Juvenile Salmon Winter Habitat Characteristics in Large Glacial Rivers

Final Report for the National Marine Fisheries Service

by

Jeffrey C. Davis, Gay A Davis, Leslie Jensen, and Eric Rothwell, National Marine Fisheries Service
P.O. Box 923 Talkeetna, AK 99676
arri@arrialaska.org

January 2015
Acknowledgements. This project was completed with funding provided by the National Marine Fisheries Service, Contract No. WE-133F-SE-2007. Additional field support was provided by Kiersten Wilber and Susan Walker (NMFS). We appreciate comments on the draft report provided by Susan Walker.
Abstract
Information is limited on the overwintering habitats used by juvenile coho and Chinook salmon, particularly within large glacial rivers. This report describes the second year of studies conducted to investigate juvenile salmon overwintering habitat in the Susitna and Talkeetna Rivers. During the winter of 2013/2014, sampling was conducted in nine locations representing three replicate tributary mouths, side sloughs, and upland sloughs, in January and February and one of each habitat type in March. Juvenile salmon were captured using 10 baited minnow traps fished for 20-24 hours within ~100 m sampling sites. Measures of water temperature, dissolved oxygen, conductivity, pH, water depth, ice thickness, water velocity, and woody debris were collected at each trap location. We tested for relationships between habitat characteristics at each trap site and number of juvenile salmon in each trap (CPUT). We then looked to see if these same relationships could be used to predict coho salmon relative abundance at larger spatial scales: sites and macrohabitat classification types. Juvenile coho salmon were the dominant species captured. Juvenile coho salmon CPUT was correlated with site measures of woody debris, water velocity, and dissolved oxygen; however, these local characteristics were not good predictors of average site or macrohabitat CPUT. Mainstem ice development had a large influence on water velocities within sampling locations, and we hypothesize that short term increases in water velocity during mainstem ice development may have precluded juvenile salmon use of side sloughs as overwintering habitat or caused emigration from previously suitable habitat even though habitat characteristics were favorable.

Introduction
Little is known about winter distribution and habitat preferences of juvenile salmon 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 (Nickleson 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 coho 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).

Studies have shown that Chinook and coho salmon have different, although partially overlapping, winter habitat preferences. 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 was associated with increased
overwinter abundance (Hillman et al. 1987) in the Lemhi River, 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 < 15 cm/s when water temperatures were below 8°C while Hillman et al. (1987) found Chinook salmon in water velocities < 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. Side channels fed by groundwater provided overwintering coho habitat in British Columbia streams (Giannico and Hinch 2003). Groundwater-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 juvenile coho salmon have been found to move long 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).

Sites with more abundant cover and deeper waters provide fish with 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).

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.

Physical habitats in glacial rivers have been classified based on differences in water sources and their connectivity to the mainstem channel and fall into five main macrohabitat categories: main channel (MC), side channel (SC), side slough (SS), upland slough (US), and tributary mouth (TM) (Murphy et al. 1989, ADFG 1984b). Side channels, side sloughs, and upland sloughs are off channel habitats and represent a geomorphic or habitat continuum based on the degree of upstream connection to the main channel. Under most flows side channels maintain an open water upstream connection to the mainstem. Side sloughs are periodically dewatered at the upstream end but are inundated often enough
to prevent colonization by upland plants at the upstream connection. The upstream end of upland sloughs are separated from the mainstem by a vegetated berm that is only overtopped during extreme high flow events. Over time as the mainstem migrates or changes elevation side channels can evolve into side sloughs and eventually into upland sloughs. The flow source and vegetation result in differences in the chemical, physical, and hydraulic characteristics of water in these habitat types.

Tributaries, tributary mouths, side channels and sloughs likely provide most overwintering habitat for juvenile salmon in large glacial rivers (Murphy et al. 1989; ADFG 1984). 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 (ADFG&G 1984b) and some coho may also use the mainstem and side channels for overwintering (ADFG&G 1981b). Similarly, some age 1 sockeye have been found in Susitna River sloughs, which suggests overwintering in these locations (ADFG 1984). 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.

Initial sampling was conducted on mainstem and off-channel habitats of the glacial Susitna River during the winter of 2013 and 2014 (Davis et al. 2013). Juvenile Chinook salmon were more often found in well oxygenated side channel, side slough, and tributary habitats, while coho salmon were more abundant in tributary mouth and upland slough habitats with deeper and warmer water. However, site physical and hydraulic habitat characteristics appeared to be more important at describing overwintering habitats than classification type. Differences in the abundance of woody debris also could explain some of the differences in juvenile salmon abundance between habitats of similar classification. However, these initial results were based on low number of replicate habitat classes sampled (n = 2 in most cases).

