positively correlated with dissolved oxygen ($R = 0.83$). Chinook salmon biomass was positively correlated with and water depth ($R = 0.86$). Coho salmon biomass also was correlated with maximum water depth and fork lengths correlated with maximum October water temperatures ($R = 0.71$).

A total of 152 fish were captured during late February/early March sampling representing 5 different species. February minnow trapping catch was dominated by Chinook and coho salmon (Figure 13). Most Chinook salmon were captured in mainstem (47%) and side slough (41%) habitats. Coho salmon were captured in side slough (70%) and upland slough (25%) habitats. The relative abundance of Chinook salmon were positively correlated with maximum water depth ($R = 0.71$) and cobble substrate ($R = 0.68$). Coho salmon relative abundance was
correlated with maximum water temperature ($R = 0.80$) and ice depth ($R = 0.91$). Water temperature and ice depth also were positively correlated with coho salmon fork lengths and coho biomass. Chinook salmon biomass was correlated with water depth ($R = 0.65$) but not water temperature ($R = 0.39$).

When comparing the change in fork lengths and biomass between October and February, we found a positive correlation between the Chinook salmon fork length changes and specific conductivity and pH. The change in coho salmon fork lengths between sampling dates was not strongly correlated with any of the variables but was negatively related to pH ($R = -0.69$). There was a strong positive correlation; however, between the change in coho biomass between sampling events and maximum water temperature ($R = 0.91$).

Table 4. Total number of fish captured in minnow traps by species during October sampling.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Chinook salmon</th>
<th>coho salmon</th>
<th>sockeye salmon</th>
<th>stickleback-unspecified</th>
<th>slimy sculpin</th>
<th>burbot</th>
<th>Total Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main channel 1</td>
<td>72</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Main channel 2</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Upland Slough Head</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Upland Slough 1</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>3</td>
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<td>Upland Slough 2</td>
<td>35</td>
<td>78</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Tributary Mouth 1</td>
<td>5</td>
<td>18</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Tributary Mouth 2</td>
<td>120</td>
<td>91</td>
<td>2</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Side Slough</td>
<td>48</td>
<td>26</td>
<td>0</td>
<td>5</td>
<td>9</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Total Captured</td>
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<td>223</td>
<td>3</td>
<td>21</td>
<td>14</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 5. Total number of fish in minnow traps during February/March for each sampling site.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Chinook salmon</th>
<th>coho salmon</th>
<th>sockeye salmon</th>
<th>stickleback-unspecified</th>
<th>slimy sculpin</th>
<th>Whitefish-unid</th>
<th>Total Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main channel 1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Main channel 2</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Upland Slough Head</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>11</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Upland Slough 2</td>
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<td>16</td>
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<td>0</td>
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<td>2</td>
</tr>
<tr>
<td>Tributary Mouth 1</td>
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<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Tributary Mouth 2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Side Slough</td>
<td>13</td>
<td>75</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Total Captured</td>
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<td>108</td>
<td>0</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 12. Average Chinook and coho salmon catch per unit trap (CPUT) for the sampling sites in October showing differences among sites and between sites with similar classification. Error bars are standard deviation.

Figure 13. Average Chinook and coho salmon catch per unit trap (CPUT) for the sampling sites in October showing differences among sites. Error bars are standard deviation.
Table 6. Indicators of fish growth as average FL and biomass (sum of estimated weight) for each sampling site in October (Oct) and February/March (Feb/Mar) showing the differences in average length and biomass (sum of total catch estimated weight) between sampling events.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Average Chinook FL (mm)</th>
<th>Chinook Biomass (g)</th>
<th>Average Coho FL (mm)</th>
<th>Coho Biomass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oct</td>
<td>Feb/Mar</td>
<td>Oct</td>
<td>Feb/Mar</td>
</tr>
<tr>
<td>Main channel 1</td>
<td>64.6</td>
<td>72.0</td>
<td>205.0</td>
<td>3.7</td>
</tr>
<tr>
<td>Main channel 2</td>
<td>63.5</td>
<td>73.5</td>
<td>21.4</td>
<td>56.7</td>
</tr>
<tr>
<td>Upland Slough 1</td>
<td>63.0</td>
<td>68.5</td>
<td>7.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Upland Slough 2</td>
<td>62.5</td>
<td>61.0</td>
<td>87.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Tributary Mouth 1</td>
<td>64.8</td>
<td>0.0</td>
<td>14.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Tributary Mouth 2*</td>
<td>64.5</td>
<td>66.0</td>
<td>337.8</td>
<td>0.3</td>
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<tr>
<td>Side Slough</td>
<td>62.7</td>
<td>66.3</td>
<td>125.0</td>
<td>41.2</td>
</tr>
</tbody>
</table>

