Characterizing Pacific sand lance habitat in the San Juan channel sand wave field

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ABSTRACT

In the pelagic zone *Ammodytes hexapterus* or the Pacific Sand lance (PSL) act as an important link in the food web feeding on planktons and being preyed on by a wide variety of higher trophic level predators (Martin et al., 1999). The San Juan Archipelago (SJA) offers a diverse, productive and tidally dynamic ecosystem for PSL to inhabit. Sand wave fields are thought to be a major habitat for PSL in the SJA. Sand waves are bed forms present under flow velocities of 0.5 to 1.0 m/s and grain size of 0.25 -2.0mm in diameter (Rebesco and Camerlenghi, 2008). Understanding how benthic substrate will shape sand lance distribution on the wave fields is critical to further understanding the life history, daily migrations and consequently the role PSL play in the pelagic environment. Understanding how fish densities change with differences with substrate, how fish size change with substrate and how does substrate change over the sand wave are important steps towards further answering questions about the life history and populations of the PSL. These questions were addressed by obtaining sediment samples from the San Juan channel sand wave field and fractioning out sediment size, measuring PSL densities and sizes in the samples. PSL preferred low gravel high sand concentrations. Sand lance densities were highest in high concentrations of sand which corresponded to the middle of the wave field.

INTRODUCTION

The *Ammodytes* genus is known for the ability to inhabit multiple oceanic realms including the pelagic water column and benthic sandy substrate. *Ammodytes hexapterus*, the Pacific sand lance (PSL), is a forage fish distributed through the North Pacific from Central

California to Japan (Robards, 1999). The San Juan Archipelago (SJA) offers a diverse, productive and tidally dynamic ecosystem for PSL to inhabit. In the pelagic zone, PSL act as an important link in the food web, feeding on planktons and being preyed on by a wide variety of higher trophic level predators (Martin et al., 1999). A few consumers of the PSL in Washington waters include the Common murre, Tufted puffin, Rhinoceros auklet and Pacific salmon (Penttila, 2007).

Much of the life history in the SJA is unknown, however it is speculated PSL are occupy additional habitat during spawning sometime between November and February around shallow water beaches composed of sand and gravel (Penttila, 2007). PSL and their eggs have been found dispersed through intertidal beaches with an estimated incubation time of 1 month (Penttila, 2007). The young of the years (YOY) are thought to reside in the shallow near shore beaches in their first summer (Penttila, 2007). After their first summer sand lance are thought to move to deeper waters where they occupy the benthic substrate during nights and move into the pelagic water column during the day to feed (Penttila, 2007). It is thought that at age two sand lance become sexually mature at age two (Martin et al, 1999).

Sand wave fields are thought to be a major habitat for PSL in the SJA. Sand waves are bed forms present under flow velocities of 0.5 to 1.0 m/s and grain size of 0.25 -2.0mm in diameter (Rebesco and Camerlenghi, 2008). The San Juan Channel (SJC) wave field is one of 36 deposited around the SJA (Greene et al., 2011). The SJC sand wave field is 1700m long, found at a depth of 50-80m (Greene et al., 2011). Individual waves have wavelengths of 50 to 100m and with heights of 0.5 to 5m (Greene et al., 2011).

In 2004 Sand lance discovered in SJC wave field during an ROV survey (Blaine, 2006). In 2006 the wave field was sampled and found to be comprised of one year old fish, and preferred course grain (Blaine, 2006). In 2010 it was determined that PSL prefer sand with majority of the substrate composition ranging 0.062- 2.0 mm in diameter, with a preference for medium and course sand (Greene et al. 2011). Within the sand wave field larger fish were found in the north and smaller fish found in the south (Greene et al. 2011). It was determined in 2010 that the majority of the fish found in the sand wave field were one year olds (Rood, 2010).

Past lab experiments have shown that PSL prefer substrate ranging from fine sand to coarse sand (Pinto et al. 1984). Lab studies have also demonstrated the ability of PSL to penetrate sediment ranging from silt to pebbles and have a preference for medium grain sand over course, very course and fine grained sand (Greene et al., 2011). Lab experiments testing sediment preference do not replicate all the variables shaping PSL distribution in the natural environment. Other factors may include crowding, oxygen availability of food sources may be contributing to sand lance choice of substrate. Understanding how benthic substrate characteristics shape sand lance distribution on the wave fields is critical to further understanding the life history, daily migrations and consequently the role sand lance play in the pelagic.

