FEDERAL ASSISTANCE **FINAL PERFORMANCE REPORT**	**ALASKA DEPARTMENT OF FISH AND GAME** **SPORT FISH DIVISION** **PO Box 115526** **Juneau, AK 99811-5526**

STATE WILDLIFE GRANT (SWG)

STATE: Alaska

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PROJECT: P-01

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PERIOD DURATION: February 1, 2015–June 30, 2016

PROJECT REPORTING PERIOD: February 1, 2015–June 30, 2016

PROJECT TITLE: Estuary Habitat Use by Juvenile Chinook and Coho Salmon in a Kenai Lowlands (Anchor) River.

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Project Objectives:

The purpose of the project: This project investigates key aspects of juvenile salmon use of estuaries in south-central, Alaska, including patterns of movement and residence in different estuary habitats.

Objective 1: Research demographic patterns of juvenile Chinook and Coho Salmon movement and residence through different reaches and channel systems in the estuary.

Objective 2: Identify characteristics (metrics) of tidal channels that potentially relate to fish occupancy, residence and feeding.

Summary of Project Accomplishments:

This project explores key aspects of juvenile salmon estuarine habitat use in a snowmelt, groundwater supported estuary of south-central Alaska. We investigated patterns of juvenile fish movement and residence in estuary habitats (objective 1), including different marsh channels and mainstem sites along a tidal gradient, through repeated fish sampling at the sites, tagging, recaptures and antenna detections. Features of those habitats that related to fish use (objective 2) were investigated through stationary loggers and point sampling. Our results revealed distinct environmental characteristics of the different habitats, with dissolved oxygen and water stratification explaining much of the variability between marsh channels and mainstem sites. Eight fish species were regularly captured in the estuary, including Chinook Salmon (*Oncorhynchus tshawytscha)*, Coho Salmon (*O. kisutch)*, Dolly Varden (*Salvelinus malma)*, Sockeye Salmon (*O. nerka)*, staghorn sculpin (*Leptocottus armatus)*, starry flounder (*Platichthys steallatus*), steelhead (*O. mykiss)*, and three-spine sticklebacks (*Gasterosteus aculateatus*). Fish community assemblages differed between the habitats. In 2016, juvenile Chinook Salmon characterized the middle and upper mainstem habitats; however chinook were rarely captured in 2015, likely due to the low adult return of the previous year. After excluding highly abundant young of the year sticklebacks, juvenile Coho Salmon were the most abundant species in the estuary in both 2015 and 2016, averaging at least 25% of the total catch in all of the habitats. Small, age 0 Coho Salmon continued to enter the estuary from June through November. Marsh channel habitats were utilized by juvenile Coho Salmon, and to a lesser degree by juvenile Chinook Salmon. These marsh channels were characterized by large numbers of staghorn sculpin and three-spine sticklebacks in addition to the salmon. Starry flounder and staghorn sculpin were most characteristic of the lower mainstem site. Data from tagged, recaptured and antenna detected salmon revealed juvenile Coho Salmon residing in the estuary for nearly 11 months, and juvenile Chinook residing for nearly 1 month. Both juvenile Chinook and Coho were documented moving upstream and downstream throughout the estuary, between mainstem and marsh channel habitats. Collectively, project results demonstrate that juvenile salmon use on a broad array of habitat types within the estuary, and highlight the importance of even small estuaries to juvenile salmon growth and resilience.

Study Site:
The Anchor River is located at the southern end of Cook Inlet (Figure 1), where there is a large tidal range (> 8 m depth) that can potentially create broad ecotones of habitat conditions within estuaries. Hydrology in the Anchor River watershed is driven by snowmelt and shallow ground water. The watershed encompasses over 580 square kilometers, including 266 river kilometers accessible to anadromous fishes (Kervliet *et al.* 2013). The estuary at the mouth of the Anchor abruptly transitions into the marine environment of Cook Inlet after flowing through an expansive marsh habitat, protected from maritime storms and erosion by a gravel and sand bar that extends along the shoreline. Measured from high-water tide line to the confluence with Cook Inlet, the estuary is nearly 3 km in length (Hoem Neher *et al* 2013b).

We established five sites within the Anchor River estuary, representing a range of conditions, including two marsh sites, one located at the lower extent of the vegetated marsh, and one located in a mid-marsh area, and three sites along the river mainstem (Figure 2).

Figure 1. Overview of the middle marsh area of the Anchor River estuary in mid-summer.

Figure 2. Aerial image of the Anchor River estuary, showing sampling locations. Sampling sites: orange stars = estuary marsh habitat; blue stars = mainstem river sampling sites along a gradient from the upper extent of saltwater influence (light blue) to the lower extent of marsh vegetation (dark blue).

Methods

We collected data in 2015 and 2016, at the five established sites. In 2015, sites were sampled approximately once per week from late-July to early-September, with additional sampling in October and November. In 2016 sites were sampled every other week beginning in late May and continuing through September. Continuous depth, temperature and salinity data were collected from stationary loggers placed in each of the marsh channel habitats (Solinst TM 3001 level loggers, Solinst Canada Ltd., Ontario, Canada), calibrated with a Solinst TM 3000 barologger set onsite. Level loggers were set at 15-min recording intervals and placed in 5 × 25 cm plastic housings attached to steel fence posts driven into the substrate. Point measurements were taken for each sampling event at all of the sites to collect data on maximum depth, flow, temperature, salinity, and dissolved oxygen, taken at three points in the water column (just below the surface, mid-water column, and just above the substrate) using a YSI model 30. Turbidity data were collected using a YSI 6600 series data sonde, with a YSI 6136 turbidity sensor (YSI Instruments Inc.)