Current habitat assessment methods use physical (hydraulic) models to demonstrate incremental changes in habitat characteristics (depth and velocity) to evaluate potential effects to habitats (Bovee 1992). These assessments generally focus on the open water period and do not account for ice and winter conditions (Alfredsen and Tesaker 2002). This may result in erroneous results as winter conditions are commonly believed to limit smolt production, and short periods of adverse conditions may be the limiting factor for fish (Alfredsen and Tesaker 2002).

The objectives of this study were to test for relationships between habitat characteristics and overwintering juvenile coho and Chinook salmon distribution and relative abundance. More specifically, we wanted to see if there were significant small-scale localized (m2) correlations between fish and habitat characteristics and, if so, could those relationships be used characterize overwintering habitat at higher spatial scales: sampling reaches (~1,000 m2) and macrohabitat classes.

Methods
Sampling Locations and Dates
The study was conducted at sampling sites located on the Susitna and Talkeetna Rivers, located near the village of Talkeetna, approximately 100 miles north of Anchorage. 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. Sites were located near the confluence of the Susitna and Talkeetna Rivers. Sampling sites were selected to provide three replicate tributary mouths (TM), side sloughs (SS), and upland sloughs (US)(Table 1). Sampling was conducted at all locations between December 30, 2013 and January 8 2014 and during the first 10 days of February 2014. The Rabideux Creek site was not sampled in February due to inadequate water depths under the ice for trap placement. Three sites representing one of each habitat type also were sampled during the first week of March 2014.

Physical, Chemical, and Hydraulic Characteristics
Stream water physical and hydraulic characteristics were measured at each trap location. We measured stream water depth and ice thickness. Water velocity was measured at 0.6 x depth using a Flow Tracker (YSI Inc.). Stream water pH and temperature were measured at mid-water depth with a YSI 63 meter and probe. This same meter was used to measure conductivity, which could not correct for water temperatures that were generally between 0° and 2°C. Dissolved oxygen concentration and percent saturation was measured with a YSI 550A meter and probe. Water samples were collected at each site and returned to the laboratory where they were tested for turbidity and apparent color. We documented the presence of large woody debris (> 10 cm in diameter and 1 m length) if adjacent to trap and could provide cover or influence water velocities at the trap location. Substrate size distribution was qualified as silt/sand, gravel, or cobble based on visual observations. We used an underwater camera (SeaViewer) to look for woody debris and substrate when visibility was limited by ice or water depth.

Table 1. Latitude and longitude of sites sampled in the winter of 2014 by classification type.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Classification Type</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapper Slough</td>
<td>Side Slough</td>
<td>62.30196</td>
<td>-150.14478</td>
</tr>
<tr>
<td>Whiskey Slough</td>
<td>Side Slough</td>
<td>62.34978</td>
<td>-150.01367</td>
</tr>
<tr>
<td>Powerline Slough</td>
<td>Side Slough</td>
<td>62.36388</td>
<td>-149.96732</td>
</tr>
<tr>
<td>Rabideux Creek</td>
<td>Tributary Mouth</td>
<td>62.16810</td>
<td>-150.18810</td>
</tr>
<tr>
<td>Whiskey Creek</td>
<td>Tributary Mouth</td>
<td>62.34702</td>
<td>-150.01273</td>
</tr>
<tr>
<td>Wiggle Creek</td>
<td>Tributary Mouth</td>
<td>62.34622</td>
<td>-150.10939</td>
</tr>
<tr>
<td>Leo’s Slough</td>
<td>Upland Slough</td>
<td>62.35393</td>
<td>-150.13562</td>
</tr>
<tr>
<td>Iron Slough</td>
<td>Upland Slough</td>
<td>62.33425</td>
<td>-150.13212</td>
</tr>
<tr>
<td>Wiggle Slough</td>
<td>Upland Slough</td>
<td>62.34914</td>
<td>-150.09970</td>
</tr>
</tbody>
</table>

Fish Collection Methods
Fish were sampled using baited minnow traps at each sampling location and on each sampling date. Ten traps were distributed at approximately 10 m intervals along the lateral channel margins. When ice was present, an ice auger was used cut a 10 inch diameter hole through the ice and traps (6.4 mm (1/4 inch) mesh Gee minnow traps). The traps were baited with salmon roe inside of perforated Whirl-pak bags, and were secured in the flowing water under the ice. A wetted depth of approximately 23 cm (9 inch) between the bottom of the ice and stream bed was necessary for trap placement. The ice opening was covered with Styrofoam insulation to aid in the recovery of the traps. Where ice was absent, traps were placed in adequate water depths to ensure the trap openings were below the water surface.
The following day, 20 to 24 hours following traps placement, traps were removed from the ice and all fish from each trap were released into separate buckets of water. Fish from each trap were identified to species and the fork length (FL) of all salmonids were measured, to provide catch per unit trap (CPUT) with 10 traps per site.

