Characterization of the Habitat of *Ammodytes hexapterus* (Pacific Sand Lance) in the San Juan Channel Sand Wave

Jennefer Lopez

Pelagic Ecosystem Function Apprenticeship
Fall 2013
Friday Harbor Laboratories
University of Washington, Friday Harbor, WA 98250

Contact Information:
Jennefer Lopez
jlop92@uw.edu

Keywords: *Ammodytes hexapterus*, Pacific sand lance, San Juan Channel, sand wave, habitat, substrate composition, sand.

Abstract:

Ammodytes hexapterus or Pacific sand lance (PSL) are forage fish that spend most of their time buried in benthic substrate (Robards 1999). PSL exhibit a peculiar behavior of actively swimming into sandy substrates as a refuge to avoid predation (Gidmark et al. 2010, Robards 1999, Blaine 2006). A sand wave field was identified in the San Juan Channel, WA in 2004 and discovered to be a suitable habitat for PSL. The San Juan Channel sand wave field is non-uniform and is composed of different substrate types. While physical attributes of the sand wave field have been explored (Greene et al. 2011), there is little known about how PSL use various substrate types as habitat. I am asking the question: How does benthic substrate composition influence the abundance and distribution of Pacific sand lance in the San Juan Channel sand wave? Samples were collected from the San Juan Chanel sand wave with the use of a Van Veen grab. The abundance and size of PSL were examined in each grab as well as the substrate composition. There were apparent trends of PSL abundance decreasing as the amount of gravel increased, and increasing as the amount of sand increased in the sample (Fig 1). Substrate composition seems to not have an influence on PSL size (Fig 3, Fig 4). A map showing the different substrate compositions in different areas of the sand wave in 2013 shows the non-uniform composition of the sand wave (Fig 6).

Introduction

Ammodytes hexapterus or Pacific sand lance (PSL) reside in pelagic waters where they school and forage (Robards 1999). A unique thing that sets PSL apart from other forage fish is that they spend most of their time buried in benthic substrate due to the absence of a swim bladder (Robards 1999). PSL exhibit a peculiar behavior of actively swimming into sandy substrates as a refuge (Gidmark et al. 2011). PSL bury at night and during the day to avoid predation (Robards1999, Blaine 2006). While not burrowed, PSL generally remain close to sandy refuges (Hobson 1986). Movements into the water column usually occur twice a day, at dawn and dusk, and it is unknown if those PSL that enter the water column at dawn remain there during daylight hours. It is suggested that this twice-daily migration into the water column is to feed rather than a single outing. During this time PSL form large schools and feed on zooplankton in the water column (Robards 1999; Geiger 1987). Annual spawning occurs generally between late September and late October. Afterwards, this species appears to be relatively dormant during the winter (Robards 1999). The burrowing behavior of PSL is peculiar and is difficult to research due to the rapid movement of PSL, although Gidmark et al. (2011) describes it as a three-step process. The first step is PSL use conventional slipping locomotion. The PSL uses these undulations to drive its pointy, cone-shape head into the sand. The second step is characterized by more pronounced body undulations. This allows the PSL to drive approximately two-thirds of its body into the substrate. The third step starts right as the aboveground undulation stops and the aboveground portion of the tail straightens. This is termed the "tail stop", where the tail ceases force-generated movements. Once enough of the body is underground the anterior portion of the body takes over (Gidmark et al. 2011). During terrestrial locomotion, PSL, just like snakes and other limbless vertebrates, use undulatory locomotion where they apply force to discrete, non-moving points on the ground via a posteriorly propagating wave (Gidmark et al. 2011)

PSL serve as a primary link between zooplankton and other higher predators and are important in the diets of common murres, rhinoceros auklets, harbor seals, minke whales, salmon, lingcod, and other bottom fish (Geiger 1987). As for bottom down control, copepods are the primary food source for PSL (Robards 1999). Having such an abundant primary food source allows for rapid accumulation of energy. PSL are among the more nutritious of forage fish with relatively high levels of certain vitamins and energy density (Robards 1999). Because of their high importance in the food web, if anything severe happened to the PSL population, it could result in cascading effects throughout the marine food web. Differences in abundance and size of sand lance would result in different potential returns for local predators (Robards 2002).

