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

GRANT: T-36-1
PROJECT: P-01

WORK LOCATION: Homer
PERIOD DURATION: July 1, 2016–June 30, 2017

PROJECT REPORTING PERIOD: July 1, 20156–June 30, 2017

PROJECT TITLE: Habitat models for juvenile salmon rearing in Cook Inlet estuaries.

PROJECT AUTHORS: Coowe Moss Walker and Brianna Pierce

Project Objectives:

The purpose of the project was to develop models of environmental variables, and fish community characteristics that are important for juvenile salmon estuary habitat use in south-central, Alaska.

Project objectives:

Objective 1: Demonstrate the influence of fish community predators on juvenile salmon use of estuary habitats.

Objective 2: Parameterize a model of estuary habitat channel features that relate to juvenile salmon occupancy

Objective 3: Validate the model in Kenai Peninsula/Cook Inlet estuaries,

Summary of Project Accomplishments:

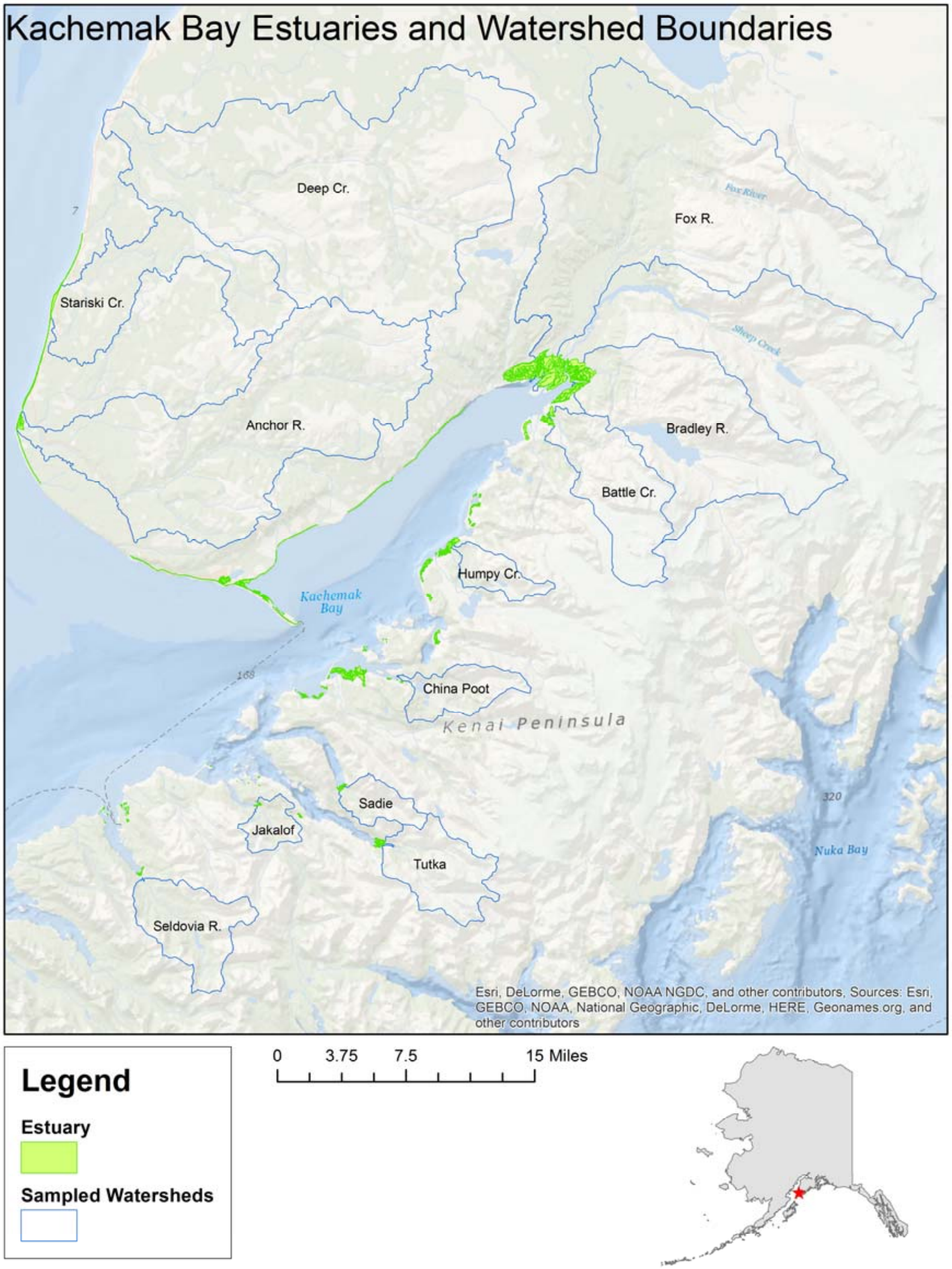
This project explores key aspects of juvenile salmon, as well as other fish, use of estuary habitats in lower Cook Inlet, south-central Alaska. We investigated twelve estuaries representing a variety of estuary habitat settings, and sampled a broad range of potential habitats in each estuary, including river mainstem, tributary, distributary, backwaters, blind marsh channels and tide pools. Habitats were sampled for environmental variables and fish. In our analyses, we explored patterns in presence/absence, density (represented as catch-per-unit effort), and fish community structure relating the sampled environmental variables. In general, habitats types were similar environmentally across estuaries. However, a few estuaries were distinctly different indicating that they had different conditions across all habitat types. Fish were captured at most sampling locations, with 3,812 fish representing sixteen species from seven families. Despite the low diversity, (which is typical of estuaries), fish community composition varied among estuaries and habitat types. Some estuaries showed little variability in fish community structure, while others were much more variable. The biggest distinctions were between mainstem/distributary channel habitats (more variable fish communities) and marsh channels (less variable). Although known juvenile salmon predators, such as staghorn sculpin (*Leptocottus armatus*) were widely present in the habitats sampled, we were unable to demonstrate the influence of fish community predators on juvenile salmon use of those habitats. All five species of Pacific salmon were present, with juvenile Coho Salmon (*Oncorhynchus kisutch)* being ubiquitous in almost all the sampled estuaries, juvenile Chum Salmon (*O. keta)* were the next most common, and juvenile Pink Salmon (*O. gorbushcha)*, Chinook Salmon (*O.*

tshawytscha) and Sockeye Salmon (*O. nerka)* found occasionally. Mainstem and distributary channel fish community composition was more variable and distinct from other habitats, while blind marsh channels tended to have a less variable community. The presence of numerous young-of-the-year Tidepool Sculpin (*Oligocottus maculossus*) at several sites, usually distributary channels, strongly influenced the analyses. Fish that distinguished different habitat types in the ordination analyses include Coastrange Sculpin (*Cottus aleuticus*), and Pink Salmon generally associated with mainstem sites, and Staghorn Sculpin and Threespine Sticklebacks (*Gasterosteus aculeatus*) associated with blind marsh channels. Greater maximum depth, which was generally a feature of blind marsh channels was correlated with Coho Salmon and Starry Flounder (*Platichthys stellatus*) abundance. Stratification of both temperature and salinity, also a feature of blind marsh channels, was correlated with higher abundances of Sockeye and Chum Salmon. Collectively, project results demonstrate that the estuaries of lower Cook Inlet support a diversity of habitat types, each with distinct environmental characteristics and support a variety of fish species, including all five species of Pacific salmon.