1) How do densities of PSL change with differences in substrate?
2) How does fish size change in with differences in substrate?
3) How does substrate change over the sand wave?

These questions were addressed by obtaining sediment sample from the SJC sand wave field and fractioning out sediment size, measuring sand lance densities and sizes in the samples. I hypothesize sand lance will prefer medium to coarse grain sand regardless of fish length and fish will be evenly dispersed across the wave.

METHODS

The benthic environment of the San Juan Channel (SJC) sand wave fields was sampled for PSL by deploying a Van Veen sediment grab off the R.V. Centennial and R.V. Auklet (Fig. 1). From September through November 2012, 40 successful grabs with fish, 3 successful grabs with no fish and 27 unsuccessful grabs were collected in various locations on the SJC sand waves. Sediment grabs are characterized as successful and usable samples when the Van Veen grab surfaced closed with no rocks fouling the seal allowing sediment and fish to escape upon recovery. GPS coordinates were taken for every grab on the sand wave field. Fish present in the Van Veen grab were collected and anesthetized with MS22 and preserved in formalin. Each fish collected was measured for mass and fork length.

A sediment sample of roughly 1500g was taken from each sample. Samples were placed in drying ovens and under heat lamps. When dried, a portion of the sample (100-350g) was massed out for an initial weight. Samples were run through sieves into fractions by grain size of 2mm, 1mm, 0.5mm, 0.125mm, and >0.125mm in diameter which measured fractions of gravel, very coarse sand, coarse sand, fine and medium sand and very fine sand and silt. Samples were sieved for 5 min before each sieve fraction was weighed.

Ten samples were picked to run as duplicates on a rotap machine to test for accuracy of the sieving method. Duplicate sample were run through a series of sieves with the rotap to determine the percent difference of the methods, because a rotap was not available. It was determined that the accuracy of the sieving method used was best in the middle range of the sieves (Table 3).

There is a relationship between age and fork length that was used a substitute for otolith processing. Fish with lengths of 0-69mm are classified as young of the year, fish with lengths of 70-109mm are characterized as age one, fish with lengths of 110-129mm are characterized as age two fish, fish with lengths of 130-150mm are characterized as and age three.

RESULTS

A total of 1001 fish were examined in relation to 40 corresponding sediment samples from the total 43 successful grabs. Catch per unit effort (CPUE) ranged between 0 and 65 fish / grab on the SJC sand wave field. PSL were found present in substrate composed of a combination of silt, fine to very coarse sand, and gravel. Substrate material included sandy glacial deposit remains and biogenic shell hash including urchin spines and whole oyster shells.

Substrate distribution and fish densities over the SJC sand wave field

Latitude conveniently serves as a proxy to describe relative location down the sand wave field as the sand field is oriented north to south in an oval shape with the long diameter running down SJC (Fig. 1). At latitudes between 48.52203 and 48.5022 degrees north, total percent sand varied between 52 and 99% (Fig2). Distributed through this total range of sand there are samples that clustered into a tighter range of 90 to 99% total sand (Fig 2.). These two differing sediment groups suggest the outskirts of the sand field to below latitudes of 48.520 and above 48.505 to have greater variability in substrate compositions. At these latitudes there were substrate samples composed of high percent sand and low percent gravel and low percent sand and higher percent gravel (Fig. 2). From latitudes of 48.52203 to 48.515 there is an increase in densities of PSL and from 48.515 to 48.5022 there is a decrease in CPUE. These patterns in latitude and CPUE suggest the middle of the sand wave field to contain high amounts of smaller fish and high PSL densities and the North and South edges to have a decrease in PSL densities.