**Intensive Sampling Sites**

The relative numbers and fork lengths of juvenile salmon increased at Tributary Mouth 2, remained stable at Upland Slough 1, and decreased at Main channel 1. The rapid change in fork lengths at Tributary Mouth 2 was followed by a large reduction in larger fish between late December and early March suggesting downstream movement between these two sampling periods.

Within the backwater mouth of Tributary 2, average Chinook salmon catch per trap declined significantly from over 10 in October, < 3.6 in December, and to 0.1 fish per trap by March (Figure 14). Chinook salmon fork lengths increased slightly from October to December at a rate of 0.10 mm/d over the 65 days. The change in fish size did not offset changes in relative abundance resulting in a loss of total Chinook salmon biomass.

Coho salmon relative abundance in Tributary 2 did not change significantly from October through December, but decreased from ~20 fish per trap in January to less than 1 fish per trap in March. Average coho salmon fork lengths increased from 65 to 90 mm from October to December at a rate of 0.38 mm/d. In October 98% of the coho salmon were between 48 and 88 mm in fork length, but by December the percent of fish in this size range decreased to 43% (Figure 15) with most fish larger than this size range. The change in coho salmon relative abundance and length resulted in an increase in biomass of 8.4 g/d.
The relative abundance of Chinook and coho salmon in Upland Slough 1 did not change significantly among sampling dates (Figure 15). Average Chinook salmon fork lengths tended to increase but the change over time was not statistically significant. There was a loss of Chinook salmon biomass through the winter in Upland Slough 2. Coho salmon average fork lengths increased at a rate of 0.1 mm/d and biomass at a rate of 0.48 g/d. Similarly, total biomass (Chinook and coho combined) increased from 79 g in October to 115 g in February.

At the Main channel 1 sampling site, the relative abundance of Chinook salmon decreased from 7 to 2 CPUT between October and November. Chinook CPUT did not change significantly through the remainder of the winter. There was no difference in coho salmon CPUT among the 4 months sampled. Average coho salmon fork lengths were >100 mm in October characteristic of age 2+ fish; however, by November and through the remainder of the sampling events, fork lengths of coho salmon ranged from 60 to 72 mm suggesting predominately age 1+ fish. Coho biomass and total biomass decreased significantly throughout the winter at the Main channel 1 site.
Figure 15. CPUT, average fork length, and total estimated biomass for all sampling dates at Upland Slough 1 (left) and Main channel 1 (right).

**Discussion**

Juvenile coho salmon tended to be more abundant in upland and side slough habitats and Chinook salmon in side slough and main channel habitats. However, these observations were based on a maximum of 2 macrohabitat replicates. Both Chinook and coho salmon were present at all macrohabitats with the exception of the Upland Slough Head. This was the only off-channel habitat that was not sampled near it's confluence with the mainstem channel. High specific conductivity and low dissolved oxygen separated this location from other sampling sites, and while not tested low dissolved oxygen likely limited use of this habitat during October and complete freezing prevented use during February.