Figure 1. Examples of some common estuary habitats; distributary channels (left), and tidal pools (right).

Study Sites:

Twelve estuaries at the southern end of Cook Inlet (Figure 2), were sampled. Cook Inlet has a very large tidal range (> 8 m depth) that can potentially create broad ecotones of habitat conditions within estuaries. Within each estuary, we sampled representative sites of all available habitat types (Tables 1 and 2, Figure 3). We also sampled one estuary (Anchor River) intensively to examine juvenile Coho movement relative to potential predators.



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 2. The twelve sampled estuaries sampled for this project.

Table 1. Operational definitions of estuary habitat types sampled.

Habitat	Definition
Mainstem	The primary channel that drains the watershed through the oligohaline marsh. Sites within the mainstem were further classified as: • Upper mainstem: At the upper extent of saltwater influence as determined by the presence of salt-intolerant vegetation. • Middle mainstem: Approximately midway through the marsh. • Lower mainstem: At the lower extent of saltmarsh vegetation.
Blind side channel	A channel connected to the mainstem or a distributary channel at one end but closed at the other end. Maintains partial or complete connection at low tides. Often dendritic.
Tidal pool	A pool within the vegetated marsh or intertidal zone that is partially or completely isolated during low tides. May drain into the mainstem or distributary channels or directly to the nearshore.
Backwater	A section of calm water adjoining a mainstem or distributary channel.
Tributary	A small channel contributing freshwater to the wetland that is separate from the primary drainage. May or may not join with the mainstem or distributary channels.
Distributary	A channel that branches off of the mainstem and may or may not rejoin with the mainstem or other distributary channels lower in the estuary.

Table 2. Sample sizes by estuary and habitat. Numbers in parentheses reflect samples where no fish were captured.

	Backwater	Blind side channel	Distributary channel	Mainstem channel	Tidal pool	Tributary channel	*Total*
Anchor	0	2	0	3	0	0	*5*
Battle	1	8 (1)	0	3	0	1	*13 (1)*
Bradley	0	2	0 (1)	3	0	2	*7 (1)*
Deep	0	3	0	3	0	0	*6 (1)*
Humpy	0	1	0	3	0	0	*4*
Jakolof	1	1	1 (1)	1 (2)	1	0	*5 (3)*
Sadie	0	2	0	4 (1)	0	0	*6 (1)*
Seldovia	0	1	3	2	2	1	*9*
Silver	1	0	0	2	1	0	*4*
Stariski	0	2	0	3	0	0	*5*
Stonehocker	0	4	0	1 (1)	0	0	*5 (1)*
Tutka	0	2	4 (1)	1 (1)	0	0	*7 (2)*
Total	*3*	*28 (1)*	*8 (3)*	*29 (5)*	*4*	*4*	*76 (9)*

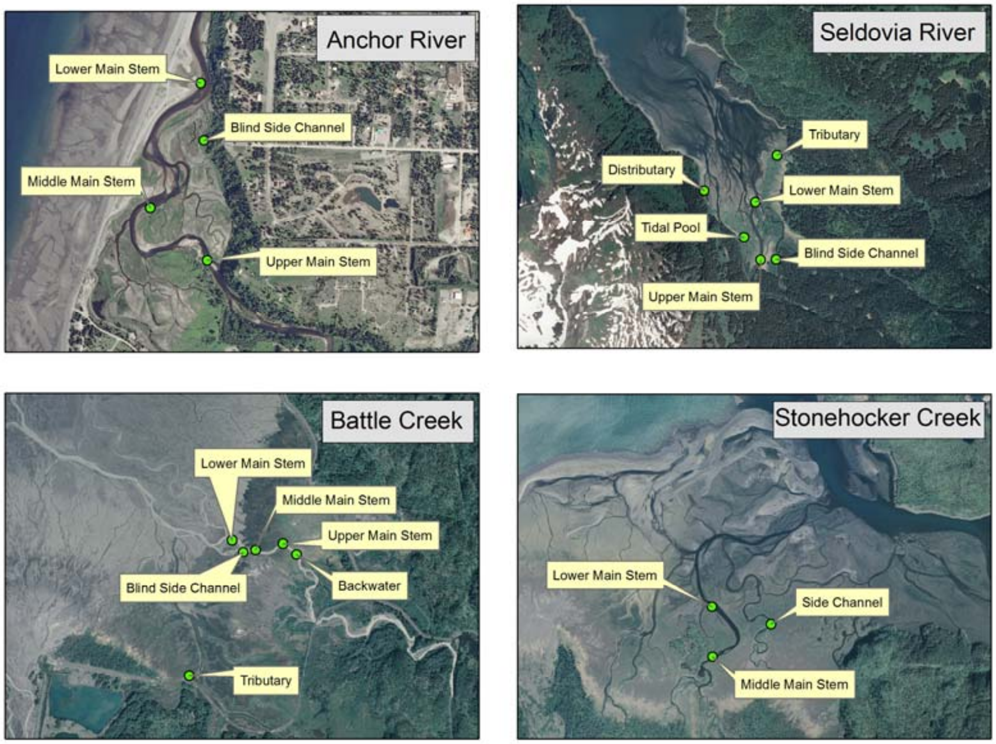


Figure 2. Examples of habitat types sampled within the estuaries shown on aerial images. (Multiple samples were taken in each habitat type- this figure is for illustrative purposes to identify habitats, and not to show the total number of sites sampled in each estuary.)

Methods
Estuary survey sampling took place from August 3-19, 2016 and May 31-June 15, 2017. In 2016, we sampled the Anchor River, Deep Creek, Stonehocker Creek, Silver Salmon Creek, Humpy Creek and Sadie Cove estuaries. In 2017, we sampled Tutka Bay, Seldovia Creek, Jakalof Bay, Battle Creek and Bradley River estuaries. Prior to accessing the estuaries, we identified potential sampling locations based on aerial images (see Figure 2). At each sampling location, we recorded GPS coordinates, and collected point measurements of maximum depth, flow, substrate, presence/type of algae. 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.) in 2016. However preliminary turbidity data was not found to be useful, and so measurements were not continued in 2017, and turbidity data was not included in the final analyses. Fish were sampled by seining, using a pole seine (2.2 × 6 m, 0.3 cm mesh) pulled across the channel (see Figure 1). Fish were counted, identified to species, measured, and returned to the channel. To compare fish catch samples across sites, we used log transformed catch per unit effort (CPUE).

$$\begin{gathered} CPUE = \#fish\ per\ area\ sampled \\ transect\ length * channel\ width \end{gathered}$$

We used non metric multidimensional scaling ordination plots, and cluster analysis to identify potential patterns in the different estuaries and habitat types. Environmental conditions and fish community were similar among mainstem sites sampled along the continuum from upper (near the tree line) to lower (near the ocean). Therefore, all river mainstem sites were combined for analyses.