Fish were sampled by seining; in the marsh channels, block nets (0.3 cm mesh) were placed at both ends of the 25 m reach and fish were captured in three passes with a pole seine (2.2 × 6 m, 0.3 cm mesh). At mainstem sites, a pole seine was pulled 25 m parallel to the bank in the upstream direction in 2015; and in 2016, we used a 20 ft beach seine, pulling either upstream, or across the channel (Figure 3). Fish were counted, identified to species, weighed, measured, and returned to the channel. Salmon over 55 mm in length received a Passive Integrated Transponder (PIT) tag, and a subset of fish had their stomach contents sampled via gastric lavage. Fish were held in recovery pens in the channel prior to release.

PIT tag reading antennas were established in four sites in 2015, reduced to three sites for 2016 due to one of the sites becoming too dry (Figure 4). Each antenna array consisted of two antennas so that direction of movement could be detected. Antenna efficiency was calculated for segments of time between each sampling event by dividing the number of unique tags detected at the antenna by the number of tags known to have passed through (as determined by detection or recapture) (Table 1).

To compare fish catch samples across sites, we used log transformed catch per unit effort (CPUE), using the first pass from each sampling event.

CPUE = #fish per area sampled
*area sampled = transect length*net curved-width for mainstem sites and*
*transect length*average channel width for marsh channels.*
average channel width = mean wetted width at 5m intervals along the transect at low tide.
CPUE was log transformed

Figure 3. Fish were captured using pole seines in block-netted marsh channels (A), or beach seining in the mainstem (B). Salmon > 55 mm in length were PIT tagged (C); gastric lavage was used to collect stomach samples from representatives of all age classes of juvenile Coho and Chinook Salmon (D); fish recovered in protected in-stream pens (E).

To estimate the standard growth rate (SGR) of PIT tagged Coho Salmon and staghorn sculpin, we measured the length and weight of recaptured fish (excluding recaptures within ten days of tagging):

Standard Growth Rate= ln(recap weight/initial weight)/days since tagging

Figure 4. PIT tag reading antenna locations, shown as yellow bars.

Results

Channel metrics

Environmental conditions varied temporally and spatially in the different estuary habitats (Figure 5). Mainstem sites were consistently deep (~1 m), with stronger flows (> 20 cm/s), salinities near zero, and consistently high dissolved oxygen levels (> 10 mg/L). Both marsh channels had consistently low flows. Marsh channel B (closest to the river mouth), showed a marked response to extreme tide events, with higher and more variable salinities. This is likely due to each channel's connectivity to the mainstem, where a silt sill at the mouth of the channel requires the tide to reach approximately 4.5 m before the channel is inundated. The mid marsh channel, Marsh channel A, by contrast, is always connected to the mainstem. This physical feature enables Marsh channel B to maintain environmental stability during low and moderate tides. Temperatures at all sites generally increased over the course of the field season, although July rains lowered the temperature and correspondingly increased turbidity in mainstem sites, but not in the marsh channels. At times during mid-summer temperatures in mainstem sites consistently exceeded 15^{O} C. Marsh channel sites were generally cooler (rarely exceeding 15^{O} C), and had much lower dissolved oxygen levels, with the mid marsh channel (A) dropping below 4 mg/L in August.

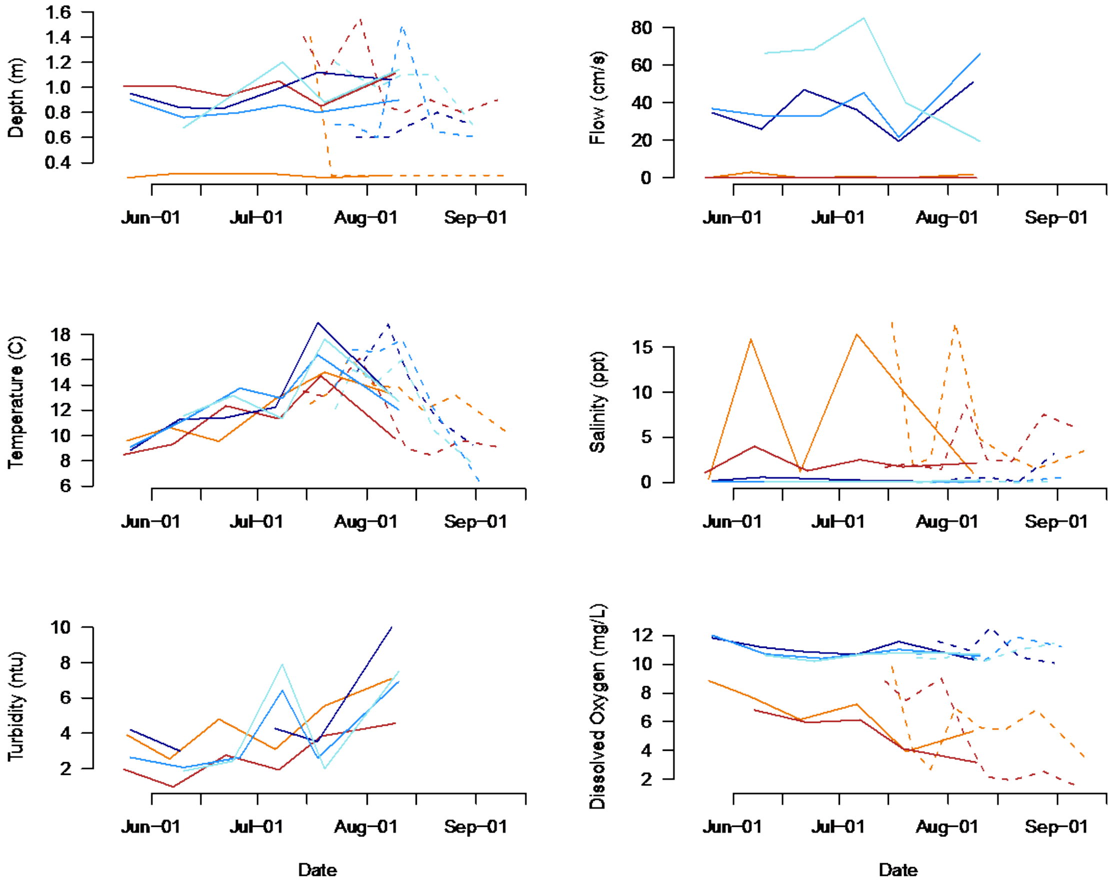

Figure 5. Point measurements of environmental variables over time at each sampling site in 2015 (dashed lines) and 2016 (solid lines). Line colors correspond to sites as indicated in Figure 2 (red = Marsh A, orange = Marsh B, purple = lower mainstem, dark blue = middle mainstem, light blue = upper mainstem). Note: Turbidity and flow were not recorded in 2015.