There were large differences in Chinook and coho salmon relative abundance between habitats with the same classification. While the causal factors could not be tested, comparisons could lead to hypotheses that explain differences in abundance among similar macrohabitats. The relative
abundance of juvenile salmon was greater in Upland Slough 2 than Upland Slough 1 in October but not in February. Specific conductivity and turbidity were higher and dissolved oxygen lower in Upland Slough 1 compared to Upland Slough 2. Upland Slough 2 also had a tributary surface water source. There were little differences in the other physical habitat characteristics measured with the except for average water velocity which was similar and near 0 at both sites in October due to mainstem backwater, but was higher in Upland Slough 2 when mainstem water levels dropped in February.

There was significant greater juvenile salmon relative abundance in Tributary Mouth 2 than in Tributary Mouth 1 in October. Both tributaries discharged to the mainstem through backwater sloughs with very low water velocities. The sites did not differ in water chemistry/physical characteristics but Tributary Mouth 2 had much greater water depths and twice the number of large woody debris pieces.

There were no differences in juvenile salmon relative abundance among these tributary mouths in February/March; however, this was likely due to early emigration from Tributary Mouth 2 prior to sampling. Early emigration also could explain why there were differences in coho relative abundance between the two upland slough sites in October but not in February; however, we did not sample Upland Sough 2 in December or January and do not know if there was apparent growth or when relative abundance dropped.

Based on comparisons between similar classified habitats, dissolved oxygen, specific conductivity, turbidity, water depth, water velocity, and woody debris could be influencing the distribution and relative abundance of juvenile salmon within macrohabitats of the same classification. Whereas, correlation analyses among all macrohabitats identified water depth, water temperature, ice depth, dissolved oxygen, and percent cobble to be related to juvenile salmon abundance and growth metrics among all sampling locations.

The characteristics important for explaining differences in juvenile salmon abundance among winter habitats is consistent with other studies. Cobble substrate and woody debris have previously been shown to be important components of juvenile salmon winter habitat. Fine sediment has been hypothesized to directly lead to emigration from a habitat through reduction in cover availability, and the addition of cobble within streams with large amounts of fine sediment can lead to increased Chinook salmon densities (Bjorn 1971, Hillman et al. 1987). The abundance of woody debris has been found to be an important component of coho salmon winter habitat in Southeast Alaska and Canadian streams (Brown and McMahon 1988). The preference of coho salmon for deep, slow velocity off-channel habitats is consistent with other studies. For example, Swales et al. (1986) found coho to be most abundant in deep side channel pools with cover, including ice cover.

Water depth may also be an important indicator of suitable habitat by providing adequate space for survival under ice and cover from predation. Bustard and Narver (1975) studied juvenile coho and steelhead trout in a small tributary of Carnation Creek, British Columbia. They found that depth preference depends on temperature, as coho move into deeper water when temperatures dropped in the early fall. At low water temperatures the majority of fish (78-87%) were found in velocities less than 15 cm/s. Cooler water temperatures also made fish seek cover more readily with upturned trees roots and logs being the most common cover type. Coho salmon were more active in cold temperature than steelhead, feeding in temperatures as low as
2.5°C. It was found that survival within this small tributary was higher than that of the greater Carnation Creek, presumably due to the woody debris that provides cover from predators and protection against displacement. They observed the “hiding behavior” initiated by cooler water temperatures as documented in other studies.

The indicators of salmon growth also suggested differences in quality of habitat among sites and between similarly classified habitats. A positive change in Chinook salmon fork lengths was measured in both main channel sampling locations and the side slough between October and February; however, biomass increased only in the side slough sampling location. Changes in average fork length could indicate either growth, loss of smaller fish or a gain in larger fish due to migration or mortality. Decreases in abundance could be associated with winter mortality, and smaller juveniles would be most susceptible to starvation or predation, not the largest individuals (Quinn and Peterson 1996). There was a reduction in CPUT at Main channel 1 between these sampling dates, but CPUT did not vary significantly between October and February at Main channel 2. Previous studies also have documented high winter site fidelity within Susitna River tributary mouths and sloughs (ADFG 1986). Juvenile salmon may be more likely to show fidelity to a site if it has high growth potential throughout the winter (Bell 2001).

