Analysis and Reporting for Snohomish County Forage Fish Data
Task 3 – Draft Report

December 18, 2018

James Selleck (NRC)

Site Descriptions and Surveys

Forage fish are an important ecological and commercial resource in marine ecosystems, and are especially important to the health of the food web in the Salish Sea (Quinn et al. 2012, Haynes et al. 2007, Robinson et al. 2013). Common species of forage fish in Puget Sound include surf smelt (*Hypomesus pretiosus*), Pacific sand lance (*Ammodytes personatus*), Pacific herring (*Clupea pallasii*), eulachon (*Thaleichthys pacificus*), northern anchovy (*Engraulis mordax*), and Pacific sardine (*Sardinops sagax*). Chinook salmon especially rely on abundant forage fish populations (Robards et al 1999). Birds will often target sand lance during nesting season due to their seasonal availability, high calorie content, and small size for transporting back to nests (Litzow et al. 2004, Therriault et al. 2009).

The focus of this study was to evaluate spawning habitat for surf smelt and sand lance in the intertidal area of the Everett shoreline and document the effectiveness of restoration efforts, particularly the potential forage fish spawning response to beach nourishment. Restoration work focused on the removal of the bulkhead at Howarth Park, and the addition of sediments to the nearshore to improve potential habitat for smelt and sand lance spawning (Faulkner et al. 2017).

The Snohomish County MRC evaluated thirteen specific sites within a 4.5-mile stretch of shoreline for potential restoration of sand lance and surf smelt spawning habitat. The shoreline was selected based on the known drift cell between Mukilteo and Everett terminating at Howarth Park, making that site a good candidate for bulkhead removal and restoration (Quinn et al. 2012). Baseline surveys of spawning habitat began in 2011, and continued through 2014. Surveys consisted of sampling for the presence of forage fish eggs, estimating sediment grain size, and photo documentation of the beach (Herrmann et al. 2015). Beach nourishment was applied to the beach in 2016, including a large-scale restoration of the beach with the removal of the bulkhead at Howarth Park. Beach nourishment provided sand to beaches where natural supply of sand from upland eroding cliffs and coastal streams have been cut off due to the railroad. 22,156 tons of sand was placed on the different beach nourishment sites. The county conducted four years of pre-restoration spawning surveys during fall and winter months from 2011-2014 and, so far, have conducted three years of post-restoration surveys (2016-2018). Post restoration data available for this analysis was from October 2016 to November 2017. Monitoring activities are planned to continue through February 2019. Sampling was conducted once per month from October through February, when both smelt and sand lance are known to spawn regionally (WDFW Forage Fish Spawning Database). Generally, all sites were sampled in a single day, but due to weather or tides some sample periods occurred across two to three days. Sites reviewed included, in order from southwest to northeast (12 N was located west of 12 S, Figure 1): 2S, 2N, 5S, 5N, 6S, 9S, 9N, 12 N, 12 S, 13 7 S, 13 7 N, 13 10 S, and 13 10 N.