A Principle Components Analysis (PCA) of environmental variables for 2015 and 2016 revealed that the two marsh channels were distinct from each other, and from the mainstem sites (Figure 6). Substantial variability in the two marsh channels contrasted with the mainstem sites, where the environmental conditions were much more stable. In both years, higher dissolved oxygen levels in the mainstem, and a greater degree of water stratification in the marsh channels were primary drivers of differences in environmental conditions between the different habitats.

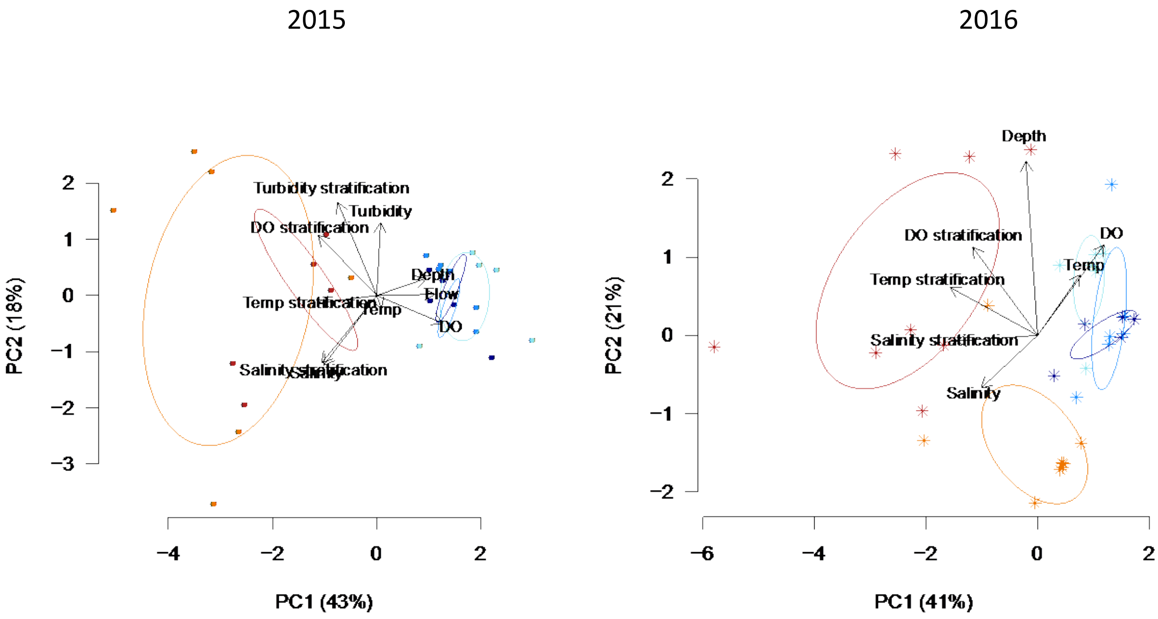

Figure 6. Principle components analysis (PCA) of environmental variables collected during each sampling event for 2015 (left) and 2016 (right). In both years, PC1 explains significantly more variability than would be expected from the null distribution ($p < 0.01$). PC2 is not significant. Points represent individual sampling events and are colored by site, corresponding to colors indicated in Figure 2. Ellipses denote the standard deviation from each site centroid. The association of environmental variables with the principle component axes is illustrated by the vector arrows, with the length of arrow proportional to the variance explained. DO = dissolved oxygen, Temp = temperature. Point readings were taken at three points in the water column (bottom, middle, and surface).

Fish

Similar to other estuaries in Alaska, the Anchor River estuary has relatively low fish diversity. Of the over 16,400 fish sampled, fifteen species were represented, nine of which were present at multiple life history stages, including large numbers of young of the year (< 20 mm) staghorn sculpin and three-spine sticklebacks (Figure 7).

Figure 7. The most abundant captured fish included three age classes of juvenile Coho Salmon (A), juvenile Chinook Salmon (B), starry flounder (C) including young of year (D) staghorn sculpin (E) including young of the year (G), and three-spine stickle backs (H) including young of the year.

Species composition varied across the sites (Figures 8 and 9). Coho Salmon were abundant in all sites, comprising on average nearly three-quarters of the total catch in the mid marsh channel (Marsh A), but only 25% in marsh channel B. In the mainstem channels, Coho were most abundant (although much less so than Chinook Salmon) in the middle mainstem site during late June. Two main pulses of Coho Salmon, one in early June and one in early August, occurred in the marsh channels, and to a lesser degree in the lower mainstem channel, and small, age 0 Coho Salmon continued to enter the estuary into November (Figure 15). Chinook Salmon comprised less than 1% of the catch in 2015, but were commonly found in mainstem sties in 2016. They were abundant early in the season at the upper mainsteam site and to a lesser degree in Marsh channel A, with another pulse of juvenile Chinook Salmon at the upper mainstem site in late August. The highest abundance of Chinook Salmon (densities of 4 fish/m^2), were in the middle mainstem site in early June. Staghorn sculpin were most abundant in the lower marsh channel (Marsh B), where they increased from June to July, reaching and maintaining densities of 3 fish/m^2 through early August. Starry flounder were most abundant in the lower mainstem site, and lower marsh channel (Marsh B), with a marked increase in abundance in early August in both marsh channel habitats, as well as the upper mainstem. Dolly Varden were only present in small numbers in the mainstem sites, and three-spine sticklebacks were only present, but in large numbers, in the marsh sites. Small numbers of Sockeye Salmon were captured in all sites, except for the lower mainstem, although they were most abundant in the marsh channels, and Steelhead were found only in the upper and rarely in the middle mainstem site.