Data Analyses
We used correlation and linear regression to test for relationships between fish catch per trap and habitat variables for each trap location (microhabitats) and site habitat variables. Analyses were conducted for coho salmon juveniles at sites where juvenile coho were present only due to the small numbers of Chinook salmon captured at these sites. We used t-tests to test for significant differences in fish catch in traps where LWD was present compared to traps where LWD was absent. Two-way ANOVA was used to test for differences in coho CPUT among sites and among habitat classes and for differences in habitat characteristics among habitat classes for January and February samples. Tukey’s test were used for pair-wise tests of CPUT between sites and habitat classes, for differences in habitat characteristics. Alpha 0.05 was used for all analyses to reject the null hypotheses that no relationships or differences among sampled variables existed.

Results
Physical and Water Quality Characteristics
Average water quality characteristics for each sampling site, date, and habitat classification type are shown in Table 2. Stream water pH was between ~ 6.5 and 7.8 with the lowest values occurring in Wiggle Creek (TM). Conductivity was lower in tributaries and ranged from 20 µS in Wiggle Creek to over 150 µS in side sloughs. Average water temperatures were below 1°C at most sites with the highest average site values in Powerline Slough (SS). Dissolved oxygen ranged from ~ 50 to 100% saturation, which at these temperatures was at a concentration that ranged from 7 to 14 mg/L. Turbidity was low (< 5 NTU) at most sites, except for Iron Slough (US) where turbidity was near 10 NTU. Apparent color varied among sites from near 0 to 20 CU.

Average water pH, temperature, dissolved oxygen, and conductivity were significantly different among macrohabitats (Figures 1 through 4). Average pH in side sloughs (7.58) was higher than tributary mouths (7.18) or upland sloughs (7.15) which were not significantly different from each other. Average water temperatures in January and February were higher in side sloughs (1.09°C) than in upland sloughs (0.59°C) and tributary mouths (0.14°C) and differences in average water temperatures in upland sloughs and tributaries were statistically significant. Average dissolved oxygen saturation was higher in tributary mouths (80.9%) than in upland sloughs (68.5%) and side sloughs (67.8%), where average saturation values were not different. Dissolved oxygen saturation could vary up to 10% within upland slough sites. Average January and February conductivity was significantly higher in side sloughs (102.5 µS) than in upland sloughs (76.8 µS) and tributary mouths (27.8 µS). Differences in conductivity between upland sloughs and tributary mouths were also significant.
Table 2. Average water quality characteristics for sampling sites by sampling event and classification type.