PSL are common in the northeast Pacific Ocean spanning from western Alaska up to northern California (Robards 1999). PSL are usually found in areas with strong bottom currents that are able to oxygenate the areas of sediment in which the fish are buried (Robards 1999; Meyer et al. 1979; Auster and Stewart 1986). PSL are known to be associated with specific benthic habitats (Robards 1999), most often with fine to course grain sand or gravel sediments in near shore and shallow water (Robards 1999). There is not much known about PSL in the San Juan Channel. Greene et al. (unpublished) first discovered PSL in the San Juan Channel sand wave in 2004 during an ROV video survey when they observed PSL burrowing and emerging from the sediment. In the year 2006, Blaine (2006) found a correlation between catch per unit effort and the substrate type in both night and day samples. Last year in 2012, another undergraduate student, Thomson, took a similar approach in trying to find a relationship in the catch per unit effort and substrate type as well as the fish size and substrate type. Thomson (2012) found some strong relationships between catch per unit effort and substrate type and a weak but existing, relationship between fish size and substrate type.

The sand wave field in the San Juan Channel is influenced by strong currents, tides, and variable water flow and covers an area of approximately 500,000 m^2 (Greene 2011). In the San Juan Channel, complex water flow transports and deposits different sized sediments at different rates resulting in non-uniform sediment throughout the sand waves that vary from 60-80m deep (Greene 2011). The continuous change in substrate in the San Juan Channel means a continuous change in the habitat of the PSL. I continued to expand a similar study to the one Thomson did last year. I want to see if even when the San Juan Channel sand wave field is continuously changing, if her patterns will be confirmed.

My overarching question is; how does benthic substrate composition influence the abundance and distribution of Pacific sand lance in the San Juan Channel sand wave? Specifically I focused on the following three questions:

1) How does abundance of PSL vary with differences in substrate composition?
2) How does PSL size vary with differences in substrate composition?
3) How does the substrate composition vary over the sand wave?

Methods

Sampling the San Juan Channel Wave Field
The Pacific Sand Lance (PSL) population in the San Juan Channel sand wave was sampled with a Van Veen sediment grab deployed from the R.V. Centennial. Samples were taken between the coordinates 48.833N to 48.491N latitude and -122.981W to -122.952W longitude in the sand wave field. The Van Veen sediment grab sampler is a clamshell type sampler with long lever arms. The scoops of the Van Veen have sharp cutting edges that cut deep into the sediment. It is sent rapidly down to the benthic environment of the SJC sand wave field. The impact of hitting the ground causes the Van Veen to close and traps and sediment and burrowing fish. Successful grabs are characterized as being completely closed when surfaced. Samples were taken from September 26 to November 5 2013 once a week, usually on a Tuesday. Collecting samples during this season is ideal due to the commencement of hibernation when the PSL can be found in the sediment. GPS coordinates and depth were taken for every sample. Fish present in the Van Veen grab were collected and anesthetized with MS-222 and preserved in formalin. Each fish was measured for mass and fork length. Sediment samples were also collected from grabs into buckets to take back to labs for analysis.

Sediment Sample Processing
A sediment subsample of about 1500g was taken from each grab sample. Those subsamples were then dried using a convectional oven and heat lamps. Once dried, about 500g of the dry sample was massed out for initial weight. Samples were then run through a series of five sieves into fractions by grain size of 2mm, 1mm, 0.5mm, 0.125mm, and <0.125mm in diameter. These measurements correspond to the categorical grades of gravel, very course sand, coarse sand, fine and medium sand, and silt, respectively (Table 2). Samples in each sieve fraction were agitated for 5 minutes, no more, no less, before each sieve fraction was weighed. Much of the silt was lost in the process. The weight of the substrate produced by each sieve fraction was divided by the total initial mass to obtain the corresponding percentage of that substrate type.

Results

Overall during this study in the San Juan Channel wave field, a total of 37 grabs were successful resulting in 37 sediment samples. 154 PSL were caught and 150 were examined due to 4 lost in the process. The number of fish found in each grab ranged from 0 to 15 fish.

PSL were found in substrate composed of a combination of gravel, very coarse sand, coarse sand, medium and fine sand, and silt. The sediment samples also included shell hash from urchins, oysters, scallops and clams.