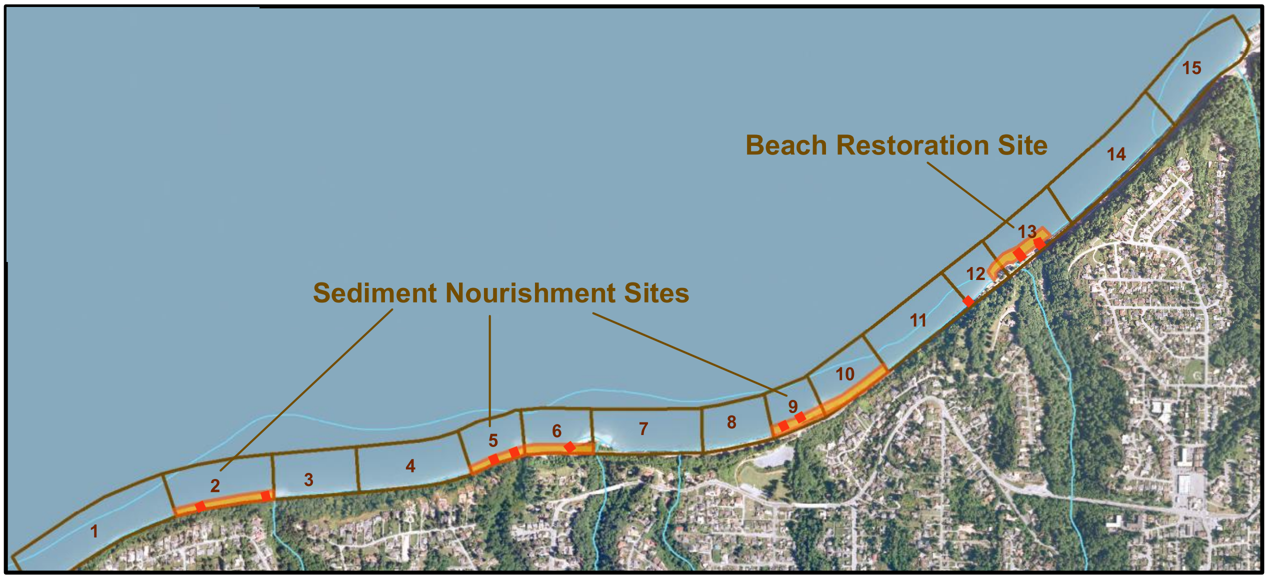

Figure 1. Sampling sites along the Everett shoreline. Site 2 to the southwest is located east of the Mukilteo Mount Baker Terminal, with Site 13 to the northeast sits just east of Howarth Park in Everett.

Sediment samples of spawning habitat were separated for grain size analysis during each spawning survey. Sediment samples were binned into size classifications using stack sieves, and optimal sediment grain size ranges for each species were quantified as percent weight of the total sediment sample, identified as 1.2 – 6.35 mm for smelt and 0.152 – 0.422 mm for sand lance (Penttila 2007). The objective was to monitor suitable substrate for both species before and after nourishment, and analyze for influence of restoration on spawning presence/absence and relative abundance.

Forage fish spawning analysis was done using the winnow method (Moulton and Penttila 2006), and was quantified by counting the number of eggs in each sample. As the number of eggs per sample is not necessarily indicative of actual abundance, because eggs move along the shoreline from an initial spawning location and total volume of available substrate is unknown, this data was analyzed by presence/absence and a ranking of dominant spawning activity for each sample date. Presence is defined as at least two eggs from a given species in a single sample. Ranking the number of eggs for a sample period consisted of assigning a value of 0 to 13 for the number of sites, with a value of 13 ranking most abundant. Sites that tied for the same rank, such as sites with a count of zero eggs, shared the same next lower rank. Ranking also helps to reduce interannual variability between years when more eggs were observed, allowing identification of spawning *hotspots* that are preferentially used by fish.

Preliminary review of the data included descriptive statistics and graphs to identify distribution and general trends for sediment change over time appropriate to each species, hypothesis testing to review assumptions of normality for a Generalized Linear Mixed Model (GLMM), and post-hoc analyses to evaluate significance between variables. All analyses were conducted in Systat, with a p-value threshold of significance of <0.05.

Analyses: Descriptive Statistics and General Trends

The optimal percent grain for each species was reviewed across years for each site (Figures 2 and 3), looking at the average availability of suitable spawning substrate among sites. Beach nourishment was applied in 2016 with varying volumes of sediment placed between sites. Fine sediments more appropriate to sand lance, as dredge material received from the Port of Everett, were applied to the southwestern side of each pair of sites (2S, 5S, west of 6S, 9S, and west of 12N), while Howarth Park received a choice mix targeting a larger grain size appropriate for smelt, which also overlapped with sites 12S and 13S. Sites northeast of each nourishment site are considered down drift, and may receive sediments over time as the initial deposited materials moves along the shoreline in the predominant direction of the drift cell. A preliminary analysis of sediment drift and site-specific composition changes post-restoration is also included in this report.

The overall average percent grain available for surf smelt (Figure 2) ranged from 0.85% to 50.94% of the total sample (N = 376), with a mean of 19.5% and median of 18.82%, and a standard error of the mean at 0.574. This represents a relatively normal probability distribution across all samples. Although there appears to be some changes in available substrate at the site level following the 2016 beach nourishment, as described in the sediment section of this report, continued presence of eggs suggests there was a high enough percentage of suitable grain size for smelt spawning to occur.

The overall average percent grain available for sand lance (Figure 3) ranged from 1.16% to 92.42% of the total sample (N = 253), with a mean of 41.95% and median of 38.46%, and a standard error of the mean at 1.535. Fewer samples overall were analyzed for sand lance because of their shorter spawning window from November through February only, and some sites were not sampled in 2011. Although a considerably broader range of substrate was available than the percent grain for smelt, the data represents a relatively normal distribution across all samples. Site 2S was noticeably lacking suitable substrate for spawning, and site 13, northeast of the Howarth Park restoration, appears to have an initial increase in suitable substrate following the 2016 beach nourishment. Elsewhere, sites 2N, 5N, 9S, and 9N, appear to have increased in the quantity of favorably sized substrate in 2016 and 2017 after beach nourishment. Year 2017 grain samples have only been processed through November so far, represented by a sample size of one in the box plots (Figure 3).