<table>
<thead>
<tr>
<th>Month</th>
<th>Site Name</th>
<th>Classification Type</th>
<th>pH</th>
<th>Conductivity (µS)</th>
<th>Temp (C)</th>
<th>DO (%)</th>
<th>DO (mg/L)</th>
<th>Turbidity (NTU)</th>
<th>Apparent color (cu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec/Jan</td>
<td>Powerline Slough</td>
<td>Side Slough</td>
<td>7.36</td>
<td>120.48</td>
<td>1.42</td>
<td>78.76</td>
<td>11.05</td>
<td>0.40</td>
<td>2.5</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Trapper Slough</td>
<td>Side Slough</td>
<td>7.99</td>
<td>42.03</td>
<td>0.24</td>
<td>64.17</td>
<td>9.10</td>
<td>0.94</td>
<td>1.8</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Whiskey Slough</td>
<td>Side Slough</td>
<td>7.44</td>
<td>104.45</td>
<td>1.84</td>
<td>72.79</td>
<td>10.11</td>
<td>1.09</td>
<td>0.0</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Rabideux Creek</td>
<td>Tributary Mouth</td>
<td>7.40</td>
<td>42.66</td>
<td>0.03</td>
<td>79.71</td>
<td>11.61</td>
<td>3.84</td>
<td>29.5</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Wiggle Creek</td>
<td>Tributary Mouth</td>
<td>6.80</td>
<td>19.21</td>
<td>0.12</td>
<td>68.41</td>
<td>10.13</td>
<td>2.42</td>
<td>0.0</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Whiskey Creek</td>
<td>Tributary Mouth</td>
<td>7.53</td>
<td>21.49</td>
<td>0.23</td>
<td>91.90</td>
<td>13.31</td>
<td>1.49</td>
<td>13.5</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Iron Slough</td>
<td>Upland Slough</td>
<td>6.94</td>
<td>87.74</td>
<td>0.45</td>
<td>53.12</td>
<td>7.64</td>
<td>8.69</td>
<td>23.7</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Leo’s Slough</td>
<td>Upland Slough</td>
<td>7.16</td>
<td>81.93</td>
<td>0.89</td>
<td>68.37</td>
<td>9.74</td>
<td>0.37</td>
<td>0.0</td>
</tr>
<tr>
<td>Dec/Jan</td>
<td>Wiggle Slough</td>
<td>Upland Slough</td>
<td>7.19</td>
<td>47.10</td>
<td>0.45</td>
<td>72.64</td>
<td>10.42</td>
<td>1.30</td>
<td>7.4</td>
</tr>
<tr>
<td>Feb</td>
<td>Powerline Slough</td>
<td>Side Slough</td>
<td>7.53</td>
<td>77.51</td>
<td>2.11</td>
<td>61.34</td>
<td>8.85</td>
<td>1.17</td>
<td>8.3</td>
</tr>
<tr>
<td>Feb</td>
<td>Trapper Slough</td>
<td>Side Slough</td>
<td>7.86</td>
<td>153.98</td>
<td>0.45</td>
<td>65.88</td>
<td>9.45</td>
<td>1.94</td>
<td>6.7</td>
</tr>
<tr>
<td>Feb</td>
<td>Whiskey Slough</td>
<td>Side Slough</td>
<td>7.30</td>
<td>101.35</td>
<td>0.49</td>
<td>63.88</td>
<td>10.06</td>
<td>0.66</td>
<td>0.3</td>
</tr>
<tr>
<td>Feb</td>
<td>Rabideux Creek</td>
<td>Tributary Mouth</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Feb</td>
<td>Wiggle Creek</td>
<td>Tributary Mouth</td>
<td>6.58</td>
<td>35.76</td>
<td>0.25</td>
<td>64.69</td>
<td>9.49</td>
<td>0.41</td>
<td>15.1</td>
</tr>
<tr>
<td>Feb</td>
<td>Whiskey Creek</td>
<td>Tributary Mouth</td>
<td>7.60</td>
<td>20.07</td>
<td>0.08</td>
<td>99.93</td>
<td>14.52</td>
<td>1.44</td>
<td>16.3</td>
</tr>
<tr>
<td>Feb</td>
<td>Iron Slough</td>
<td>Upland Slough</td>
<td>7.02</td>
<td>97.08</td>
<td>0.38</td>
<td>48.02</td>
<td>6.92</td>
<td>9.72</td>
<td>20.2</td>
</tr>
<tr>
<td>Feb</td>
<td>Leo’s Slough</td>
<td>Upland Slough</td>
<td>7.17</td>
<td>86.31</td>
<td>0.98</td>
<td>72.95</td>
<td>10.44</td>
<td>0.79</td>
<td>6.4</td>
</tr>
<tr>
<td>Feb</td>
<td>Wiggle Slough</td>
<td>Upland Slough</td>
<td>7.43</td>
<td>51.95</td>
<td>0.39</td>
<td>96.09</td>
<td>13.93</td>
<td>1.46</td>
<td>17.9</td>
</tr>
</tbody>
</table>
Juvenile salmon winter habitat

Figure 1. Average pH by classification and sampling event. Error bars are one standard deviation (SD). Unique letters signify statistical differences.

Figure 2. Average water temperature by classification type and sampling event. Error bars are one SD. Unique letters signify statistical differences.

Figure 3. Average percent saturation of dissolved oxygen by classification type and sampling event. Error bars are one SD. Unique letters signify statistical differences.

Figure 4. Average conductivity by classification type and sampling event. Error bars are one SD. Unique letters signify statistical differences.
Average physical habitat characteristics for each sampling site, date, and habitat classification type are shown in Table 3. Ice varied from open water in side sloughs to up to 0.4 m thick in tributary mouths. Average ice thickness was significantly different among habitat classes in January and February. Average ice thickness in side sloughs was 0.04 m, 0.14 m in upland sloughs, and 0.24 m in tributary mouths. Ice thickness measures in tributary mouths are a measure of cover thickness over open water and not average thickness across the channel. Border ice in tributary mouths covered ~0.5 x channel width, and was > 1 m thick with little or no flowing water under the ice, with a thinner ice layer covering the thalweg. Water depth did not vary significantly among sites or macrohabitat types with average macrohabitat values ranging from 0.4 to 0.6m (Figure 5).

Water velocity was higher in tributary mouths than in side sloughs or upland sloughs (Figure 6). Water velocities also were higher in January than February. January velocities in tributary mouths averaged 11 cm/s with maximum values over 20 cm/s. These higher water velocities in tributary mouths appeared to be the result of ice-constricted channels caused by border ice. In February tributary mouth water velocity was lower and averaged 5.9 cm/s. This drop in water velocity was due primarily to the absence of measurements in Rabideux Creek, a tributary mouth with high water velocities in January. In February, ice had developed to the streambed of Rabideux Creek mouth (TM) and there was little to no surface (< ~5 cm) water under the ice thus water velocity was not measured in February or used in analyses. The absence of velocity data from this site, which has high values in January, reduced mean tributary mouth velocities in February.