Overall, the two marsh channel habitats generally had higher densities of fish than the mainstem sites, with the exception of the middle mainstem site, which had high densities of Chinook Salmon in early June, steadily decreasing throughout the summer. Trends in abundance appear relatively consistent between 2015 and 2016;

with the exception of Chinook Salmon, which were only present in very small numbers overall in 2015, and juvenile steelhead, which were rare in 2016.

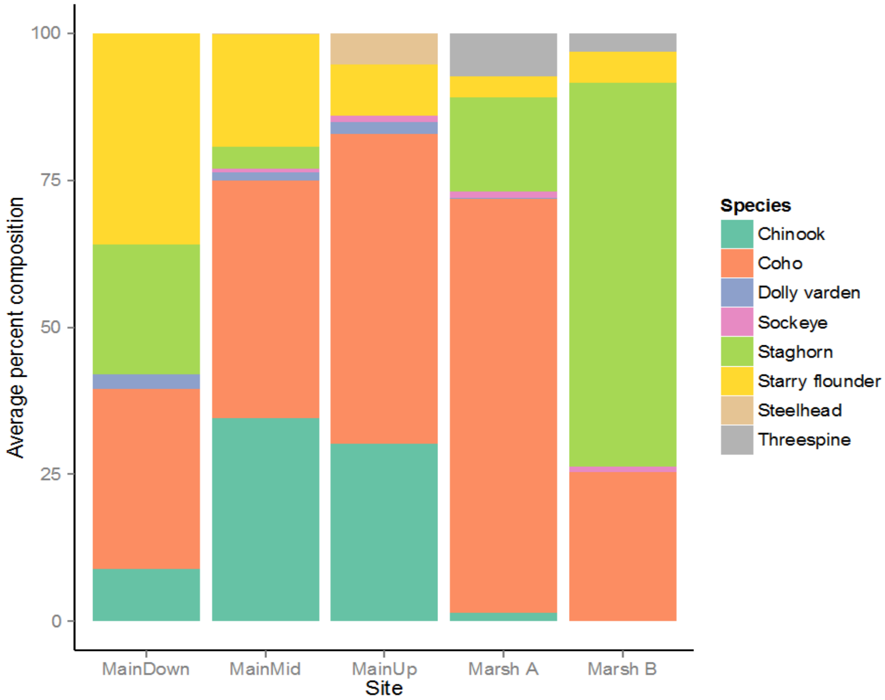

Figure 8. Average species composition at each site (2015 and 2016 data combined) based on log-transformed catch per unit effort. Staghorn = staghorn sculpin, Threespine = three-spine stickleback.

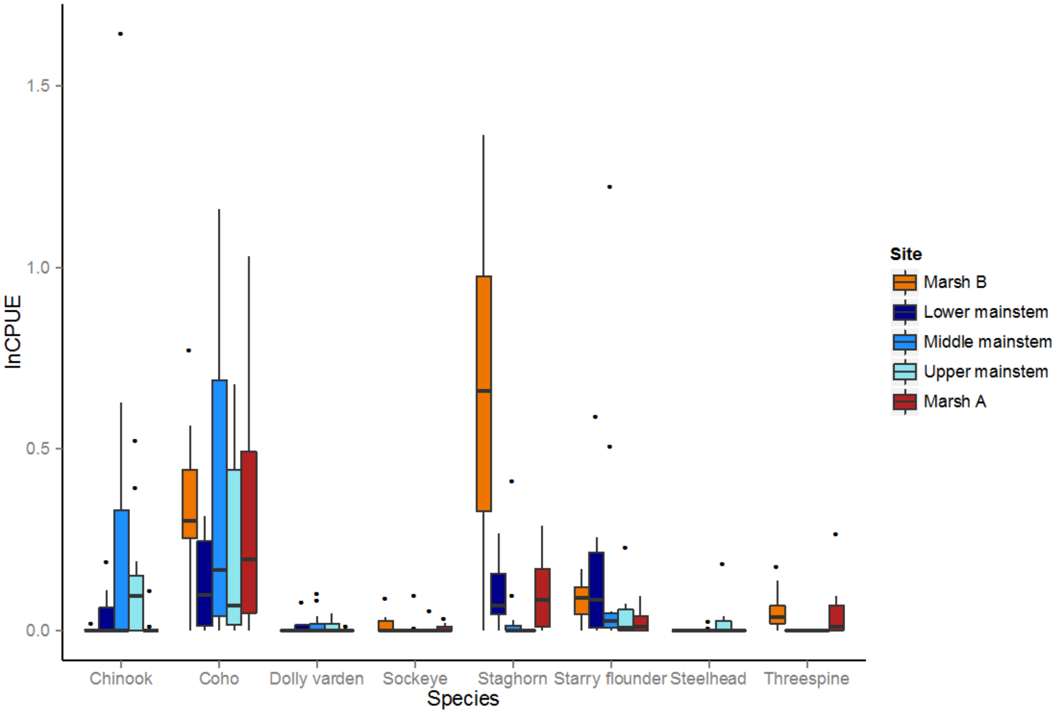

Figure 9. Boxplot of catch per unit effort of the primary fish species at each site (2015 and 2016 data combined). Staghorn = staghorn sculpin, Threespine = three-spine stickleback.