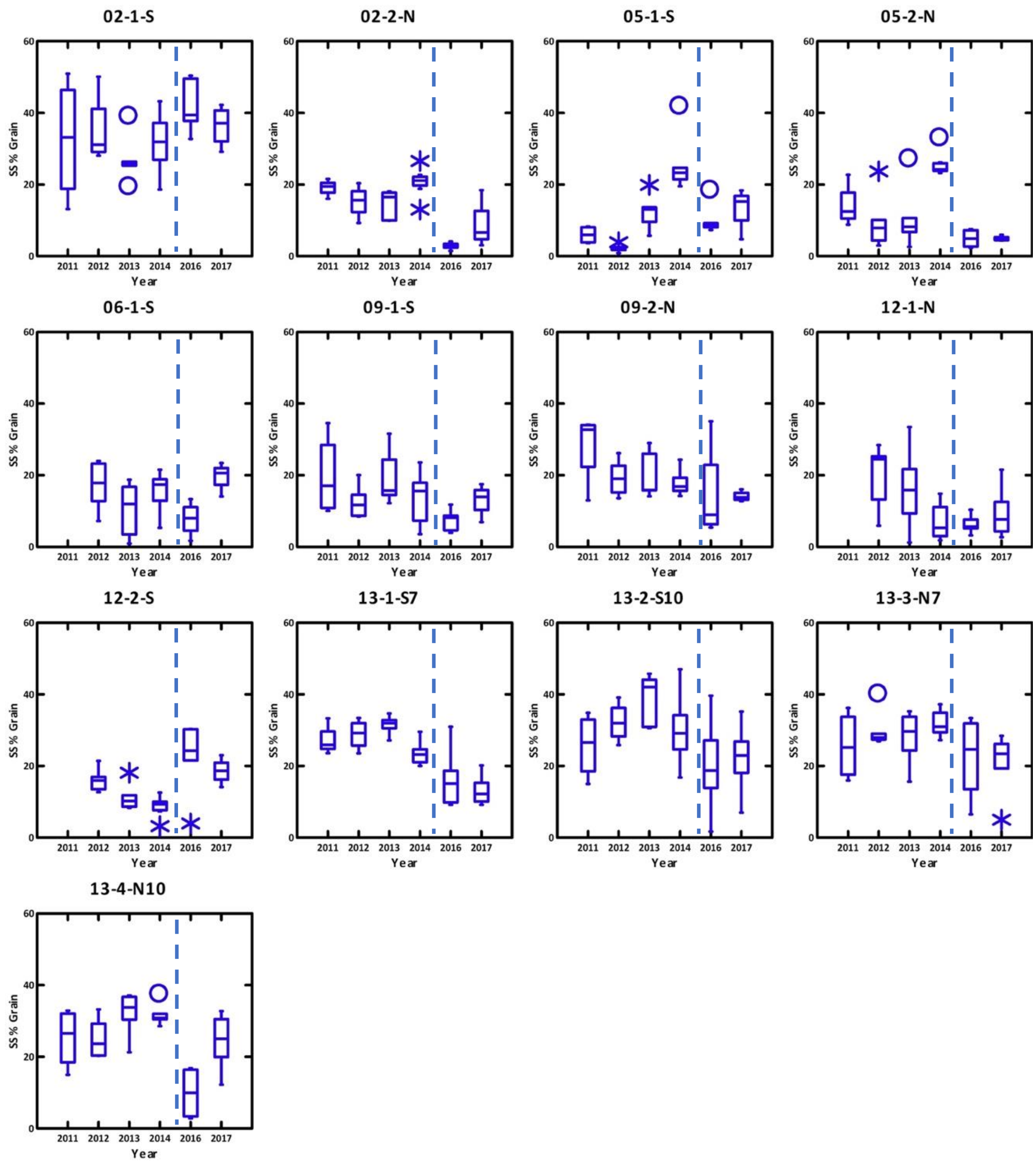

Figure 2. Percent of suitable grain size for surf smelt (SS), 1.2 – 6.35 mm, across years by site. 2016 and 2017 results are post-nourishment, separated by the dotted line. The box top and bottom represent the 25th percentiles, the top and bottom of the lines represent maximum distribution, circles represent outliers, and stars indicate extreme outliers that are 1.5 times the interquartile range. The order of these graphs is representative in the same southwest to northeast order of the sites as displayed in Figure 1.