Table 3. Average physical habitat characteristics for each sampling location by classification type. Wood debris is reported as portion of traps where LWD was present.
Water velocities in side sloughs were lower in February due to changes in main channel ice (Figure 6). Average side slough water velocity dropped from 6.7 cm/s in January to 2.9 cm/s in February. Temperatures in late January increased slightly which resulted in ice movement on the Talkeetna River. Ice jammed downstream from Whiskey Slough (SS) causing water to backup into the mouth of this side slough (see Photograph A-6 and A-7). There are two channels at the mouth of Powerline Slough (SS) with the sampling site located in the downstream channel. During January the upstream channel had ice cover and most of the flow was diverted into the downstream channel. In February, the upstream channel was ice free and flowing, and the downstream channel was ice covered with backwater from the Talkeetna River. The changes in ice cover resulted in differences in water velocity between the two sampling dates. In contrast, the outlets of all of the upland sloughs were hydraulically controlled by the channel outlet and mid-season changes in mainstem and slough ice thicknesses had little effect on water velocities in these macrohabitats.

Fine material dominated the substrate in upland sloughs and tributary mouths. There was some larger cobbles at six of the Whiskey Creek (TM) trap locations in February. Trapper and Whiskey side sloughs had fine material at ~ 55% of the trap locations, with large gravel or cobbles at the remaining trap sites (Table 3). The number of traps locations with woody debris was higher in side slough and tributary mouths than in upland sloughs (Figure 7).
Figure 5. Average January and February water depths by habitat classification type. Error bars are one SD.

Figure 6. Average water velocity for January and February sampling events by habitat classification type. Error bars are one SD. Unique letters signify statistical differences.

Figure 7. Average portion of trap locations associated with large woody debris in January and February for each macrohabitat classification type.
Fish Distribution and Abundance

Juvenile coho salmon (*Oncorhynchus kisutch*) were the most abundant fish captured and were present at most sampling locations (Table 4 and Figure 8). A total of 166 coho were captured during January and February sampling. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were present in catches from Whiskey Creek mouth (TM), Wiggle Slough (US), and Iron Slough (US) in January and February. All Chinook salmon were captured in traps located within partial mainstem flow during these two sampling periods. The highest Chinook salmon CPUT was in Powerline Slough (SS) during March sampling (Figure 9), although Chinook were not present in samples collected at this site previously. One sockeye salmon (*Oncorhynchus nerka*) was captured in Powerline Slough (SS) in February and one in Wiggle Slough (US) in March, and rainbow trout (*Oncorhynchus mykiss*) were captured at the mouth of Whiskey Creek (TM) in February. Three-spine stickleback and slimy sculpin were also present in fish catches in small numbers.

There were at least two size classes of coho salmon (Figure 10). There was not a clear difference in age 1 and older fish based on the size distribution, which was likely between 70 and 80 mm. In order to remain consistent all fish < 70 mm in FL were considered age 1. We were unable to distinguish different age classes of coho salmon with fork lengths 70 mm or greater. There were a number small coho 40 to 50 mm in fork length that either were from spawning in 2012 and emerged in the spring and had slow growth rates, were from spawning in 2012 and emerged in mid to late summer, or were from spawning in 2013 and emerged early. Average FL of age 1 coho salmon was 55.8 mm in January and 59.4 mm in February. Average FL of larger coho salmon (> 70 mm) was 93.4 mm in January and 92.4 mm in February, and 76 mm in Wiggle Slough (US) in March, and 101 mm in Whiskey Creek (TM) in March. Chinook salmon fork lengths ranged from 58 to 81 mm (n = 5) in January and February with an average of 73.6 mm. Average Chinook salmon FL in March from Powerline Slough (SS) was 83.4 mm (n = 5).