In one estuary, the Anchor River, we selected three tidal channels representing different estuarine habitats as sampling sites for monitoring juvenile Coho Salmon, Chinook Salmon, Dolly Varden and Staghorn Sculpin immigration and emigration, as a way to demonstrate the influence of predators (large Dolly Varden and Staghorn Sculpin) on juvenile salmon movements. At each sampling, we used seining to capture fish within the channels; as described in Walker *et al*. 2013. Double block-nets were used to close channels within 25 m reaches and all captured juvenile Chinook Salmon, Coho Salmon, Dolly Varden and Staghorn Sculpin were marked, if large enough (> 60 mm, age 1+ fish), with PIT ((passive integrated transponder)) tags, an electronic marking system that allows each fish to be assigned a unique identification code (Roussel *et al*. 2000). We utilized PIT tag reading antennas in the channel networks that allowed us to track movements of tagged fish. The antenna arrays are described in detail in Walker and Pierce 2016. Basically, each antenna array consisted of two antennas spaced roughly 10 m apart in order to detect movement direction. Channels were sampled twice a month beginning in early July and continuing through the end of October. A handheld PIT tag reader was used to detect fish that were marked during previous samplings, and all untagged juvenile salmonids were tagged if they were >60mm, and did not have a previous tag. We recorded length and weight for recaptured fish, as well as newly captured fish. Patterns of movement of juvenile salmon, and their potential fish predators (Staghorn Sculpin and Dolly Varden) were analyzed relative to estuary channel physical conditions across seasons.

Results

Fish were captured at 76 out of the 85 sites sampled across 12 estuaries (counting Silver Creek and Stonehocker Creek, which are different rivers flowing into China Poot estuary, separately). A total of 3,812 fish representing 16 species from 7 families were captured. Staghorn Sculpin were the most frequently captured fish (occurring in 42% of all samples), followed by Coho Salmon (38%) and Starry Flounder (33%). Coho Salmon were the numerically dominant fish species comprising 25% of the total catch, followed by Chum Salmon (20%), and Threespine Stickleback (18%). When they were present, tidepool sculpin (young of the year), Chum Salmon, Coho Salmon, and threespine stickleback had the greatest average density – all around 1 fish for every 2 m^2 (Figure 3, Table 3).

Salinity, depth, temperature, dissolved oxygen and substrates were substantially variable within the different habitat types of the estuaries, and also between estuaries (Table 4, Figures 4 and 5). Mainstem sites tended to have fairly consistent conditions (small standard deviation ellipsis), while backwater, distributary, and tidal pool habitats were highly variable (Figure 6). Some estuaries, such as Seldovia, showed high variability in environmental conditions across all habitats, while others, such as Sadie and Deep Creek, had a more narrow range. However, it is important to note that sample size varied among estuaries and habitat types thus influencing the variance. For example, one sample from a backwater sites in Seldovia that was warm and thermally stratified strongly influenced both the Seldovia and backwater ellipses (Table 2, Figure 6).

Table 3. Summary of sampled fish species. Frequency of occurrence is the proportion of samples in which a given species was present. Proportion of total catch is based on numerical abundance. Average density was calculated from only those samples in which a given species was present. Fish were measured by fork length (for species with a forked tail) or total length (species without a forked tail). Fish smaller than 20 mm were not measured.

						Fish length (mm)	
Family	**Species**	**Common name**	**Frequency of occurrence**	**Proportion of total catch**	**Average density (fish/m^2)**	**Median**	**Range**
Agonidae	*Pallasina barbata*	Tubesnout Poacher	0.01	0.00	0.01	44	--
Cottidate	*Cottus aleuticus*	Coastrange Sculpin	0.21	0.01	0.05	31.5	< 20 – 50
	Clinocottus acuticeps	Sharpnose Sculpin	0.11	0.01	0.08	35.5	< 20 – 49
	Leptocottus armatus	Staghorn Sculpin	0.42	0.15	0.28	75	< 20 – 208
	Oligocottus maculosus	Tidepool Sculpin	0.09	0.06	0.55	< 20	< 20
		Sculpin sp.	0.03	0.00	0.02	--	--
Gaddidae		Gaddid sp.	0.01	0.00	0.02	35	--
Gasterosteidae	*Pungitius pungitius*	Ninespine Stickleback	0.07	0.00	0.02	52	44 – 57
	Gasterosteus aculeatus	Threespine Stickleback	0.29	0.18	0.48	63	< 20 – 84
Pholidae	*Pholis laeta*	Crescent Gunnel	0.07	0.00	0.04	115	52 – 157
Pleuronectidae	*Platichthys stellatus*	Starry Flounder	0.33	0.04	0.09	48.5	< 20 – 247
Salmonidae	*Oncorhynchus tshawytscha*	Chinook Salmon	0.07	0.01	0.13	73	45 – 89
	Oncorhynchus keta	Chum Salmon	0.29	0.20	0.53	49	23 – 84
	Oncorhynchus kisutch	Coho Salmon	0.38	0.25	0.51	68	29 – 132
	Oncorhynchus gorbuscha	Pink Salmon	0.08	0.01	0.06	38.5	31 – 620
	Oncorhynchus nerka	Sockeye Salmon	0.09	0.03	0.26	57.5	29 – 70
	Salvelinus malma	Dolly Varden	0.20	0.05	0.18	145	25 – 325