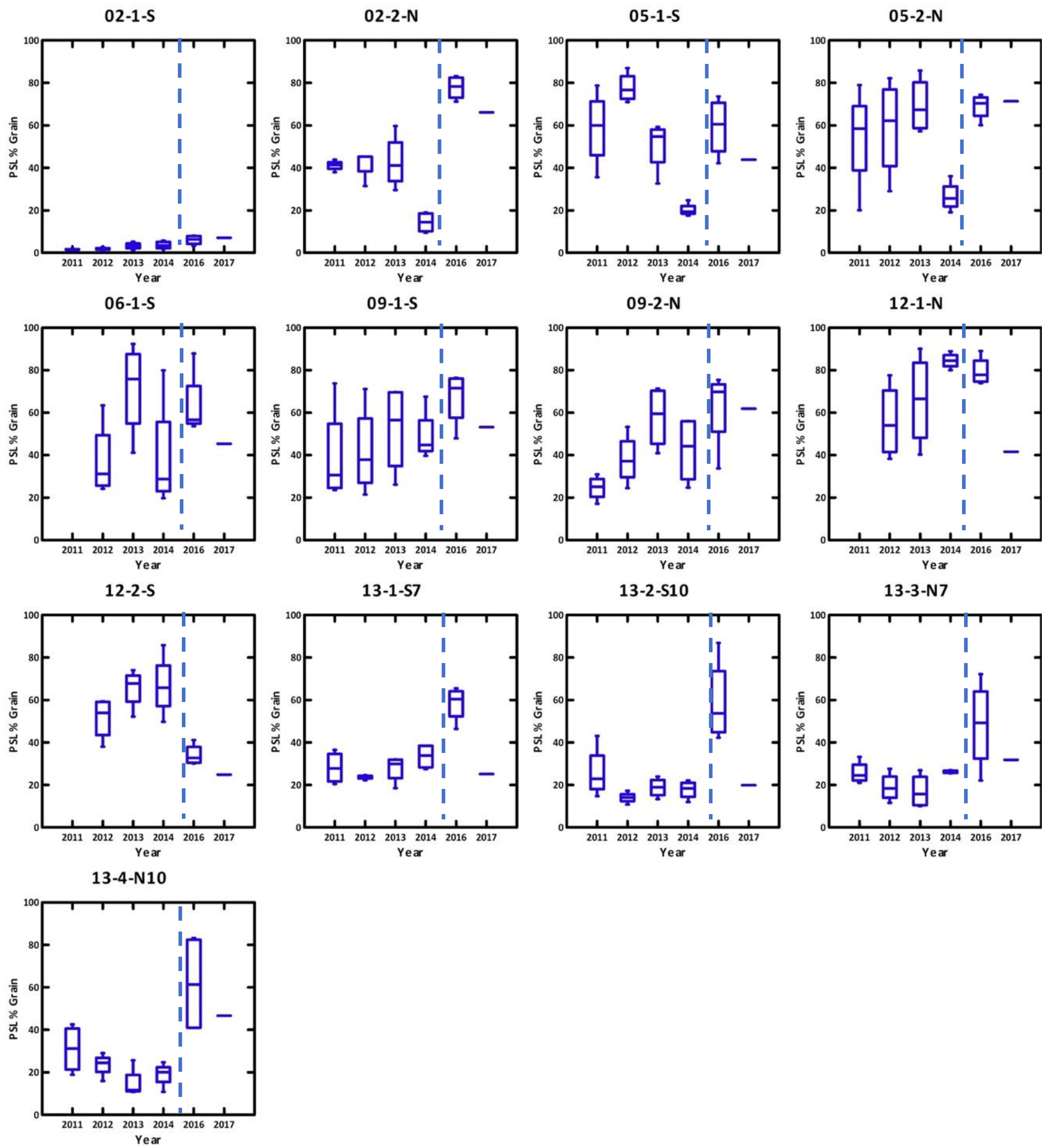

Figure 3. Percent of suitable grain size for Pacific sand lance (SS), 0.152 – 0.422 mm, across years by site. At the time of this report samples had only been processed up till November 2017, representing a sample size of one for year 2017. 2016 and 2017 results are post-nourishment, separated by the dotted line. The box top and bottom represent the 25th percentiles, the top and bottom of the lines represent maximum distribution, circles represent outliers, and stars indicate extreme outliers that are 1.5 times the interquartile range. The order of these graphs is representative in the same southwest to northeast order of the sites as displayed in Figure 1.

Percent grain data was reviewed for normal probability distribution against presence/absence of each species (Figure 4). Percent grain was normally distributed across samples for both species. There were considerably more cases of absence of spawning than presence (smelt N = 478 and mean presence =

0.19, sand lance N = 300 and mean presence = 0.28). A two-sample t-test suggests some preference for a greater percentage of available substrate for both species (p-value < 0.001), but the distributions overlap greatly and there is unequal sample size between presence/absence data.