### Table 4. Coho and Chinook salmon catch per unit trap for each sampling site and sampling event. NS is not sampled.

<table>
<thead>
<tr>
<th>Site</th>
<th>Classification Type</th>
<th>January</th>
<th>February</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Coho Ave</td>
<td>Coho Ave</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CPUT</td>
<td>CPUT</td>
</tr>
<tr>
<td>Powerline Slough</td>
<td>Side Slough</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td>Whiskey Slough</td>
<td>Side Slough</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Trapper Slough</td>
<td>Side Slough</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Wiggle Creek</td>
<td>Tributary Mouth</td>
<td>0.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Whiskey Creek</td>
<td>Tributary Mouth</td>
<td>1.70</td>
<td>0.20</td>
</tr>
<tr>
<td>Rabideux Creek</td>
<td>Tributary Mouth</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Leo's Slough</td>
<td>Upland Slough</td>
<td>0.60</td>
<td>0.00</td>
</tr>
<tr>
<td>Wiggle Slough</td>
<td>Upland Slough</td>
<td>2.70</td>
<td>0.10</td>
</tr>
<tr>
<td>Iron Slough</td>
<td>Upland Slough</td>
<td>0.60</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Figure 8. Average coho and Chinook CPUT for the January and February sampling events.
Juvenile salmon winter habitat

Figure 9. Average coho and Chinook CPUT for 3 sites from January through March 2014.

Figure 10. Size distribution of coho salmon captured at all sites and on all sampling dates. Juvenile coho< 70 mm were considered age 1.

Coho Salmon Habitat Relationships

At sites where coho salmon were present, there were significant relationships between catch in individual traps and habitat characteristics measured at the trap location. The number of coho salmon in each trap was related to the presence of large wood, water velocity, and dissolved oxygen. No other
habitat variables measured at trap sites including temperature and water depth were related to coho catch. Coho salmon catch was significantly higher in traps associated with woody debris compared to traps without woody debris ($p = 0.005$). Average coho salmon catch was $3.0$ with wood present and $1.1$, without. There was no significant relationship between water velocity and coho catch when all trap data were used. However, there was a significant negative relationship between coho salmon catch and velocity when LWD was absent ($R = 0.34, p = 0.009$), but not when wood was present ($p = 0.70$). At trap locations without wood, water velocity was significantly lower at traps with fish ($3.6 \text{ cm/s (0.12 ft/s)}$), compared to sites where coho salmon were absent ($7.0 \text{ cm/s (0.23 ft/s)}$). There was also a positive relationship between coho catch and the percent saturation of dissolved oxygen ($R = 0.22, p = 0.04$).

There were no significant relationships between coho trap catch and other habitat variables including water depth, ice thickness, water temperature, or other water quality parameters.

Coho salmon CPUT was significantly different among sampling sites ($p < 0.001$) but not between sampling events. Coho CPUT was significantly higher in Wiggle Slough (US) than in all other sites except for Whiskey Creek (TM). CPUT in the mouth of Whiskey Creek (TM) was higher than in Powerline Slough (SS), Whiskey Slough (SS), and Rabideau Creek (TM). Average dissolved oxygen concentration was the only habitat variable at the site level that was weakly related to the average coho salmon CPUT at each site ($R = 0.26, p = 0.04$). There were no significant relationships between average site water velocity, water depth, ice depth, substrate, or LWD and average coho CPUT among sites. There was however a significant relationship between coho and Chinook salmon CPUT, with Chinook, when present, generally at sites where coho salmon also were present.

The habitat characteristics within a site that explained differences in individual trap catch (LWD, velocity, and dissolved oxygen) did not explain differences in average catch per site. That is, sites with more wood or lower velocities did not always have higher average coho salmon CPUT. The two sites with the highest CPUT (Wiggle Slough (US) and the mouth of Whiskey Creek (TM)) were well oxygenated, with low water velocities but only moderate levels of woody debris. For example, 37 coho salmon were captured in Wiggle Slough (US) in February, with only 4 traps associated with woody debris, average water velocity was $4.1 \text{ cm/s}$, and dissolved oxygen was $96\%$ saturated ($13.9 \text{ mg/L}$). Similarly, 24 coho salmon were captured in the mouth of Whiskey Creek (TM) in February, with 4 traps associated with woody debris, average water velocity of $3.3 \text{ cm/s}$ and dissolved oxygen at $99\%$ saturation. However, only 1 coho salmon was captured in Whiskey Slough (SS) and Powerline Slough (SS) in February even though habitat conditions were similar to Wiggle Slough (US) and Whiskey Creek (TM). Average water velocity was low in Whiskey Slough (SS) ($3.2 \text{ cm/s}$), three traps were associated with wood, and dissolved oxygen was at $73\%$ saturation. Only one coho was captured in Powerline Slough (SS) in February, even though water velocities were $\sim 0.5 \text{ cm/s}$, 5 traps were associated with wood and dissolved oxygen was at $61\%$ saturation. The only appreciable difference between sites with and without coho was dissolved oxygen saturation, which was slightly lower at the side slough sampling sites.