Although correlations were not all statistically significant, there were apparent trends between the fish abundance and substrate type. As the percent of gravel in the sediment sample increased, there was a decrease in the amount of fish caught per grab (R^2=0.0829, P=0.0934, exponential decay; Fig 1). As the percent of total sand in the sample increased there was an increase of PSL abundance. (R^2=0.1159, P=0.0445, exponential growth; Fig 1). As the percent of course sand increased in the sediment sample, the amount of fish caught in the sample also increased (R^2=0.1215, P=0.0402, exponential growth; Fig 2)

The substrate used by PSL varied widely in the percent of gravel, sand and silt (Fig 1). PSL showed to be most abundant in certain substrate compositions. The percent of gravel in all 40 sediment samples ranged from 0.92-80.81. PSL were found in substrate where gravel values ranged from 0.92-56.00%. The percent of sand ranged from 18.99-98.62 for all substrate samples. Fish were found in substrate where the sand values ranged from as low 21.17 to 98.62%. Silt in all sediment samples ranged from 0-1.12%. PSL were found in substrate where gravel values ranged from 0-1.12%. Overall, the substrate composition of the sediment samples with the highest abundance of fish, 5 fish or more, was about 0-30% gravel, 70-100% sand and 0% silt.

PSL abundance varied among types of sand. Sand is divided up into three subcategories, the percent of very coarse sand ranged from 1.70-47.68, coarse sand ranged from 6.19-75.05%, and percent of medium and fine sand ranged from 2.55-18.00. Respectively, PSL were found in the following ranges: 1.70-47.68%, 6.56-75.05%, and 2.55-18.00%.

The amount of variation of fish size (fork length) explained by the sediment size was statistically not significant, except for one relationship (Fig 3, Fig 4). As the percent medium and fine sand increased in the sediment sample, the fork length of PSL decreased. Although it was found that PSL of different sizes did appear in narrower ranges of substrate compositions. Fish larger then 130mm and smaller than 100mm were found in ranges of less than 20% gravel and more than 80% sand. PSL between that range of 100-130 mm were able to tolerate higher ranges of substrate composition.

The Sand Juan Channel sand wave field does not provide a uniform habitat for PSL. The sand field has an oval shape with a long diameter running from north to south down the San Juan Channel; therefore latitude was used as a proxy to describe the relative location down the sand wave field. Most of the samples were taken between the latitudes 48.4905N to 48.5187N with the exceptional outliers being 48.666N and 48.8330N. Substrate composition varied across the sand wave field (Table 3).

Discussion

Grabs with a fish abundance of 5 or more were composed of about 0-30% gravel and 70-100% sand. This has showed to be a suitable substrate composition for PSL, although they can tolerate a larger range (Fig 1, Fig 2). Looking at the composition of total sand, in grabs with a fish abundance of five or higher, it seems that a suitable sand composition for PSL is majority coarse sand and not too little very coarse sand and not too much medium and fine sand (Fig 2). This apparent preference in substrate composition could have to do with the PSL's ability to burrow or the ability of the substrate to hold shape.

The results of my project could provide a bridge between laboratory and field research.

Laboratory conditions provide PSL with a larger range and combinations of substrate compositions that may not exist in the field, as opposed to my research that looked at substrate compositions that truly exist in the field. PSL have to use what is available in nature and the substrate compositions present in this paper and in Thomson's (2012) research is a sample of the limited range of what is out there. Research has been done at the Friday Harbor Labs looking at which substrate compositions PSL prefer to burrow in within the context of laboratory conditions. They found that PSL were able to burrow in all of the provided substrates, but they preferred coarse sand (Peterson 2013). In both the lab and the field, PSL have a higher affinity to sand.

The fall 2013 pattern of PSL abundance varying with substrate composition was similar to previous studies. Last year, Thomson (2012), found that abundance and fish size varied with substrate composition. So this year my objective was to follow up and build on her work to see if I could confirm patterns. Trends of 2012 were looked at compared to trends of 2013. The trends of the correlation between substrate type and PSL abundance were similar in the two years. Both years it appeared that as the amount of gravel in the sample increased, the abundance of fish decreased (2012: R^2=0.24, P=0.003, exponential decay; 2013: R^2=0.0829, P=<0.0001, exponential decay; Fig 1), as the amount of sand increased, the abundance of fish increased (2012: R^2= 0.99, P<0.001, quadratic polynomial; 2013: R^2=0.0352, P=<0.0001, exponential growth; Fig.1) and lastly as the amount of silt increased in the sediment sample, the abundance of fish decreased (2012: R^2=0.25, P=0.001, exponential decay; 2013: R^2=0.0237, P=<0.0001, exponential decay; Fig.1). Even though apparent trends seemed to stay consistent, the variation explained by the difference in sediment size this year was a lot lower this year than it was last year. It seems as if last year the PSL had a stronger preference for the sand they burrowed in compared to this year. Last year the correlations were more statistically significant than his year. I will refer as to why this may be after discussing the following trends.