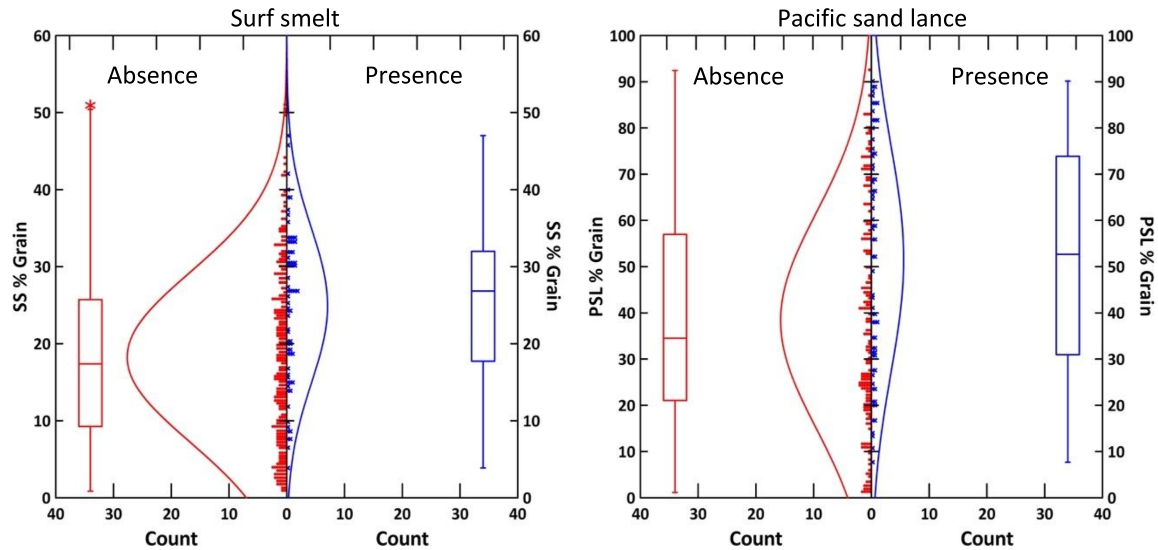

Figure 4. Distribution of percent grain for each species, smelt on the left and sand lance on the right. For each graph absence is on the left in red, and presence is on the right in blue.

Ranking data was reviewed across sites by year (Figure 5). A higher rank indicates the location of the greatest amount of eggs found within an individual sample period, and a higher average rank for the year suggests a continued higher ranking for that site across samples (i.e., notes a *hotspot*). Smelt had a clear preference for spawning on the most northeastern sites (12 through 13) based on the number of eggs found both before and after nourishment in 2016, while sand lance spawning site preference varied between pre-nourishment years (2011-2014) and post-nourishment years (2016-2017). After nourishment, spawning for sand lance was noticeably absent from samples at some sites where it was present prior to nourishment (5S, 9S, and 13N). At other sites (5N and 6S) sand lance rank was higher post-nourishment, suggesting a potential shift in spawning locations.

Exploratory analysis and graphs were initially reviewed for differences among months. Similar trends were found for higher average smelt ranking at the northeastern sites 12 and 13, but samples between years were not consistently available outside of the winter months (October through February). Sampling in August and September started in 2014, with June and July sampling added during 2016 and 2017. April was also sampled in 2017, making comparisons among all months across years difficult. While smelt spawning varies seasonally between north and south Puget Sound (Penttila 2007), it was documented that smelt spawning occurs year-round in the region of this project. Local populations of sand lance are known to only spawn during the months of November through February (Selleck et al. 2015), so data for this species was only analyzed during these months. Spawning for both species is rare or absent during the early spring (March through May).