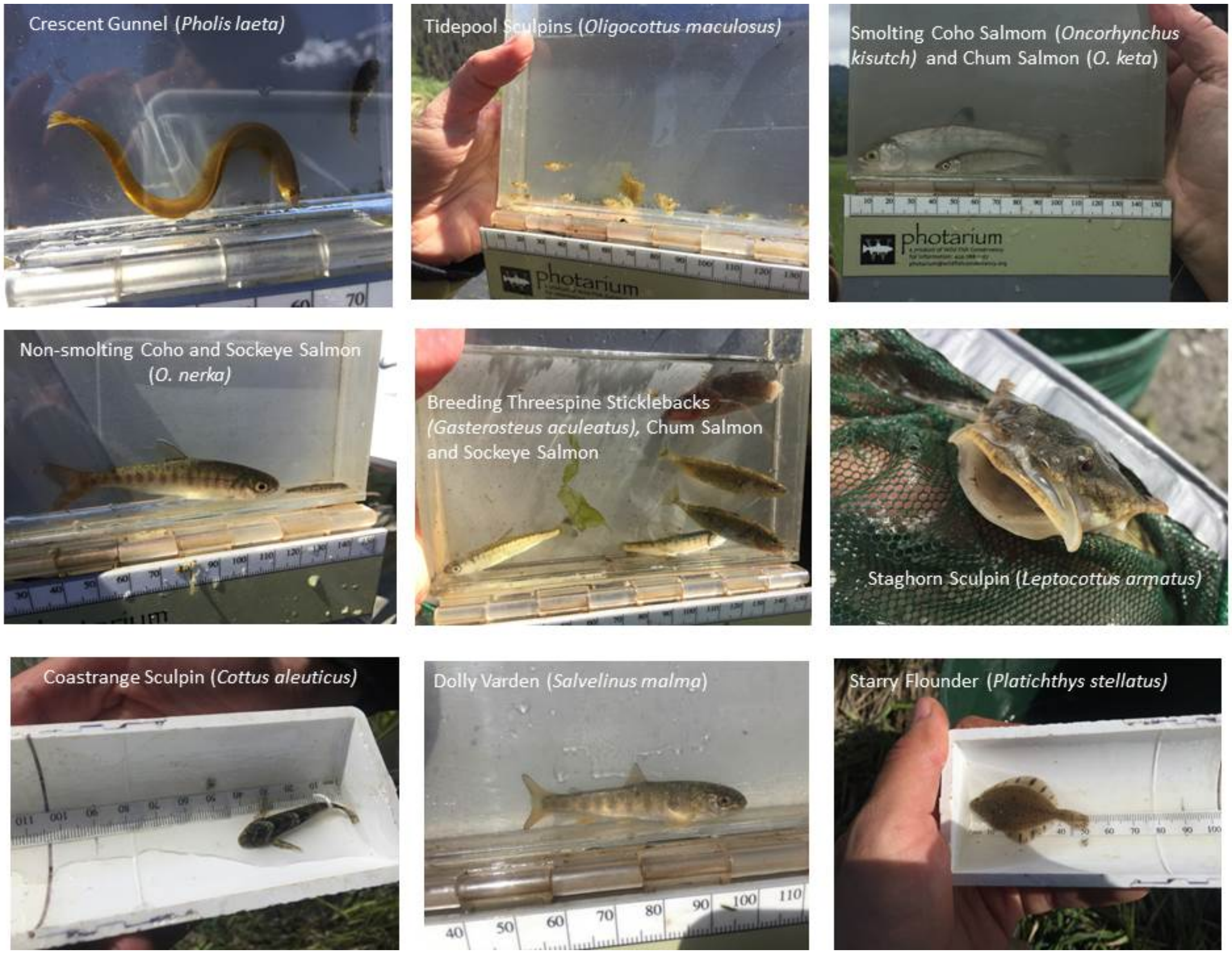


Figure 3. Fish species commonly found in the sampled estuaries.

Table 4. Summary of environmental metrics across all estuaries and habitat types.

Metric	**Mean**	**Range**
Thalweg depth (m)	0.5	0.1 – 1.1
Thalweg flow (m/s)	0.3	0.0 – 1.2
Edge flow (m/s)	0.2	0.0 – 0.9
Temperature (C)	9.2	3.7 – 22.2
Salinity (psu)	1.4	0.0 – 17.1
Dissolved oxygen (mg/L)	11.1	3.2 – 17.0
Percent cover		
Silt	33.9	0 – 100
Sand	16.6	0 – 80
Fine gravel	29.1	0 – 90
Coarse gravel	19.6	0 – 90
Cobble	0.9	0 – 20
Submerged aquatic vegetation	11.5	0 – 90

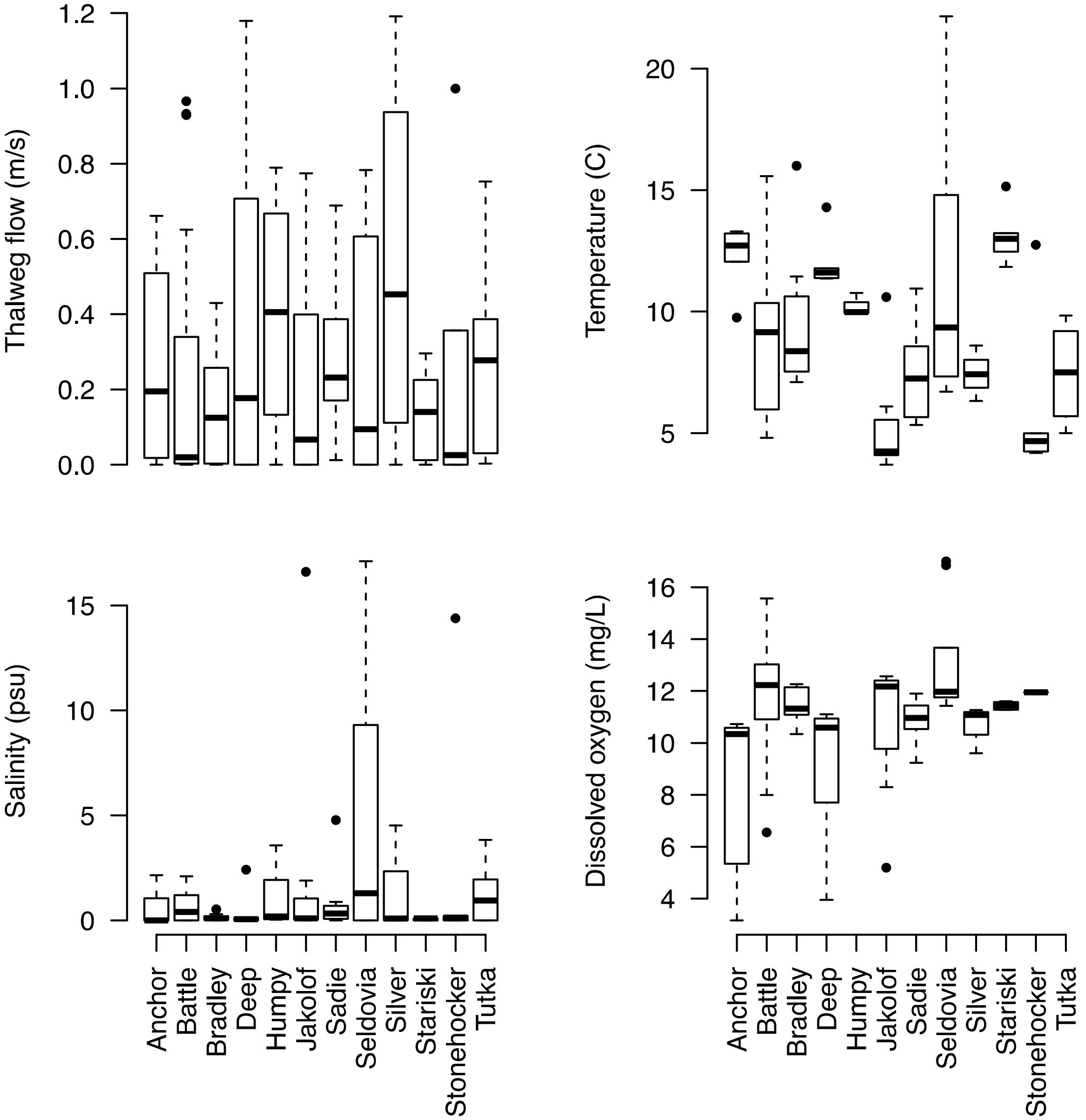


Figure 4. Summary of environmental metrics observed at each estuary. Note the substantial variability both within and among estuaries. (Dissolved oxygen was not measured at Humpy Creek, Tutka Creek, or most of Stonehocker Creek due to equipment difficulties.)