The trends we saw last year in the correlations between the sediment size and the fish size, we did not see this year. Last year they saw the following trends: an increase in average fork length with an increase in amount of gravel (R^2=0.068 P=0.104, linear), amount of medium and fine grain sand (R^2=0.36, P<0.001, linear), and silt (R^2=0.42, P<0.001, linear). Last year they also saw a decrease in fork length with an increase in amount of very coarse sand (R^2=0.27, P= 0.086, linear) and course sand (R^2=0.15, P=0.014, linear). This year we saw in every case but one, no statistically significant correlations (fig.3, fig.4).

Due to the interannual variance between 2012 and 2013, the population structures of PSL in 2012 and 2013 were compared. In 2012 there were 40 grabs, 1001 fish caught, with 50% of the data ranging between about 87-83mm in length, and the overall range between 77-91mm in length with 4 outliers (fig.5). In 2013 there were 37 grabs, 154 fish caught, with 50% of the data ranging between 106-113mm in length and the total data ranging from 100-115mm in length with 3 outliers. The population structure in reference to abundance and fish size was very different this year than last year. This year there was a smaller population, almost a degree of magnitude smaller, composed of larger fish.

There are certain factors that can affect the population. One example is the size dependence of feeding and vulnerability meaning that different age classes of different sizes will have different probability of success in surviving and reproducing (DeAngelis 1993). This year we could have been tracking the same group of fish from last year, which got bigger this year and fewer. Also like mentioned before, PSL serve as an important link between zooplankton and the higher tropic level predators. An example bottom up effect is oceanic conditions. Auster and Stewart (1986) found that sand lance require certain environmental conditions in regards to temperature and salinity. The difference in temperature and salinity could have been different enough between the two years to cause a difference in PSL populations. For example, temperature and salinity could have affected the lipid storage of zooplankton. Storage lipids provide zooplankton with the energy to reproduce and escape predators among other things (Lee et al. 2006). This effect on the zooplankton population could have a cascading effect on the PSL population. As for top down effects, predation from the sea bird population in the San Juan Islands could have varied from interannually, which in return could have also affected the sand lance population.

The San Juan Channel sand wave field proved to be non-uniform again this year. Mapping pie charts of substrate composition allowed analysis of how the substrate composition varied over the wave (Fig 6). The perimeter of the wave appeared to have a higher percentage of gravel and a lower percentage of sand. As for the sand wave itself, it appeared to have a higher percentage of sand and lower percentage of gravel. This is consistent with last year's results. Although the sand wave field is mostly composed of sand, individual habitat location show great variability between the percent of gravel and sand, possibly having to do whether the location was at a crest or a trough.

Overall, it is important to continue looking at the interannual variability of the habitat of the PSL to continue to look at if trends are being consistent throughout the years. It would also be interesting to look at other factors that affect the variability in PSL abundance and size besides substrate. Examples would be; tides, predations, food supply and lipid contents. For the future to expand on this project, scientists here at Friday Harbor Labs could start comparing in lab research with field research to see of PSL are living in their prime habitat.

Table 1: Raw data of successful samples in the San Juan Channel sand wave field.