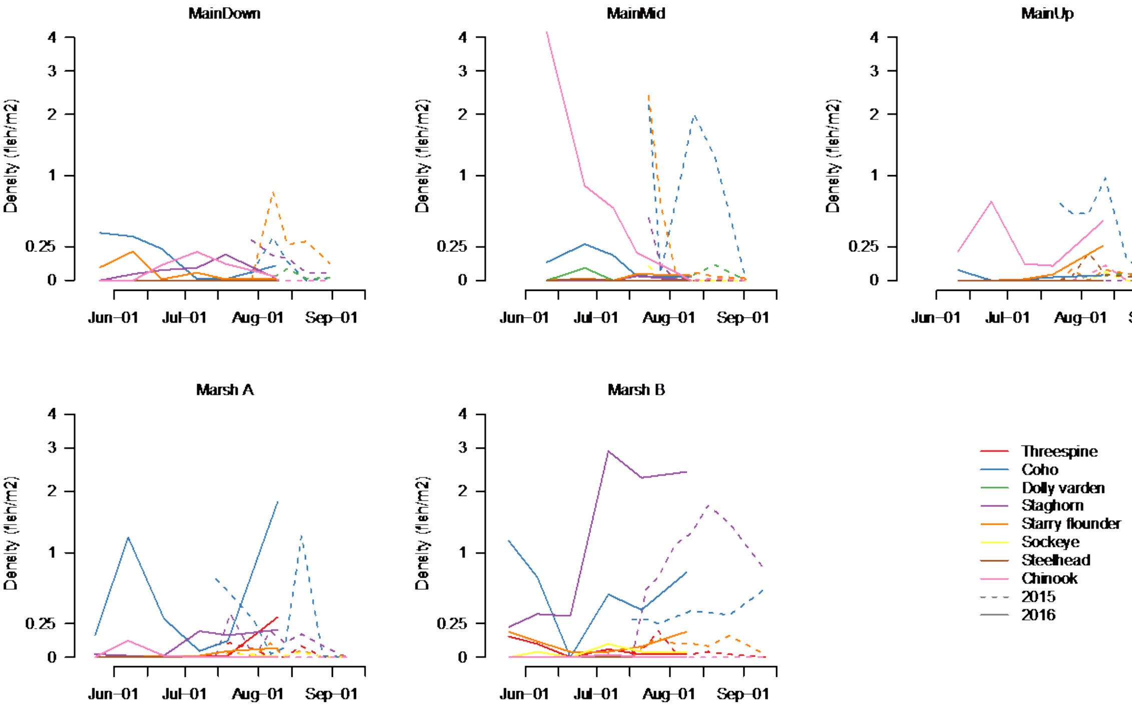

Figure 10. Catch per unit effort over time at each site for the primary fish species. Note log scale on the y-axis. Staghorn = staghorn sculpin, Threespine = three-spine stickleback. Dashed lines are 2015 data, solid lines are 2016 data.

A non-metric multidimensional scaling (NDMS) analysis of relative fish species abundance revealed distinct differences that remained fairly consistent for the two marsh habitats and the lower mainstem habitats. Newly hatched three-spine sticklebacks numerically dominated the fish community in the mid marsh site (Marsh A), staghorn sculpins dominated the lower marsh site (Marsh B), and a mix of staghorn sculpin and starry flounder typified the lower mainstem site (Figure 11). The middle and upper mainstem sites were characterized by Coho Salmon and steelhead in 2015; however Chinook Salmon were the characteristic species for these two sites in 2016 (Figure 11). The middle mainstem site exhibited the most variable fish assemblage in both years, as evidenced by the wide spread of sample points.

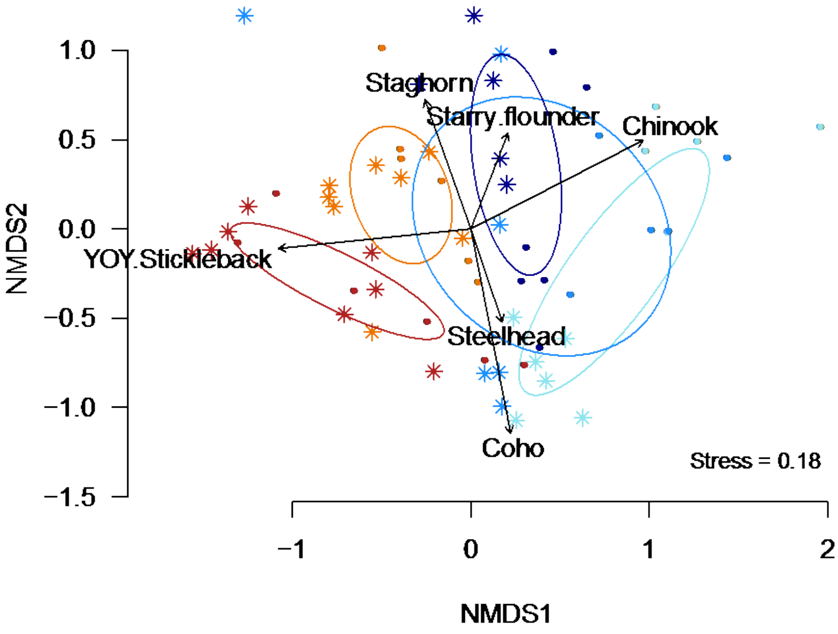

Figure 14. Two-dimensional nonmetric multidimensional scaling plot of relative species abundance for 2015 (stars) and 2016 (points) using Bray-Curtis dissimilarity. CPUE was log-transformed because the data were heavily right-skewed, and then row-standardized to compare relative species abundance across samples. Points represent samples and are colored according to site as indicated in Figure 2. Ellipses represent the dispersion of each site, and are based on the standard deviation to the site centroid. Vectors indicate the magnitude and direction of species loadings (variable weights) on the composite axes. Only those species that significantly contribute to the ordination ($p < 0.01$) are displayed. YOY = young of year sticklebacks (< 20 mm fork length), Staghorn = staghorn sculpin.

In both 2015 and 2016, three age classes of Coho Salmon were present in the estuary habitats. Length frequency distributions for 2015 and 2016 indicates that small, age 0 fish continue to enter the Anchor River estuary throughout the summer and fall (June – November) (Figures 15 and 16).