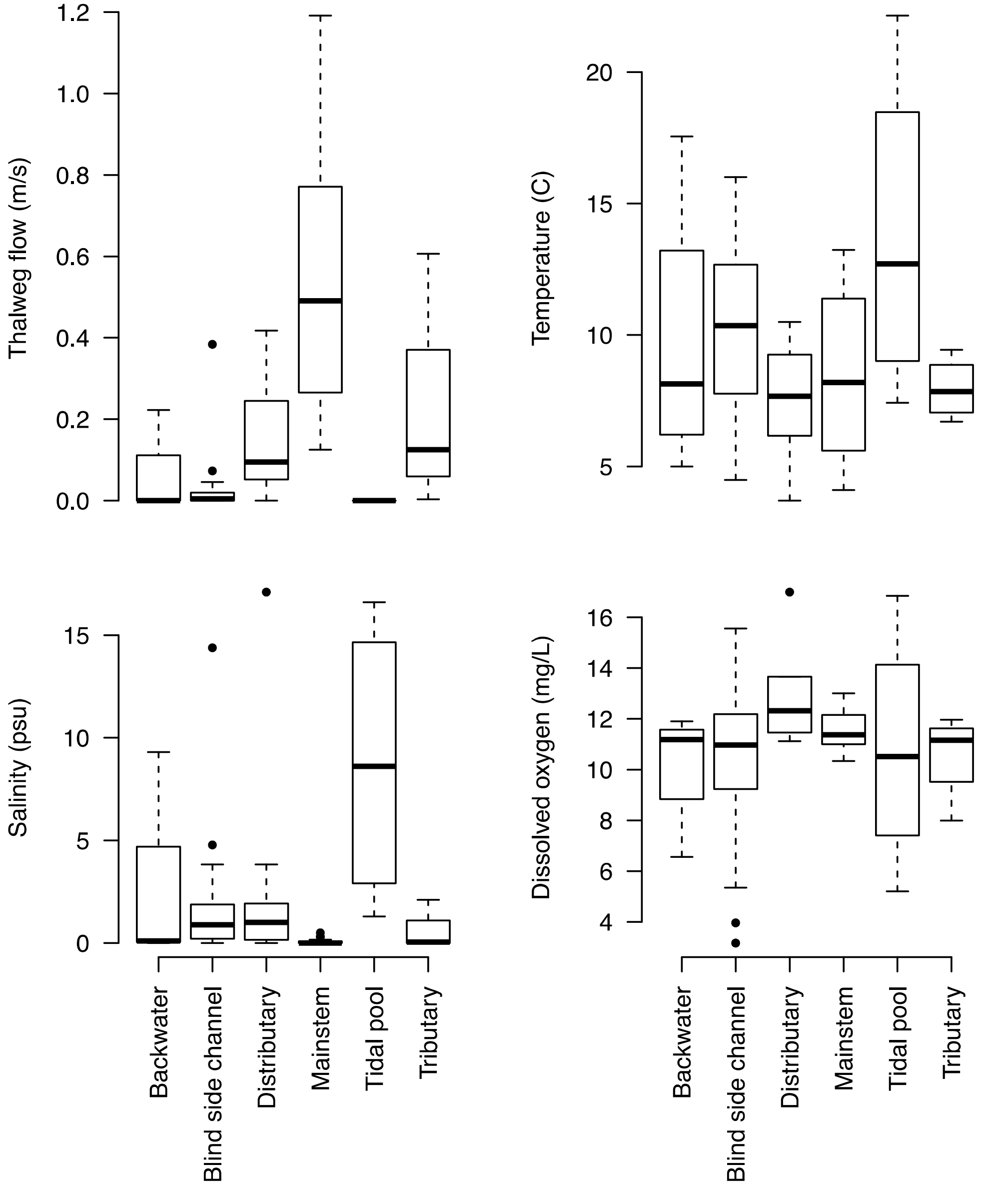


Figure 5. Summary of environmental metrics by habitat type. Note the substantial variability both within and among habitat type.

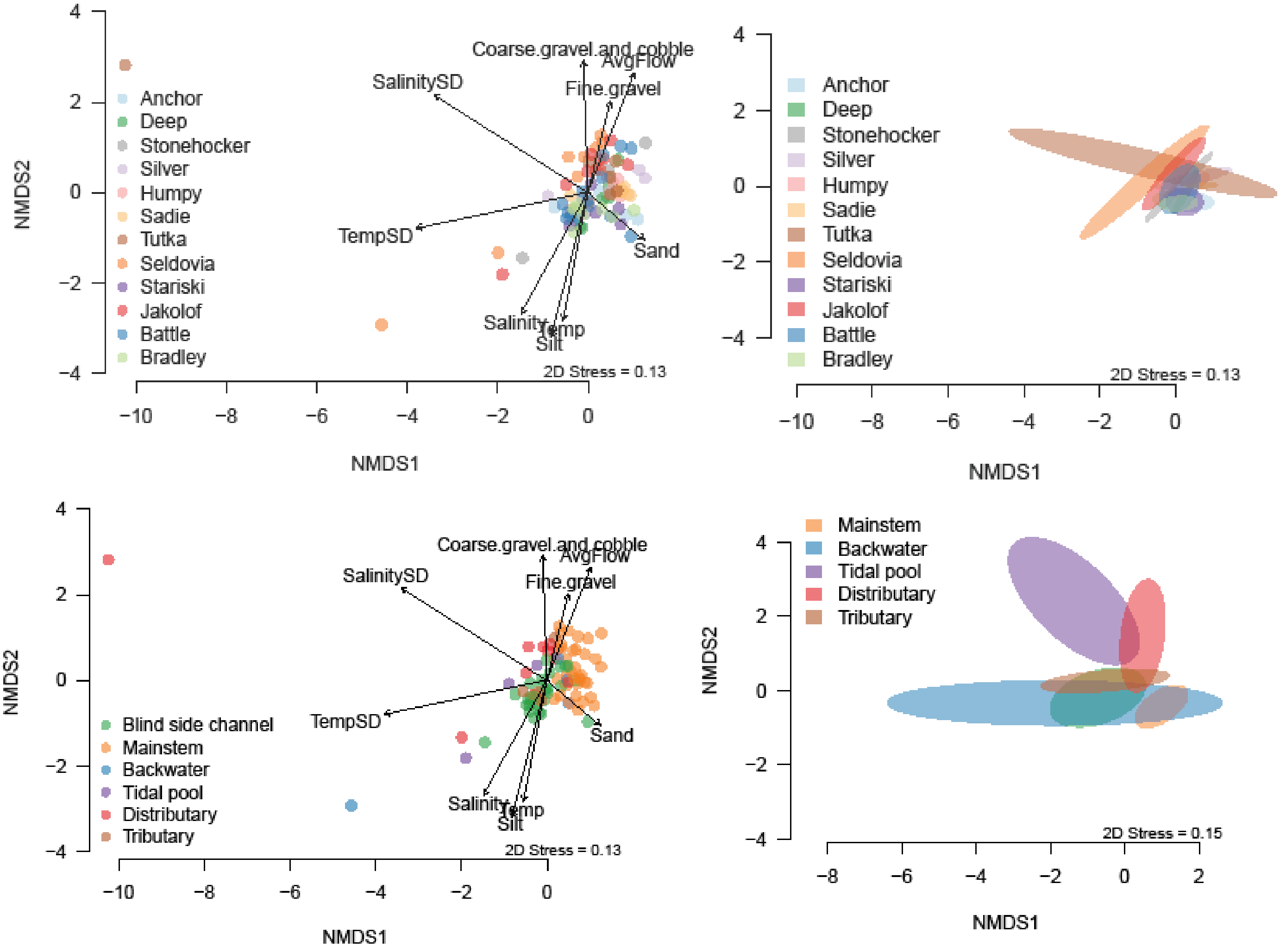


Figure 6. Nonmetric multidimensional scaling ordination plots of environmental variables recorded at 84 sites in 12 estuaries colored by estuary (upper panels) or habitat type (lower panels). Left panels: Points represent individual sites and vectors represent the degree and magnitude of the variable loadings that significantly contributed to the ordination (Monte Carlo permutation, $p<0.05$; Thalweg depth was the only nonsignificant variable). SD = standard deviation and represents the degree of stratification for each variable. Right panels: Ellipses represent the standard deviation from the group centroid with groups defined by estuary (upper panel) or habitat type (lower panel). The observed stress value was lower than expected if there were no relationships among environmental variables (Monte Carlo permutation, $p=0.040$). One outlier was removed to facilitate data visualization: a tidal pool that was uncharacteristically warm with high salinity and strong stratification. Data were z-score standardized and ordination was performed on the sample-wise Euclidean distance.