Date	Drop	Latitude	Longitude	# Fish Caught	% Gravel (phi=-1)	% Very Coarse Sand (phi=0)	% Coarse Sand (phi=1)	% Fine & Medium Sand (phi=3)	% Silt and Very Fine Sand (phi=>3)
9/13/13	C1.1	48.5223667	-122.9518	0	?	?	?	?	?
9/13/13	C1.2	48.51	-122.9532333	0	?	?	?	?	?
9/13/13	C1.3	48.5083333	-122.9516667	1	56	1.7	25.2	17	0.053
9/13/13	C1.4	48.5083333	-122.9516667	4	6.48	20.9	60.7	13.12	0
9/13/13	C1.5	48.515	-122.9533333	4	0.92	16.75	6.56	4.11	0
10/9/13	C2.1	48.5187	-122.9503333	11	13.5	16.5	59	11.5	0.026
10/9/13	C2.2	48.5168833	-122.9525667	4	8.8	22.2	62.7	6.3	0.04
10/9/13	C2.3	48.5165	-122.95215	15	26.2	17	50.2	6.7	0.04
10/9/13	C2.4	48.51575	-122.95095	7	3.5	28.9	59.5	8	1.12
10/9/13	C2.5	48.5153167	-122.9503333	3	10.8	17.9	63.9	7.4	0.022
10/15/13	C3.1	48.517	-122.9521667	3	7.9	20.2	63.5	8.4	0.05
10/15/13	C3.2	48.6663333	-122.9533333	6	6.6	20.5	66.3	6.6	0.026
10/15/13	C3.3	48.5165	-122.955	9	15	24.5	55.8	4.6	0.0226
10/15/13	C3.4	48.4905	-122.9806667	4	3.6	16.59	74.2	5.8	0.196
10/15/13	C3.5	48.5131667	-122.9566667	2	32.9	11.1	39	18	0.4
10/22/13	C4.1	48.8330167	-122.95445	0	78.6667	9.2908	8.8696	3.0106	0.1565
10/22/13	C4.2	48.5106833	-122.9540667	2	4.9612	27.0650	63.7459	4.0911	0.0184
10/22/13	C4.3	48.5089833	-122.954	8	7.9699	24.2708	61.8857	5.6710	0.0181
10/22/13	C4.4	48.5105	-122.954	4	52.4940	9.4633	30.1277	7.9210	0.0120
10/22/13	C4.5	48.50345	-122.9531667	7	1.3242	15.1841	75.0453	8.3860	0.0423
10/22/13	C4.6	48.5106667	-122.9532667	6	7.5942	19.1691	63.1498	4.8754	0.0290
10/22/13	C4.7	48.5093833	-122.9531667	2	4.0587	21.6194	71.4868	2.5495	0.0082
10/29/13	C5.1	48.5179167	-122.95625	0	54.8662	6.6145	21.4470	16.3290	0.9435
10/29/13	C5.2	48.5170833	-122.9534833	5	2.0939	35.1928	59.4750	2.9820	0.0451
10/29/13	C5.3	48.5171167	-122.9548167	0	38.3360	41.3142	8.3004	8.6522	0.0237
10/29/13	C5.4	48.5128667	-122.9546167	9	32.7059	34.4060	59.0164	3.0621	0.0364
10/29/13	C5.5	48.5129167	-122.9553333	4	2.8980	21.1949	70.7821	4.9682	0.0278
11/5/13	C6.1	48.5175	-122.9551667	4	28.5626	14.4702	44.5380	12.3039	0.0739
11/5/13	C6.2	48.5176667	-122.956	0	80.8050	4.4498	8.8774	5.6594	0.1942
11/5/13	C6.3	48.5168333	-122.9528333	1	6.3114	29.1700	58.8437	5.3586	0.0866
11/5/13	C6.5	48.5175	-122.9533333	2	4.6718	28.0553	62.4484	4.5809	0.0434
11/5/13	C6.6	48.5178333	-122.9536667	5	5.3597	21.9917	67.5676	4.9896	0.0312
11/5/13	C6.7	48.5125	-122.954	5	2.4735	20.3076	70.6619	6.7968	0.0403
11/5/13	C6.8	48.5125	-122.9545	6	3.7824	31.0781	60.2489	4.8785	0.0181
11/5/13	C6.9	48.5128333	-122.9546667	3	5.2000	47.6768	42.3434	4.6727	0.0222
11/5/13	C6.10	48.513	-122.9548333	8	10.1673	28.6210	56.4259	4.7450	0.0592
11/5/13	C6.11	48.5133333	-122.9553333	0	5.5724	23.0969	65.5345	5.5405	0.0400

Table 2: Grain size fraction classification.