Water velocity, turbidity, and specific conductivity were the primary measured characteristics that differed between these two mainstem locations. While not apparent based on field measurements, Main channel 2 was at the bottom end of an abandoned channel resulting in a groundwater supplied flowing channel throughout the winter similar to side slough habitat. Whereas groundwater discharge along the channel margin was the only source of open water flowing water habitat at Main channel 1. Total available habitat that changed due to ice development may also explain differences in the change in Chinook salmon fork lengths and growth rates between these two habitats.

There was a small increase in Chinook salmon average fork lengths and a decrease in biomass due to fewer fish between sampling dates at the side slough sampling site; however, there were large increases in coho salmon fork lengths and biomass. There did not appear to be an open water connection to the mainstem at either the upper or lower end of this side slough sampling site, limiting possible migration effects on changes to growth indicators. This site had lower velocities, with abundant cobble substrate and warmer water temperatures than the mainstem sites; however, dissolved oxygen during the February sampling event was low ranging from 30 to 50% saturation. These differences suggest that coho salmon were able to grow under conditions of warmer temperatures and low dissolved oxygen, whereas, Chinook salmon numbers and growth declined under similar conditions.

The changes in relative abundance, fork lengths, and biomass over time at the Tributary Mouth 2 sampling location provides evidence of winter growth and emigration to mainstem habitats under the ice. Factors contributing to growth at this location could be used to identify important winter habitat characteristics. However, none of the variables measured could be used to explain the apparently rapid growth at this location. The majority of fish captured at this site in November and December were large age-1 or age-2 juveniles, but none were present in March, suggesting outmigration under ice between these two sampling events, which may be linked to the rapid growth rates. ADFG (1986) also reported moderate Chinook and coho salmon growth in the tributary mouth of Indian River.
The big difference in relative abundance of juvenile salmon between the December and February/March sampling events at Tributary Mouth 2 also shows that we should be cautious when using the relative abundance of target species under conditions of a range of physical, chemical, or biological characteristics to determine important habitat variables. This is particularly true, when sampling is conducted over short temporal or spatial scales.

Salmonids may move to rearing areas with more cover if groundwater prevents anchor ice formation, or they may be forced into areas devoid of cover if frazil ice and anchor ice makes habitats unsuitable (Brown et al. 1994; Bjornn 1971). We expected juvenile salmon to be relatively sedentary in water temperatures below 1.0°C because previous studies have documented “hiding behavior” initiated by cooler water temperatures (Bustard and Narver 1975). However, fish captured in this study with minnow traps and video recordings were active and were attracted to bait at these temperatures.

Although mid-winter may provide the least amount of wetted usable area, it offers a relatively stable environment for rearing salmon as compared to freeze-up and break-up conditions that may have high associated mortality (Linnensaari and Cunjak 2010). Habitat stability and protection from high water velocities may also drive winter habitat preferences among juvenile salmonids and the abundance of these habitats can limit salmon production (Nickleson et al. 1992).

In early winter, both Chinook and coho salmon were more abundant at sites with greater water depths. Larger Chinook salmon were associated with sites that had high levels of dissolved oxygen, and larger coho salmon were found at sites with higher water temperatures. In mid to late winter, Chinook salmon relative abundance and growth were associated with water depth and high dissolved oxygen concentrations. Water depth and temperature remained the most important habitat characteristics for rearing coho salmon. This suggests that coho salmon were able to take advantage of warmer sites, presumably due to groundwater discharge, even under conditions of relatively low dissolved oxygen. These conditions were most often present in side slough and upland slough habitats. Whereas, Chinook salmon favored deeper main channel sites that remained saturated with oxygen throughout the winter, perhaps excluding them from warmer waters. These conditions were most often associated with main channel and side slough habitats. Chinook and coho salmon were abundant and appeared to grow through the winter at the tributary mouth of a wetland stream with deep saturated waters near the mainstem confluence and lower dissolved oxygen concentration with increasing distance from the mainstem confluence.
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