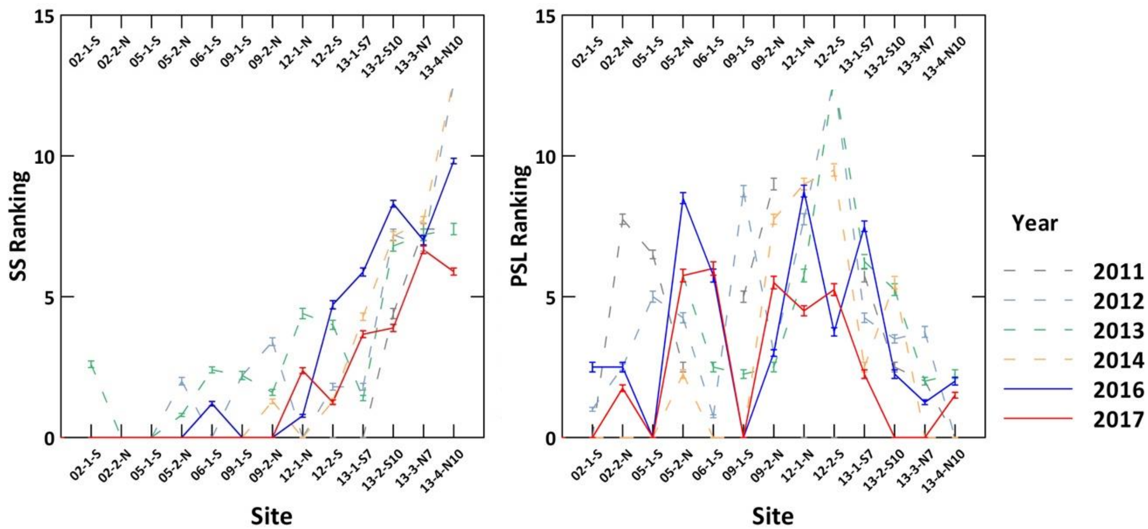

Figure 5. Average ranking across sites by species, with smelt on the left and sand lance on the right. Pre-nourishment years (2011-2014) have dotted lines, and post-nourishment years (2016-2017) have solid lines.

Analyses: Statistical Review and Generalized Linear Mixed Model

The use of continuous and categorical data required the use of a Generalized Linear Mixed Model (GLMM). Other published literature utilized principal component and regression analyses to correlate a large range of environmental factors to egg abundance and mortality (Quinn et al. 2012), but that requires a greater sampling effort that evaluates spawning behavior, egg survival, and egg development. While ranking sites between sampling periods is useful for general trends in spawning preference, these data were not collected in a consistent manner to imply actual abundance.

Ranking for each species across samples was analyzed against percent grain (representative for each species), site location, and years. The GLMM for smelt found no significance for percent grain (p-value = 0.442) or year (p-value = 0.231), but did find significance differences among sites (p-value < 0.001, R^2 = 0.387). There is a clear preference for smelt to the northeastern sites 12 and 13, regardless of available substrate (Figure 6).

The GLMM for sand lance found significance for percent grain (p-value = 0.013), year (p-value = 0.009), and site (p-value < 0.001), but with a weak R^2 of 0.274. Overall there was greater variability among sites and year in spawning activity (Figure 6), and a considerably greater range of suitable substrate corresponding with spawning events. The reduced window for spawning surveys, fewer occurrence of spawning presence between sites, and fewer eggs found overall contribute to the low R^2 for sand lance, and should be considered when comparing significance between variables. The lower overall ranking in 2017 for sand lance is reflective of fewer eggs found overall. Many fish species have high inter-annual variability in spawning activity.

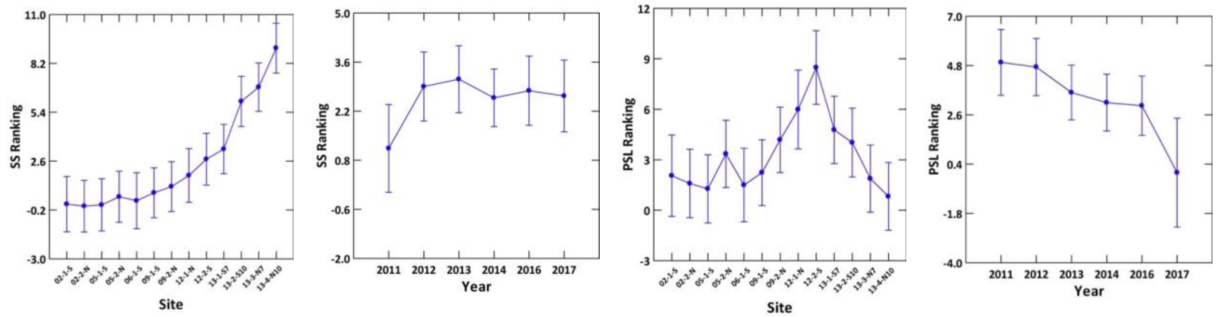

Figure 6. GLMM least squares means from left to right for smelt by site, surf smelt by year, sand lance by site, and sand lance by year.

Discussion

Pacific sand lance and surf smelt form an important link in the food chain, as a high calorie resource connecting smaller energy producing phytoplankton to upper trophic level predators (Sisson and Baker 2017). As such, conservation and restoration of their spawning habitats, given much shoreline degradation and alteration, is seen as vital to the health of the Salish Sea (Selleck et al. 2016) and has been recognized in Washington State law for decades (WAC 220-660-320). Many fish species exhibit episodic or opportunistic recruitment, where spawning efforts are greater in some years (Essington et al. 2015). As such, modeling forage fish biomass is challenging, but monitoring for spawning activity over time is seen as a useful solution in tracking general fish abundance and habitat use.