Substrate Type	Grain Size Diameter (mm)	phi
Gravel	2	-1
Very Coarse Sand	1	0
Coarse Sand	0.5	1
Fine and Medium Sand	0.125	3
Silt (and Very Fine Sand)	<0.125	>3

Table 3: The range of substrate composition and fish abundance in the San Juan Channel sand wave field when divided up into four sections in reference to its latitudinal position.

	Latitude - Latitude	# Grabs	% Gravel Range in Grabs	% Sand Range in Grabs	%Silt Range in Grabs	# Fish Range in Grabs
Section 1	48.4905N to 48.4976N	1	3.6	96.59	0.196	4
Section 2	48.4976N to 48.5046N	1	1.324	98.615	0.042	7
Section 3	48.5046N to 48.5117N	8	4.962 to 52.494	36.130 to 94.902	0 to 0.029	1-8
Section 4	48.5117N to 48.5187N	25	0.92 to 80.805	18.987 to 97.766	0 to 1.12	0-15

Figure 1

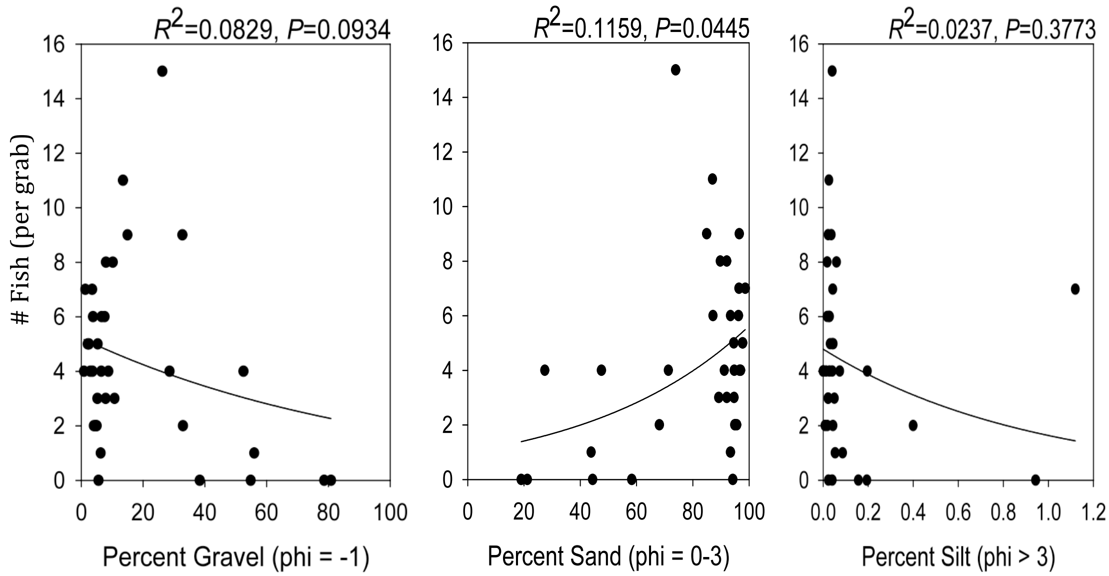

Figure 1: Number of PSL caught in respect to varying amounts of gravel, sand, and silt.