Despite the low diversity typical of estuaries, the fish community composition varied among estuaries and habitat types. Some estuaries, like Stariski, showed little variability in fish community structure, while others, like Seldovia, were much more variable, as shown by the size of the ellipses in Figure 7, upper panel. Mainstem and distributary channel fish communities were more variable, and distinct from the other habitats, while blind marsh channels tended to have a less variable community typified by an abundance of Staghorn Sculpin and Threespine Stickleback (Figure 7, lower panel).

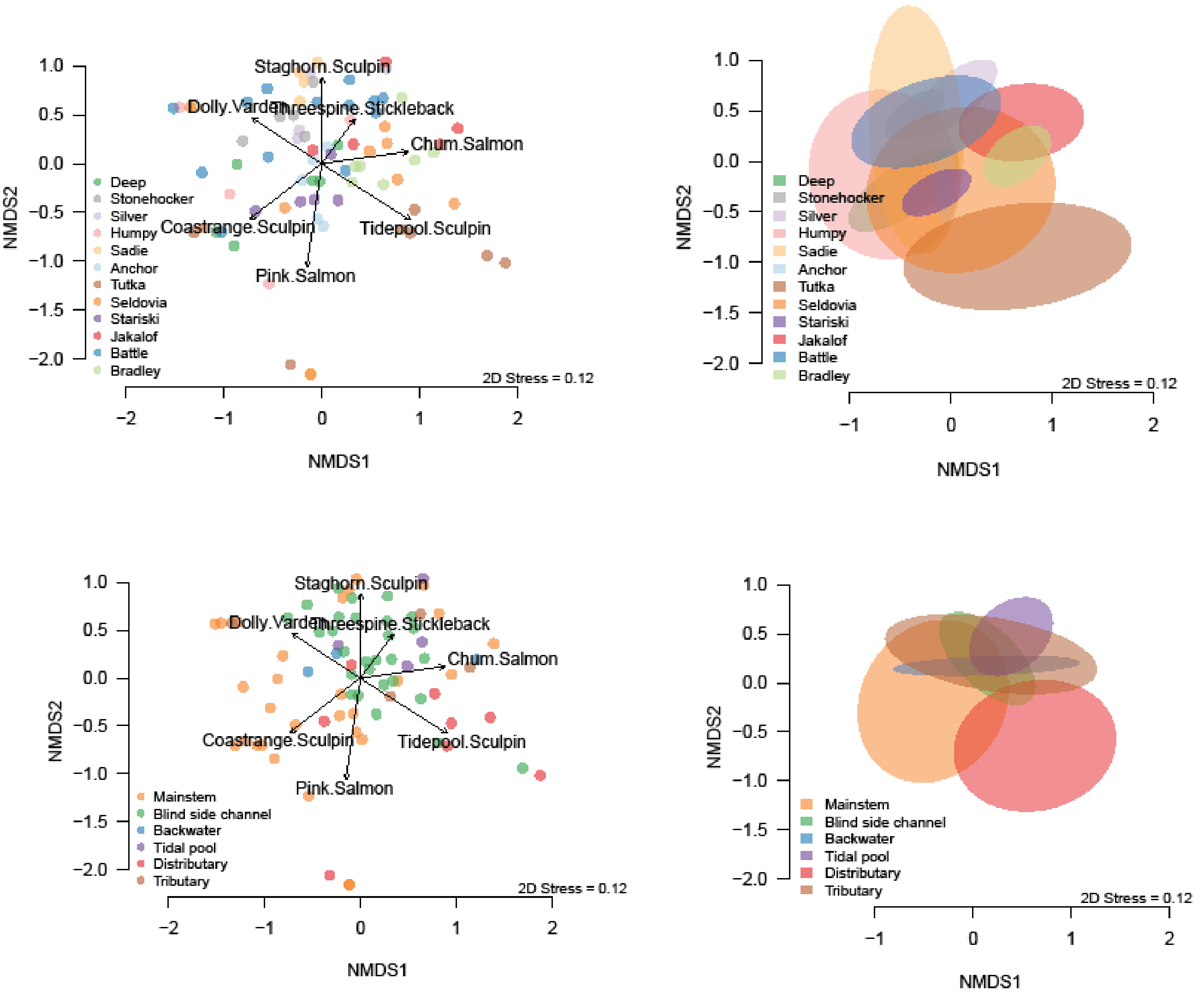


Figure 7. Nonmetric multidimensional scaling ordination plots of fish species abundance (CPUE) recorded at 76 sites in 12 estuaries colored by estuary (upper panels) or habitat type (lower panels). Left panels: Points represent individual sites and vectors represent the degree and magnitude of the species loadings that significantly contributed to the ordination (Monte Carlo permutation, $p<0.05$). Right panels: Ellipses represent the standard deviation from the group centroid with groups defined by estuary (upper panel) or habitat type (lower panel). Rare species (occurring in <5% of samples) were removed prior to analysis. Data were log-transformed and ordination was performed using Bray-Curtis dissimilarity.

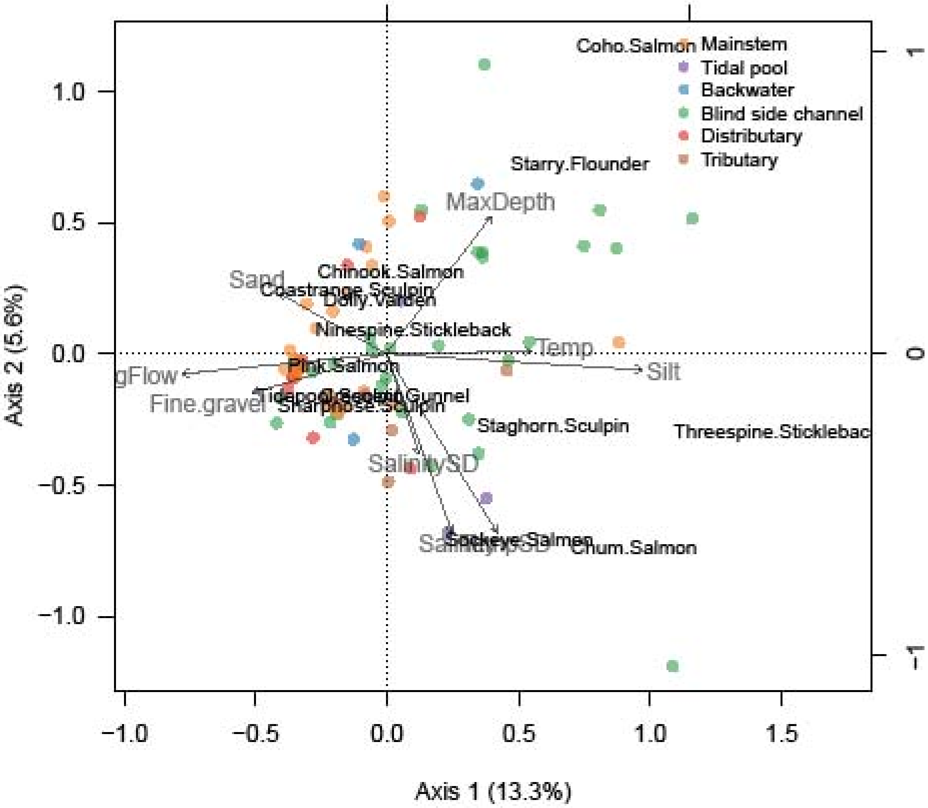


Figure 8. Constrained analysis of principle components (CAP; also known as distance-based redundancy analysis) triplot. Scaling is symmetrical between site and species scores. Points represent samples and are colored by habitat type. Samples located close in ordination space tend to be compositionally similar and are usually dominated by the nearby species. Vectors depict the magnitude and gradient of environmental variable loadings. The location of species in perpendicular relation to arrows depicts their response to that environmental metric. The measured environmental metrics explain 25.9% of the variability in fish species abundance, which is greater than would be expected by chance (Monte Carlo permutation, $F_{9,66}=2.56$, $p=0.001$). Rare species (occurring in <5% of samples) were removed, and data were z-score standardized and fish data were log-transformed prior to analysis.