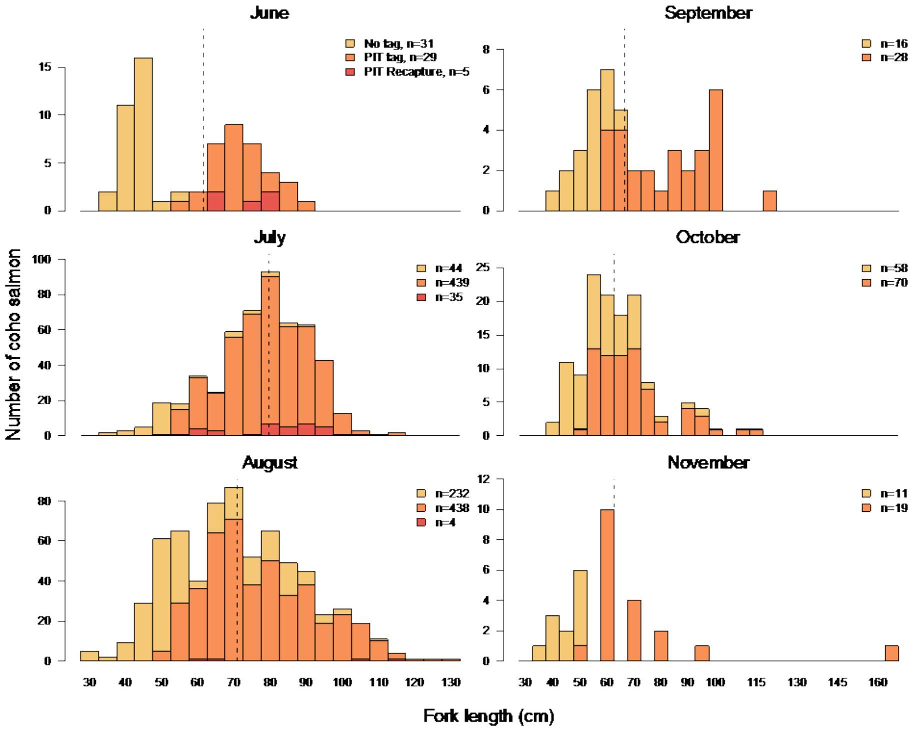

Figure 15. Length frequency histograms for Coho Salmon sampled in 2015. Bars are colored to indicate fish that were not PIT tagged (yellow), PIT tagged (orange), and PIT tagged fish that were later recaptured (pink). The vertical dashed line marks the median length.

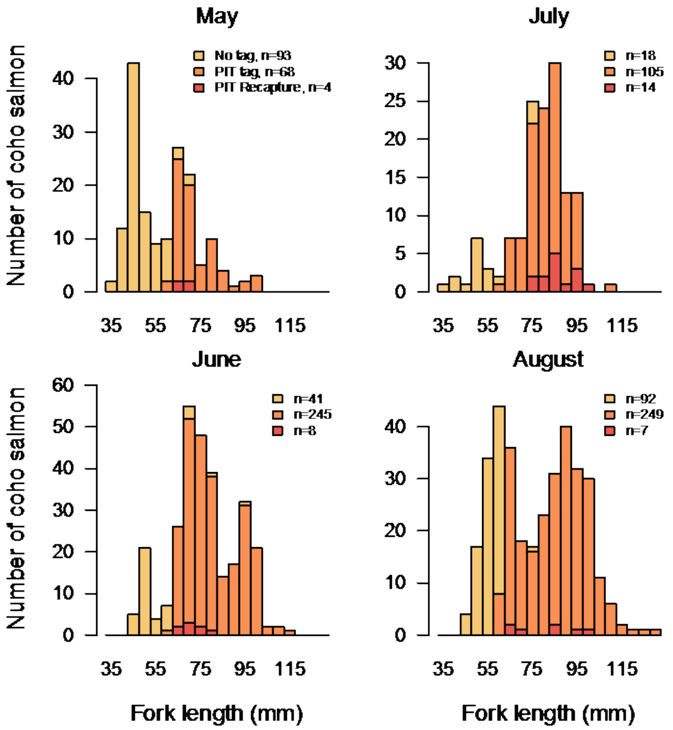

Figure 16. Length frequency histograms for Coho Salmon sampled in 2016. Bars are colored to indicate fish that were not PIT tagged (yellow), PIT tagged (orange), and PIT tagged fish that were later recaptured (pink).

Movement and residence

Unfortunately, the PIT tag detecting antenna arrays were rarely working in synchrony in 2015, and were inoperable during the winter due to severe icing and tidal movement of large pieces of wood debris. Antenna operation was re-established in April 2016, and we calculated detection efficiencies for each antenna that was consistently operational as the number of unique tags detected by the antenna divided by the number of tags known to have passed through (as determined by detection or recapture). As Table 1 shows, detection efficiencies were marginal during most periods (Connolly *et al* 2011).

Table 1. Detection efficiencies for each PIT antenna in 2016 in approximately two-week intervals corresponding to tagging events at each site.

Data range	**Marsh A up**	**Marsh A down**	**Marsh B up**	**Marsh B down**
Late May – early June	0.381 (8/21)	0.532 (25/47)	0.571 (16/28)	0.571 (8/14)
Mid June	0.097 (3/31)	0.419 (13/31)	0.533 (8/15)	0.00 (0/2)
Late June – early July	0.654 (17/26)	0.442 (19/43)	--	0.500(2/4)
Mid July	0.714 (5/7)	0.000 (0/4)	0.500 (8/16)	0.00 (0/5)
Overall efficiency	*0.388 (33/85)*	*0.456 (57/125)*	*0.542 (32/59)*	*0.400 (10/25)*

Over three-hundred Chinook Salmon, the majority of which were in the upper and middle mainstem sites, as well as approximately sixteen-hundred Coho Salmon, the majority of which were tagged in the marsh channels, were PIT tagged between 2015 and 2016; (Figure 17). Although recapture rates of PIT tagged fish were low, they appear to reflect the size distribution of tagged fish, indicating that recapture is not biased by fish size (Figures 15 and 16).