Figure 2

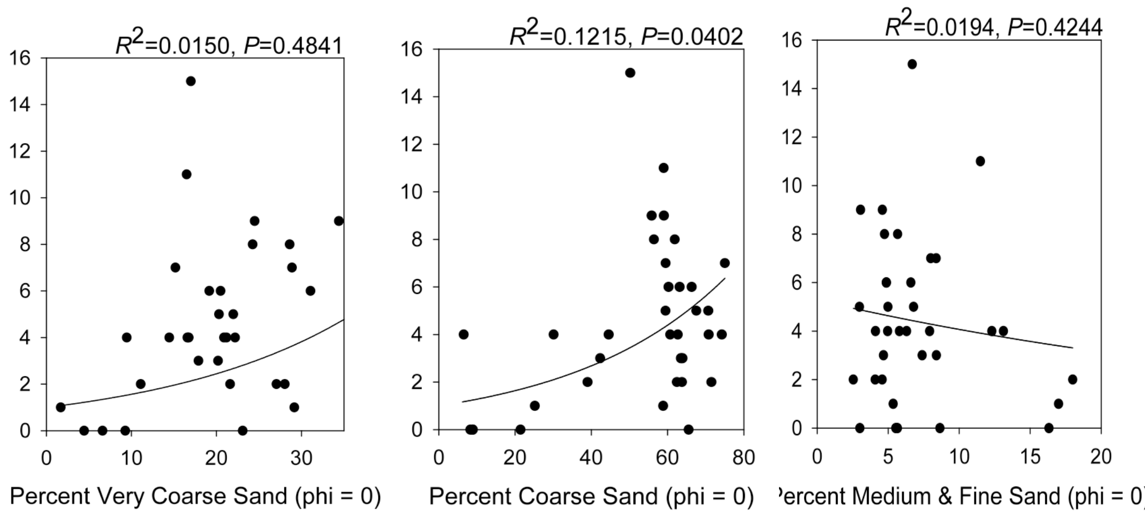

Figure 2: Number of PSL caught in respect to varying amounts of very coarse, coarse, and medium and fine sand.

Figure 3

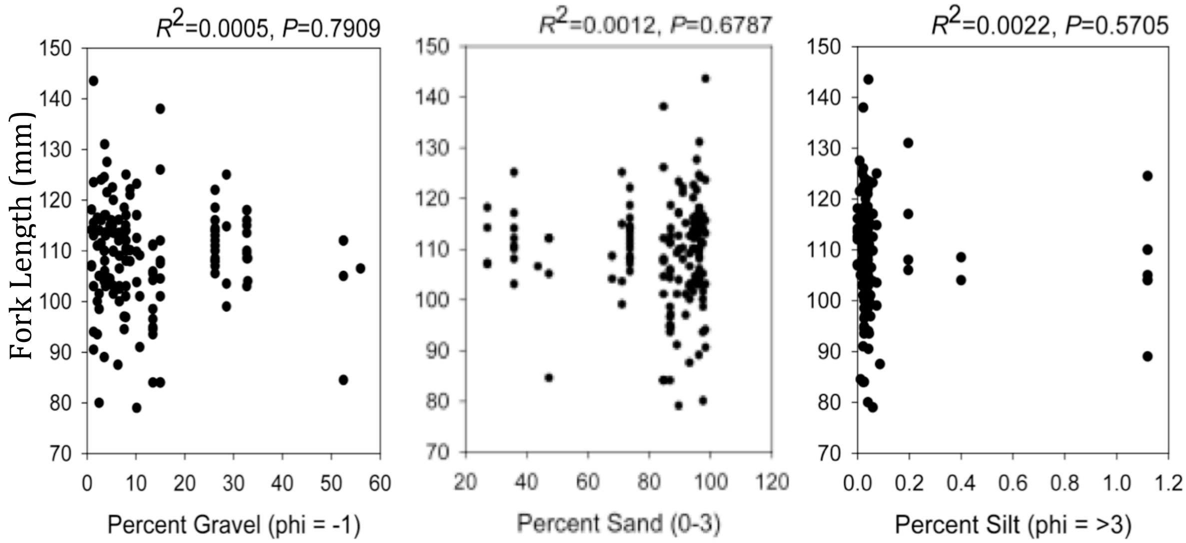

Figure 3: PSL fork length size in respect to varying amounts of gravel, sand, and silt.