A regression-tree analysis to see which environmental variables related to fish community features was not very informative (Figure 9).

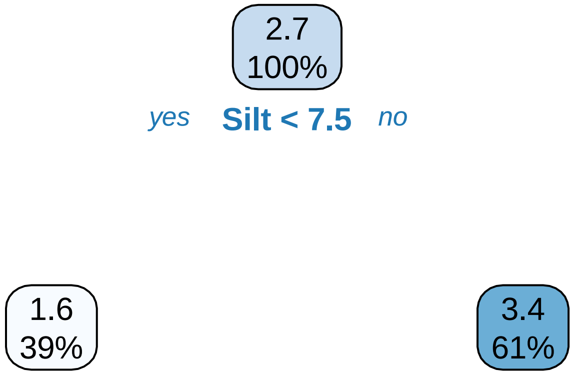


Figure 9. Species richness regression tree. Average species richness was 2.7. Silt percent cover was the only variable that significantly contributed to the regression tree with sites that had < 7.5% silt cover having an average species richness of 1.6 (39% of sites) and sites with > 7.5% cover having an average richness of 3.4 (61% of sites).

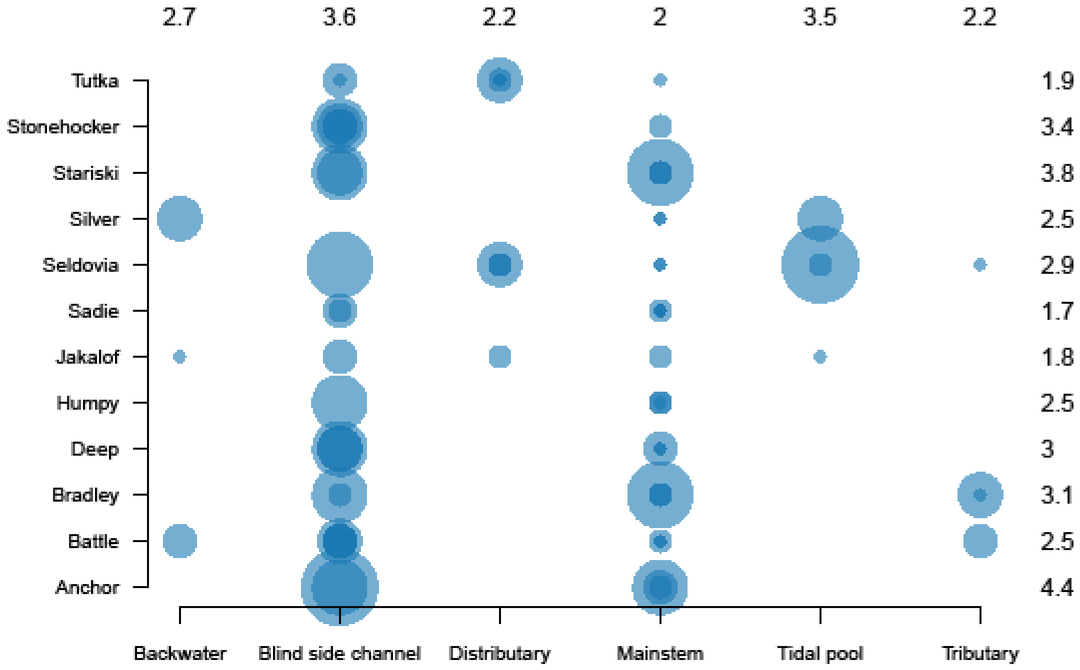


Figure 10. Species richness by estuary and habitat type. Each point represents a sample and is scaled by species richness. Points are semitransparent to view over-plotting. Margin values give the mean species richness for each estuary (rows) or habitat type (columns).

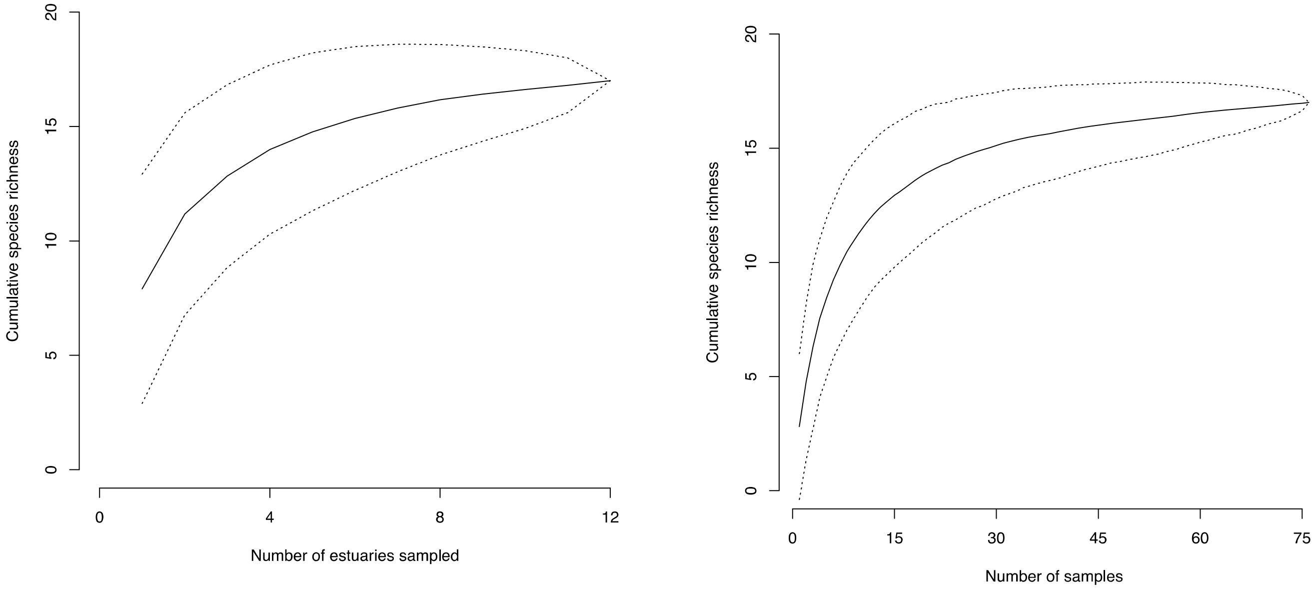


Figure 11. Cumulative species curve to evaluate estuary sample size, with samples pooled within each estuary (left) and total sample size sufficiency, with samples pooled across all estuaries and habitat types (right).) Lines represent the mean (solid) and standard deviation (dashed) from random permutations of the data. Sample sizes were deemed sufficient for describing the fish community as the slope of a linear regression line through the five terminal data points was not significantly different from zero ($b < 0.001$, $p < 0.001$), and the number of estuaries sampled was deemed sufficient for describing the fish community as the slope of a linear regression line through the five terminal data points was not significantly different from zero (b 0.3, t=3, p= 0.06)

Our study of fish community predation dynamics was hindered by the low number of predator fish that we captured, and subsequently detected (Table 5). However, we were able to gain understanding of how tidal flows affect fish movement in different channels (Figure 12).