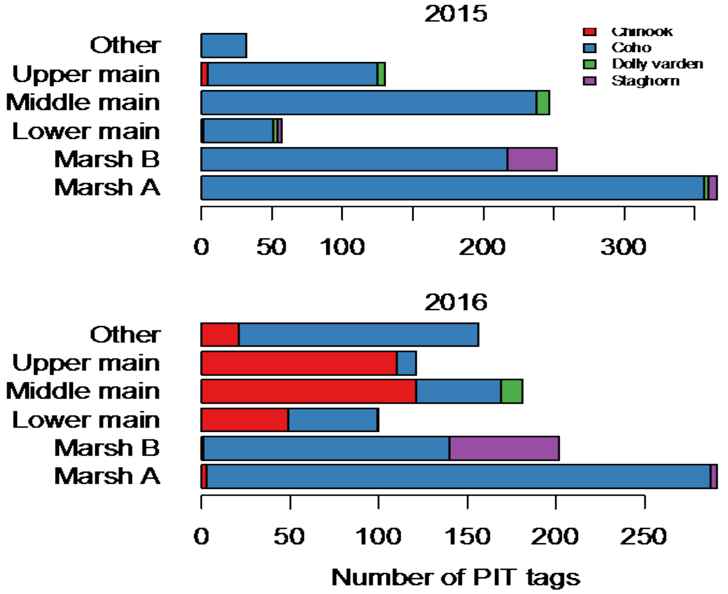

Figure 17. Distribution of PIT tags by site and species in 2015 and 2016. Data extends through 9/2/16.

Through a combination of antenna data and recaptures, we were able to detect fish movement between sites. Although fish were commonly recaptured in the same site that they were first tagged in, they were also frequently recorded in other habitats, indicating a broad range of movement, including upstream and downstream, from the mainstem into marsh channels, and from marsh channels into mainstem habitats (Figure 18).

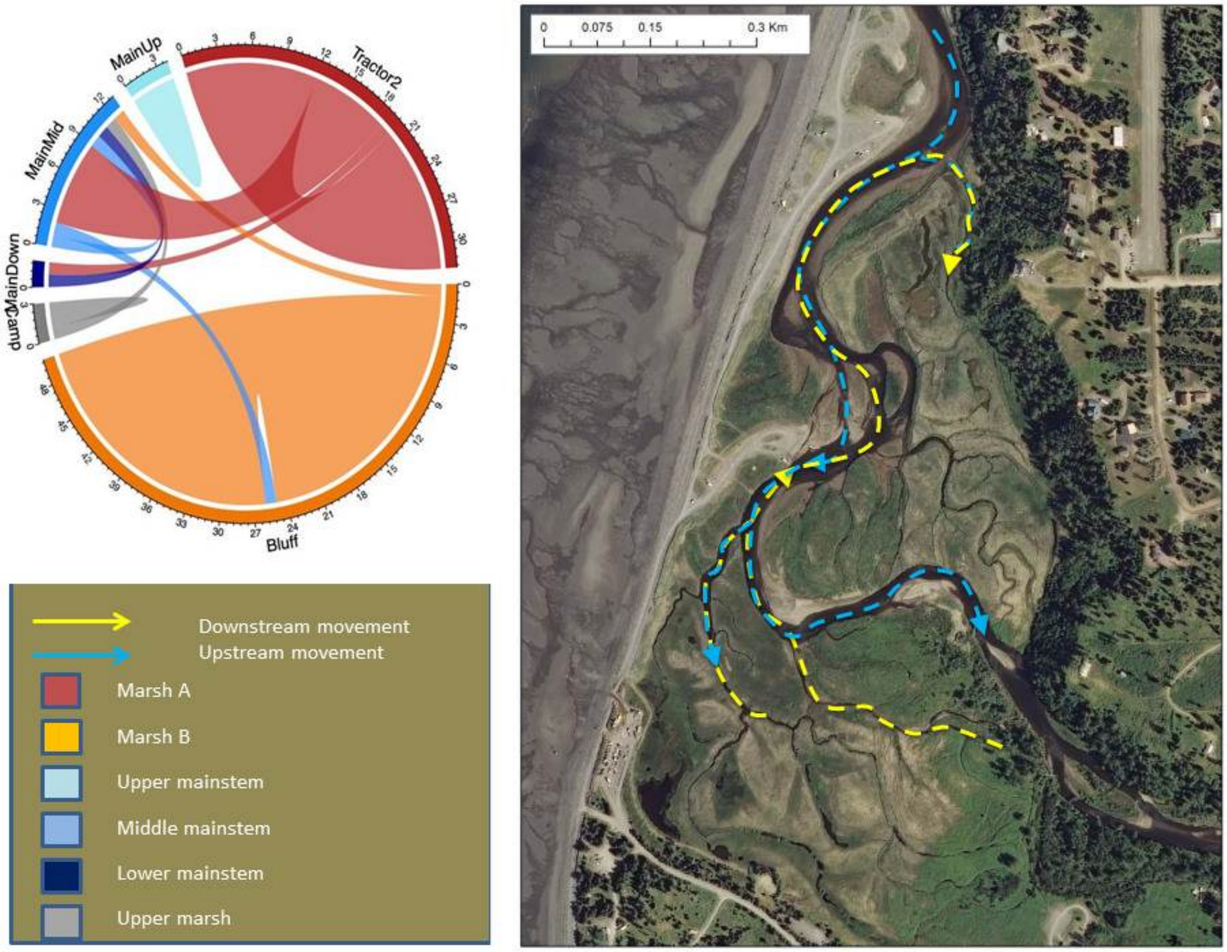

Figure 18. (*left top)* A chord diagram indicating the number of recaptured Coho Salmon and their movement among sites (colored by original tagging location); and (*right)* generalized observed patterns of movement.

Recaptured juvenile Coho Salmon and staghorn sculpin showed an average standard growth rate (% increase in body weight per day) of 1.43% and 3.06%, respectively, over the 2016 season. In terms of length, this corresponds to approximately 0.37 mm/d for Coho Salmon and 0.91 mm/d, for staghorn sculpin (Figure 19).