Habitat characteristics that explained some of the variability in individual trap catch (LWD, water velocity, dissolved oxygen) also did not explain differences in average catch per macrohabitat class. Coho salmon CPUT was higher in upland slough macrohabitats than side sloughs. Average CPUT was not different between upland sloughs and tributary mouths or tributary mouths and side sloughs (Figure 11). While coho salmon CPUT was higher in upland sloughs than in side sloughs, there were no differences in water velocity or dissolved oxygen concentrations between these two habitat classes and LWD was more abundant in side sloughs. There were no differences in water depths between side
sloughs and upland sloughs but water temperatures were higher in side sloughs than in other macrohabitats.

There were no significant differences in coho salmon CPUT between tributary mouth and upland slough macrohabitats, but few habitat characteristics were similar. Water depth and percent fines were the only two habitat characteristics that did not vary between these two macrohabitat classes. Tributary mouths had higher water velocities than upland sloughs, but also more woody debris and higher oxygen saturation. Water temperatures were cooler with thicker ice cover in tributary mouths. Tributary mouth pH was higher and conductivity lower than was observed in upland sloughs.

Figure 11. Average coho salmon CPUT by classification type and sampling event. Error bars are one standard deviation.

Discussion
Habitat characteristics measured at trap locations and representing localized conditions were correlated with juvenile coho salmon catch; but the abundance of these characteristics within a site or within a macrohabitat class were not related to coho CPUT. This suggests that some other characteristics influenced winter habitat selection for juvenile coho salmon, which could include site location, or previous temporary adverse conditions that affected distribution. Therefore, the abundance of preferred habitat characteristics within a site at a specific point in time should not be used to estimate juvenile coho winter habitat abundance at that site.

Large wood, low water velocity, and dissolved oxygen were localized habitat characteristics associated with increases in juvenile coho salmon abundance during winter. The importance of woody debris and low water velocities for juvenile coho summer rearing and overwinter habitat observed in this study, through the relationship between trap catch and habitat conditions at each trap, is consistent with other studies (Bilby and Bisson 1987, Bustard and Narver 1975, Giannico and Hinch 2003). The role of large
wood in this study was in part related to its influence on water velocity, as the relative abundance of coho salmon was only related to water velocity in the absence of wood. Other studies have also documented decreased coho emigration from sites with increasing water velocities when wood was present (McMahon and Hartman 1989; Fausch 1993).

Water velocities within tributary mouths and side sloughs appeared to be modified by mainstem ice development. Water velocities in the mouths of Wiggle Creek and Rabideux Creek (TMs) were relatively high (13.5 and 12.5 cm/s respectively (~0.5 ft/s)) and very likely were the cause of low coho salmon abundance at these sites. High water velocities were due to border ice development that appeared to reduce the channel cross-section and result in a narrow fast flowing channel under the surface ice. These conditions were not observed in the mouth of Wiggle Creek (TM) during the winter of 2012/2013 or during this study in Whiskey Creek (TM). We hypothesize that these differences are due to mainstem ice formation.

The location of mainstem ice development can influence backwater conditions in tributary mouths and other off-channel habitats by creating a hydraulic control. During the winter of 2012/2013 mainstem ice developed at the mouth of Wiggle Creek (TM) creating a backwater pool in the tributary mouth. Ice developed as a uniform surface layer and water velocities beneath the ice were ~0 cm/s. Similar conditions developed in the mouth of Whiskey Creek (TM) during the winter of 2013/2014. The Talkeetna River flows through a confined channel downstream from Whiskey Creek (TM). Mainstem ice development across this confined channel caused a backwater pool in the mouth of Whiskey Creek TM and slower water velocities (5.2 cm/s average). However, during 2013/2014 there was an open water lead in the Talkeetna River at the mouth of Wiggle Creek, a backwater was not created, and border ice developed in the Wiggle Creek tributary mouth creating much higher water velocities than in 2012/2013.

We had hypothesized that presumably warmer open water side sloughs would provide preferred overwintering habitat for juvenile salmon in the glacial Susitna and Talkeetna Rivers. Results from winter 2012/2013 sampling provided some support for this hypothesis due to the high relative abundance of coho and Chinook salmon juveniles captured in the Whiskers Creek (SS) which was not sampled in 2013/2014 (Davis et al. 2013). The Whiskers Creek side slough was ice covered during February 2013 sampling but had warmer water temperatures than other sampling locations (1.9 to 3.4°C). However, this was the only side slough habitat sampled in 2013. During 2013/2014, three additional side slough habitats were sampled. Water temperatures were significantly higher within these macrohabitats; however, juvenile salmon abundance was lower than in other macrohabitat types; this hypothesis deserves further study.