Figure 4

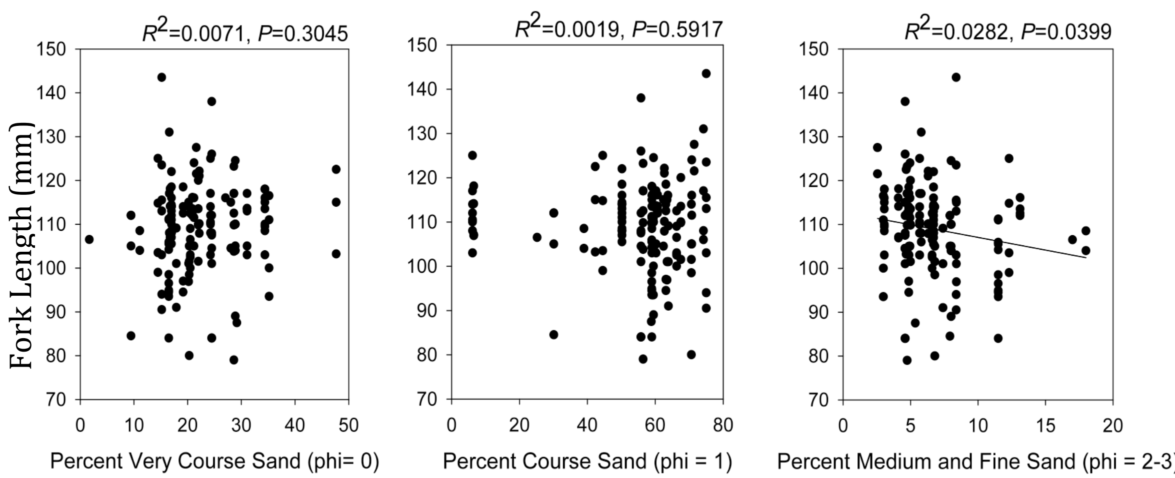

Figure 4: PSL fork length size in respect to varying amounts of very coarse, coarse, and medium and fine sand.

Figure 5

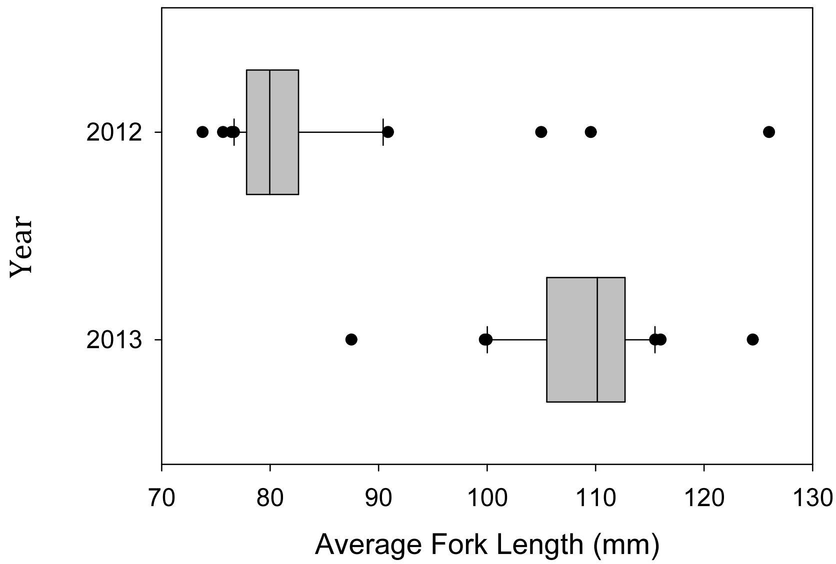

Figure 5: Comparing PSL population structure between the years 2012 and 2013

Figure 6

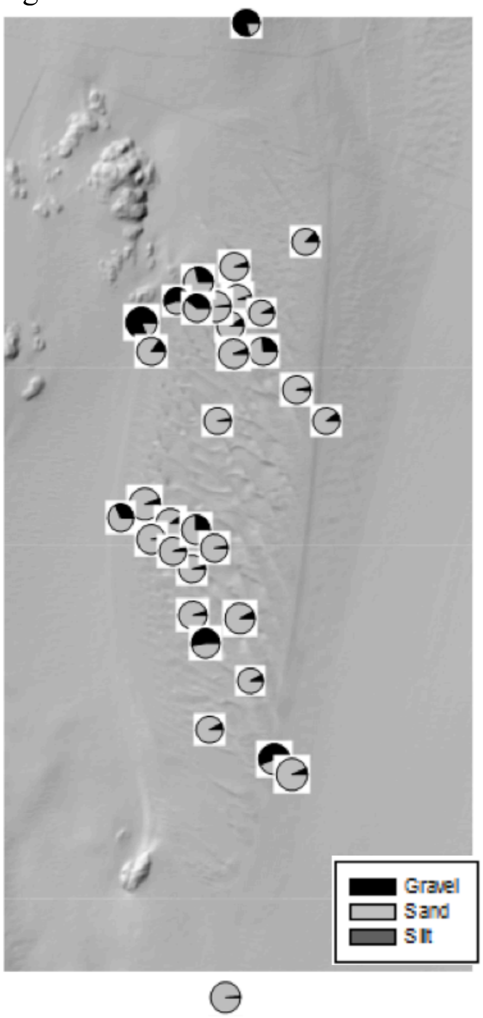

Figure 6: Substrate compositions varying across the sand wave.

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