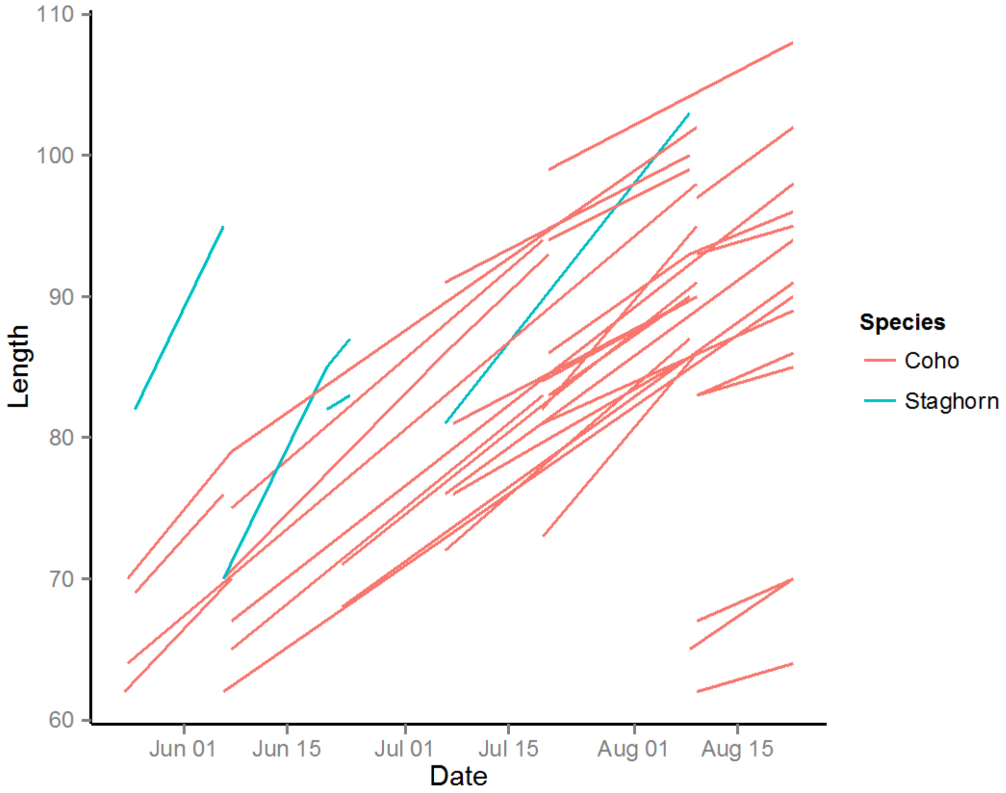

Figure 19. Growth of recaptured fish over time. Each line segment refers to an individual fish indicating its length when it was initially tagged and subsequently recaptured. Data presented here are from 2016 only, extending through 9/2/16.

Discussion

Coho and Chinook Salmon have different life history types, with some individuals spending considerable portions of their life cycle (1-3 years) in freshwater and estuarine environments before migrating to open ocean. It is believed that this diversity in life histories results in high resilience of these salmon populations to environmental variability and change (Bottom *et al.* 2011). Results from this project show that distinct environmental conditions can exist even within a rather small estuary, such as the Anchor, and that juvenile salmon are present across a broad range of habitats. Juvenile Coho Salmon were present in marsh channels and mainstem habitats, with pulses of small, age 0, fish coming into the estuary throughout the summer and fall. The longest record of estuary residence from this study was a Coho Salmon that was initially tagged in mid-June of 2015 in a small channel near the upper mainstem site that went dry soon after the tagging event. Although we thought that the fish present at that site would be trapped by low river flows, it is likely that high tide events allowed the fish to escape, enter the mainstem, and eventually make its way to the mid marsh channel, where it was recaptured 327 days later (mid-June 2016). Residing nearly a year in the estuary, this fish illustrates the long term use of estuary habitats that may be a distinct life history strategy for juvenile Coho Salmon (Miller and Sadro 2003; Koski 2009, Hoem Neher *et al* 2013a). This adds to the growing recognition that estuaries may support alternative life history strategies of Coho Salmon that contribute to overall population resilience and health (Schindler 2010; Hoem Neher *et al* 2013a; Hoem Neher *et al* 2013b).

Chinook Salmon were predominantly present in mainstem sites, although there was some movement into the marsh channel sites as well. In general, Chinook Salmon had lower residence times within the estuary than Coho Salmon, with the longest record being a juvenile Chinook that was tagged in the middle mainstem site in early July, and was detected at a PIT antenna nearly 30 days later in the mid marsh channel. Interestingly, two other species; staghorn sculpin and Dolly Varden, also exhibited long residence times within the estuary (189 days, and 231 days, respectively). Few Chinook Salmon were captured in 2015, which is likely due to the very low adult returns of the previous year. In 2014, roughly 2,500 adults returned, whereas in 2015, over 10,000 adults Chinook Salmon returned to the Anchor River, with the result that far more juvenile Chinook Salmon were rearing in the estuary in the 2016 season.

The range of environmental conditions present at the different sites in the Anchor, including fast flowing mainstem sites that are well mixed, with high dissolved oxygen levels, to marsh channel sites that have low flows, and a high degree of stratification, provide a broad suite of conditions, and juvenile salmon apparently take advantage of their ability to move between habitats, as evidenced by the observed movement patterns. Further study is needed to understand the drivers of movement. The presence of other fish species likely has some influence on juvenile salmon. For example, small staghorn sculpin were observed as prey for juvenile salmon, yet will become predators of juvenile salmon when they are larger.

The high densities, prolonged residence, movement and growth of juvenile salmon in the Anchor River estuary support the importance of even relatively small estuaries to juvenile salmon rearing. The amount of movement among estuary habitat types supports the concept of conservation for the entire estuary in order to maintain full habitat potential and resilience.

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