For surf smelt there has been extensive monitoring around Puget Sound for decades (WDFW Forage Fish Spawning Database), and general trends in spawning behavior are well documented. While spawning events are irregular within individual sites, site selection is generally widespread given suitable habitat (Penttila 2007). Smelt are opportunistic, and are known to spawn on a range of substrate. Smelt appear to favor north facing beaches that experience low solar exposure, and beaches with moderate wave action that facilitate the burying of eggs in the sand. Both factors help reduce egg desiccation and improve egg survival and development (Quinn et al. 2012). This general trend was found in these surveys, where smelt use of suitable substrate was not significant, but spawning was consistently more frequent towards the north end of the drift cell, where substrate size was consistently greater than all other sites, except 2S. This south to north trend of suitability relative to the direction of the drift cell has been observed in other studies (Quinn et al 2012). Overall for this study an average percent grain availability of 25-30% appeared enough for spawning to occur, but site preference was the dominant factor determining frequency of eggs found. While egg condition was not examined in the study, it has been previously described that sites with more suitable substrate and gentle slopes have increased egg survival (Selleck and et al. 2016). Improving the habitat of preferred sites towards the northern end of the drift cell around Howarth Park are likely to have the greatest impact on surf smelt egg development, an important life history stage. Egg survival is seen as an important contributor to maintaining healthy populations of forage fish (Moulton and Penttila 2006).

Pacific sand lance are known to be more difficult to survey (Bizzarro et al. 2016). Their cryptic behavior of burrowing in the sand, lack of a swim bladder recognized in acoustic studies, and their smaller eggs that can attach to multiple sand grains make them challenging to study. These surveys demonstrated that repeated long-term monitoring with trained volunteers can capture repeated spawning events with enough frequency to determine some substrate and habitat preferences. Sand lance appear to have less site affinity than smelt within the study area, and may have a greater preference for suitable substrate when selecting spawning sites (Haynes et al. 2008). While there was significance among site selection based on ranked egg presence, this varied considerably among years, and suggests that there may be other environmental factors driving site selection for spawning activity. Fine sediments preferred by sand lance are more mobile along the shoreline in a dynamic wave-driven system, and the availability of percent grain at individual sites varied between samples and years both before and after nourishment, particularly for sites 2 and 5 at the southern end of the drift cell. Improving the habitat of the entire shoreline, or targeting areas near or adjacent to preferred sites where spawning is known to occur will likely have the greatest impact on egg survival for Pacific sand lance. It is unclear yet if relying on sediment drift from adjacent nourishment locations suitably improves habitat at individual sites.

While the number of eggs found does not directly correlate to actual population abundance, as discussed earlier, the continued presence of eggs in samples demonstrates that the long-term surveys along the shoreline is effective at monitoring the spawning activity for both surf smelt and Pacific sand lance. Many of the sites chosen for this project exhibited spawning events prior to restoration or beach nourishment, but the area of suitable habitat was restricted to a small band in the intertidal zone. The addition of fine sand material broadened the slope of the beach and extended the total area along the shoreline, increasing the potential habitat available that fish can deposit eggs. These changes also have the potential to improve habitat favorable for egg condition and survival. The addition in 2016 of fine sediments preferred by sand lance between sites 2 through 12 may explain the pattern of ranked spawning seen in Figure 5, where eggs were most common at sites directly adjacent to beach nourishment (Figure 1). Site 6S in particular had little to no spawning activity prior to beach nourishment, but became among one of the more preferred sites for spawning in 2016 and 2017.

For smelt, improving the substrate towards the north end of the drift cell is important for targeting sites generally preferred for spawning. The railroad bulkhead above the beach blocks the sediment source contributed by bluff erosion, and subsequently the drift cell along the Everett shoreline lacks good source material to prevent the coarsening of the substrate on the beach, such that continued nourishment would be needed to replenish material lost over time. Additional nourishment also helps maintain a broader slope on the beach, helpful to forage fish spawning. Continued monitoring of the nourished sediment will help address the rate of loss, and determine if material is retained along the shoreline or moves offshore. Sediment moves to the northeast along this portion of shoreline, and it may be at least two to three years before the movement of materials down drift from nourishment sites is seen as also improving adjacent potential spawning sites, though we do know drift from nourishment moved hundreds of meters within the initial months since placement.