Table 5. Number of fish tagged, recaptured and detected at stationary PIT arrays in the Anchor River estuary by species.

Species	Number Tagged	Number Recaptured	Number Detected
Chinook salmon	305	0	15 (5%)
Coho salmon	708	36(5%)	379 (54%)
Staghorn sculpin	67	5 (8%)	16 (24%)

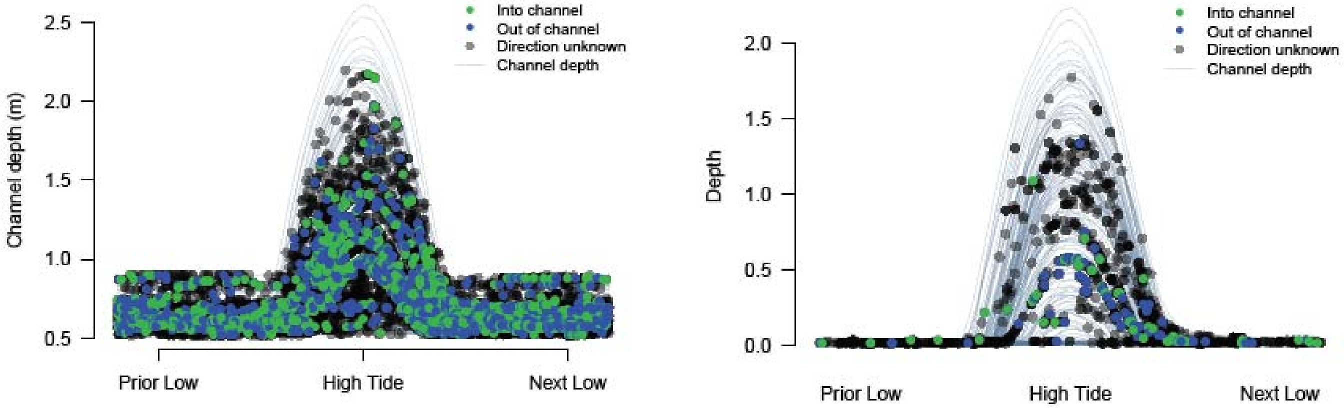


Figure 12. Detections of PIT-tagged juvenile Coho and Chinook salmon by tidal stage, channel depth, and time of day in the continually connected marsh channel (left), and the marginally connected marsh channel (right), between 25 May and 1 September 2016, with channel depth normalized tidal stage. Points denote a PIT-tag detection and are colored by movement direction (black points representing unknown direction of movement are semi-transparent to reduce over-plotting). Fish could easily pass undetected when PIT antennas were fully submerged at channel depths ≥ 0.6 m (from Pierce 2016).

Discussion

This study supports our previous findings from the Anchor River (Walker and Pierce 2016), and Fox River (Hoem Neher 2013a, Hoem Neher 2013b) in showing that the estuaries of the Cook Inlet area provide a broad range of environmental conditions and different habitat types. In the previous studies, we investigated the glacial Fox river estuary, and snow-melt, groundwater supported Anchor River estuary. Our new findings result from a broader sampling a broader range of estuaries. From the fast flowing mainstem sites, characterized by gravel or sand substrates, high flows, well mixed water columns, with high dissolved oxygen levels, to marsh channel sites that are warmer, more saline, stratified and tend to have silty substrates, these estuaries contained a broad suite of conditions that generally showed stronger similarity within habitat types than within estuaries (ie a mainstem site at one estuary was more similar environmentally to mainstem sites in other estuaries than to other habitats within the same estuary). However, some estuaries were distinctly different from other estuaries (for example, in Figure 6, the Jakolof and Bradley ellipses do not overlap indicating that they generally had different conditions across all sites/habitat types).

In trying to understand relationships between habitat types, estuaries and fish communities, we completed a number of ordination and cluster analyses. General patterns were as follows:

Group 1:Mainstem river sites. This group is characterized by coarser substrates (gravel/cobble/sand), moderate flows and variable fish community composition.

Group 2:Marsh channel sites. This groups is characterized by fine sediments, and stratified salinity and temperatures. These warm, silty, saline, and stratified sites were favored by Staghorn Sculpin, Threespine Stickleback, Coho Salmon and Starry Flounder. The latter two were most abundant in sites that had greater maximum depth, which were generally blind marsh channel sites.

Our attempt to understand the influence of potential predators on juvenile salmon estuary habitat use did not yield the results we expected. We had anticipated that smaller juvenile salmon would move in and out of marsh channels with the tidal regime, and that larger fish predators would follow when water levels were deep enough. However, the low number of tagged predator fish and antenna inefficiencies precluded us from obtaining the data necessary. We did, however, learn that the nature of the channel connectivity –whether it was fully connected to the main channel at low tide, versus only marginally connected- influenced fish movement, which could be an important measure of fish response to potential predators. Fish were detected throughout the tidal cycle and at all channel depths, indicating that they used the marginal connection to move between habitat patches, even at low tide. This could indicate that juvenile salmon are using the marsh channels as a way to avoid predators at low tides. Concurrent studies into fish community diets in the Anchor River estuary showed that when juvenile salmon are small, they are prey for larger sculpin, and when they are larger, they become predators of young of the year sculpins (Pierce 2017), which creates a compelling reason for further investigations into fish community dynamics in estuaries.

This study clearly demonstrates the importance of Cook Inlet estuaries as valuable nursery grounds for anadromous Pacific salmon, providing diverse habitats that serve as rearing areas, as well as transitional habitats between freshwater and saltwater environments. We captured all five species of Pacific Salmon, with Coho and Chum Salmon being most prevalent- found in 38% and 29% of the habitats sampled, respectively. The diversity of habitats provided in estuaries provide opportunities for juvenile salmon to express multiple life history strategies, which can lead to greater population stability (Hoem Neher 2013a, Hoem Neher 2013b). Although, the estuaries of lower Cook Inlet are largely intact, pressure from human impacts, as well as climate-related changes could result in habitat losses. Variability in environmental conditions defines estuary habitats, and as we have demonstrated with this project, an estuary should be considered a sum of its' collective parts in terms of fish communities. All estuaries, even the smaller ones sampled in this study, present important rearing habitat for juvenile salmon (and other fish), and it is vital that we protect the full range of habitats expressed in these estuaries in order to maintain sustainable fish populations.

References

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Final Report Status: This performance report is the final report for this project during the reporting period (July 1, 2016–June 30, 2017).

Prepared By:

Coowe Moss Walker
Watershed Ecologist, Kachemak Bay National Estaurine Research Reserve, UAA

Brianna Pierce,
University of Washington

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