The abundance of juvenile salmon in side sloughs was lower than expected based on habitat characteristics and may be due to ice or hydraulic conditions during early winter. Water velocities were low and there was more woody debris in side sloughs than in other sampling locations. Dissolved oxygen was below saturation, but not significantly different than in upland sloughs. Side sloughs are more susceptible to mainstem flow conditions, which could result in habitat conditions that cause emigration from these sites during early winter. Since the upstream ends of side sloughs are connected to the mainstem, rising stage heights during the upstream progression of ice could divert mainstem flows into the upstream end of side sloughs. The diversion of mainstem flows into side sloughs during early winter could increase water velocities in these habitats and introduce frazil ice. Conditions of high water
velocity or frazil ice would likely result in juvenile salmon emigration from these sites or avoidance of these sites (McMahon and Hartman 1989, Brown et al. 1994). Rising mainstem stage height would only result in increasing backwater flow into tributary mouths and upland sloughs and would be unlikely to have a large influence on water velocities. Therefore, periods of high water velocity in side slough habitats may offset any benefits due to higher water temperatures.

Juvenile Chinook salmon were rarely found in the macrohabitats sampled. When present, Chinook salmon juveniles were found in close association with the mainstem. This is consistent with 2012/2013 sampling results that found Chinook salmon in mainstem alcoves and backwater pools. Sampling in 2012/2013 also documented the reduction in juvenile Chinook salmon during late winter (March) which we hypothesized to be the result of early outmigration prior to ice breakup. During 2013/2014 sampling we documented an increase in Chinook salmon abundance in a side slough habitat in March where they were previously absent. This also suggests late winter movement of juvenile Chinook salmon. Further studies should investigate the characteristics of mainstem habitat selection by juvenile Chinook salmon and timing of spring migrations.

Juvenile coho salmon were observed overwintering in upland slough and tributary mouth macrohabitats. Their abundance within these habitats increased in the presence of woody debris, low water velocity, and high dissolved oxygen concentrations. The formation and location of mainstem ice had a large influence on ice formation and water velocities and depths within tributary mouths. Mainstem ice that created backwater conditions and surface ice formation in tributary mouths resulted in low water velocities in these macrohabitats; whereas, the lack of mainstem backwater resulted in tributary boarder ice and high water velocities. Juvenile coho salmon were absent from side slough macrohabitats that were warmer than other sampling locations, with low water velocities, and abundant woody debris. We hypothesize that in early winter as mainstem ice developed, flow was diverted into the upstream ends of these channels increasing water velocities and causing juvenile salmon emigration from these habitats. Future studies should focus on the relationships between mainstem ice development in early winter and habitat characteristics within tributary mouths and side sloughs, and juvenile salmon site fidelity.

Literature Cited


Bell, E. 2001. Survival, growth and movement of juvenile coho salmon over-wintering in alcoves, backwaters, and main channel pools in Prairie Creek, California.


Fausch, K.D. 1993. Experimental analysis of microhabitat selection by juvenile steelhead (Oncorhynchus mykiss) and coho salmon (O. kisutch) in a British Columbia stream. Canadian Journal of Fisheries and Aquatic Sciences. 50: 1198-1207.


Hiscock, MJ; Scruton, DA; Brown, JA; Pennell, CJ. 2002. Diel activity pattern of juvenile Atlantic salmon (Salmo salar) in early and late winter. Hydrobiologia 483: 161-165.


Johnston, NT; Irvine, JR; Perrin, CJ. Coho salmon (Onchorhynchus kisutch) utilization of tributary lakes and streams in the Kech River drainage, British Columbia. ISSN: 0706-6473.


Murphy, ML; Koski, KV; Lorenz, JM; Thedinga, JF. 1997. Downstream migrations of juvenile Pacific salmon (Oncorhynchus spp.) in a glacial transboundary river. Canadian Journal of Fisheries and Aquatic Sciences 54(12): 2837-2846.


Riehie, M. D. and J. S. Griffith. 1993. Changes in habitat use and feeding chronology of juvenile rainbow trout (Oncorhynchus mykiss) in fall and the onset of winter in Silver Creek, Idaho. Canadian Journal of Fisheries and Aquatic Sciences 50(10): 2119-2128.


Appendix A: Site Photographs
Photograph A-1.
Powerline Slough, looking downstream, January 6, 2014.

Photograph A-2.
Powerline Slough, looking upstream, February 5, 2014.
Photograph A-3, Powerline Slough, looking downstream, March 12, 2014.


Photograph A-7. Whiskey Slough, looking upstream on February 4 (left) and February 6 (right), 2014.


Photograph A-12. Whiskey Creek, looking downstream, February 6, 2014.


Preparing minnow traps at Whiskey Slough, January 7, 2013.

Photograph A-27.
Measuring water velocities at Whiskey Creek, February 5, 2014.

Photograph A-28.
Juvenile Chinook salmon captured at Whiskey Creek, January 8, 2014.

Photograph A-30. Juvenile rainbow trout captured at Whiskey Creek, February 6, 2014.