The results from this study suggest that restoration actions can directly influence the composition of preferred substrate size for forage fish spawning, and that a positive forage fish spawning response may have occurred at some sites. Forage fish are a key trophic level to the health of the Puget Sound ecosystem, as identified in the 2018 Southern Resident Orca Task Force Report and Recommendations. Focusing conservation and restoration efforts in an area preferred for spawning activity by forage fish is identified by state and federal agencies as a priority to restoring other ESA-listed species (e.g., salmon, rockfish, birds, and mammals), while also improving the general productivity of coastal ecosystems (Lee et al. 2018). It will be important to continue the monitoring of these sites to determine whether future actions will be needed, and inform new opportunities for large-scale restoration of the shoreline.

References

Bizzarro, J., A. Peterson, J. Blaine, J. Balaban, G. Greene, and A. Summers. 2016. Burrowing behavior, habitat, and functional morphology of the Pacific sand lance (*Ammodytes personatus*). Fishery Bulletin, 114: p. 445-460.

Essington, T., P. Moriarty, H. Froehlich, E. Hodgson, L. Koehn, K. Oken, M. Siple, and C. Staritz. 2015. Fishing Amplifies forage fish population collapses. Proceedings of the National Academy of Sciences.

Faulkner, M. 2017. Shoreline restoration monitoring in Puget Sound. Washington Department of Fish and Wildlife.

Haynes, T., R. Ronconi and A. Burger. 2007. Habitat use and behavior of the Pacific sand lance (*Ammodytes hexapterus*) in the shallow subtidal region of southwestern Vancouver island. Northwest Naturalist, 88: p. 155-167.

Haynes, T., C. Robinson, and P. Dearden. 2008. Modelling nearshore intertidal habitat use of young-of-the-year Pacific sand lance (*Ammodytes hexapterus*) in Barkley Sound, British Columbia, Canada. Environ Biol Fish, 83: p. 487–498.

Herrmann, K., F. Leonetti, J. Herrmann, E. Whitney, M. LaForge, and A. Rae. 2015. Snohomish County intertidal forage fish spawning surveys between Mukilteo and Everett. Snohomish County Marine Resources Committee.

Lee, T., J. Toft, J. Cordell, M. Dethier, J. Adams, and R. Kelly. 2018. Quantifying the effectiveness of shoreline armoring removal on coastal biota of Puget Sound. Peer J.

Litzow, M., J. Piatt, A. Abookire, S. Speckman, M. Arimitsu, and J. Figurski. 2004. Spatiotemporal predictability of schooling and nonschooling prey of pigeon guillemots. The Condor, 106: p. 410–415.

Moulton, L. and D. Penttila. 2006. San Juan County forage fish assessment project. Washington Department of Fish and Wildlife.

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Technical Report 2007-13.

Quinn, T., K. Krueger, K. Pierce, D. Penttila, K. Perry, T. Hicks, and D. Lowry. 2009. Patterns of surf smelt, *Hypomesus pretiosus*, intertidal spawning habitat use in Puget Sound, Washington State. Estuaries and Coasts.

Robards, M., M. Wilson, R. Armstrong, and J. Piatt. 1999. Sand Lance: A review of biology and predator relations and annotated bibliography. Research Paper PNW-RP-52. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Robinson, C., D. Hrynyk, J. Vaughn Barrie, J. Schweigert. 2013. Identifying subtidal burying habitat of Pacific sand lance (*Ammodytes hexapterus*) in the Strait of Georgia, British Columbia, Canada. Progress in Oceanography, 115: p. 119–128.

Selleck, J., C. Gibson, S. Shull, and J. Gaydos. 2015. Nearshore distribution of Pacific sand lance (*Ammodytes personatus*) in the inland waters of Washington State. Northwest Naturalist, 96(3): p. 185-195.

Selleck, J., A. Fain, and L. Fore. 2016. Removing bulkheads to protect property and create habitat for forage fish: Weaverling Spit Nearshore. Background Summary. Puget Sound Partnership, Tacoma, WA.

Sisson, N. and M. Baker. 2017. Feeding ecology of Pacific sand lance in the San Juan Archipelago. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 9: p. 612–625.

Therriault, T., D. Hay, and J. Schweigert. 2009. Biological overview and trends in pelagic forage fish abundance in the Salish Sea. Marine Ornithology, 37: p. 3-8.

Acknowledgments

I would like to thank the Snohomish County Marine Resources Committee for their support and review of this report. I would also like to thank contributing reviewers who provide comments, discussions, and insight into this report, including Kirk Krueger, Phill Dionne, and Dayv Lowry of the Washington Department of Fish and Wildlife.