Variation in substrate and PSL densities

Significant differences of CPUE with change in percent gravel exist along the sand wave (R^2=0.24, *P*=0.003, exponential decay; Fig. 3). There is no significant difference in CPUE with variation in grain sizes ranging from very course to silt. PSL were present in sediment composed of 3 to 73% gravel (Fig. 3). PSL densities were highest when gravel concentrations were low Fig. 3). Increased gravel corresponded to a decrease in PSL densities, (R^2=0.25, *P*=0.001, exponential decay; Fig. 3). Total percentage of sand in samples including very course sand, course sand, medium sand and fine sand ranged from 32- 99% (Fig. 3). PSL were found in increased densities in locations with high percentages of total sand (R^2= 0.99, *P*<0.001, quadratic polynomial; Fig. 3). Within the category of total sand, there were smaller grain size fractions. Very course sand varied in samples from 3-31% (Fig.4). PSL densities increased with increase percentages very course sand (R^2=0.04, *P*=0.226, linear; Fig. 4). Coarse sand varied in samples ranging from 4 - 71% (Fig4). Samples with higher percentages of course sand had increased PSL densities (R^2=0.99, *P*<0.001, linear; Fig. 4). Samples were composed of sand ranging from 2-28% fine and medium sand (Fig. 4). PSL densities were not higher in larger concentrations of medium and fine sand and likewise were not detracted by higher concentrations. (R^2=0.002, *P*=0.76, linear; Fig.4). Differing fractions of fine and medium sand had similar densities of PSL present in samples. Sample contained 0-0.86% of very fine sand and silt. Low concentrations of very fine sand and silt had higher PSL densities then higher concentrations of silt. There was an exponential decreased in PSL density with a small increase with samples with silt. (R^2=0.25, P=0.001, exponential decay; Fig. 4).

Change in substrate with fish size

An increase in gravel corresponded to an increase in fork length (R^2=0.068 P=0.104, linear; Fig. 5). An increase in very coarse sand corresponded to a decrease in average fork length (R^2=0.27, P= 0.086, linear; Fig. 5). An increase in coarse sand corresponded to a decrease in average fork length (R^2=0.15, P=0.014, linear; Fig. 5). An increase in medium and fine sand corresponded to an increase in average fork length (R^2=0.36, P<0.001, linear; Fig. 5). In increase in silt and very fine sand corresponded to an increase in average fork length (R^2=0.42, P<0.001, linear; Fig. 5). Average fork length of grabs ranged from 75- 127mm**.** Samples with an average fork length of 75-85 mm were present in substrate with 1-75% gravel, 10- 30% very course sand, 5–70 % course sand, 5-25% medium and fine grain sand and less than 0.05 % very fine sand and silt (Fig. 5). Samples with an average fork length of over 100m were present in substrate with 25-70% gravel, 5-20% very course sand, 20-35 % course sand, 15-30% medium and fine grain sand and less than >0.05 % very fine sand and silt (Fig. 5). Samples with an average fork length of 75-85 mm were present in a wide a range of substrate. Over the spectrum of substrate PSL were present in, the majority of the samples that has fork length average fall between 75-85mm clustered in substrate with a smaller range of 1-15% gravel, 10- 35% very course sand, 50 – 60 % course sand, 5-25% medium and fine grain sand and less than 0.05 % very fine sand and silt (Fig. 5). Samples with an average fork length of over 100m were present in substrate with 25-70% gravel, 5-20% very course sand, 20-35 % course sand, 15-30% medium and fine grain sand and less than >0.05 % very fine sand and silt (Fig. 5). There was less clustering between samples with an average fork length greater then 100mm. These data suggest the one year old fish were found in highest concentrations in substrate with high percent sand, whereas the two year old fish were found distributed evenly in in lower numbers through a wide variety of sand concentrations.

Fish age and sediment

7.2 % of the individuals caught on the SJC were classified them as YOY, 90.0 % of the classified as one year olds, 2.5% classified as two year olds and 0.3% classified as three year olds. No four year old fish were found in the sample. There was no increase in densities of age zero PSL with increase an increase in gravel (R^2<0.001, *P*=0.948), sand (R^2=0.002, *P*=0.948) and very fine sand and silt (R^2=0.004, *P*=0.319). However age zero fish were found clustered in low gravel and high sand concentrations (Fig. 6). An increase in gravel corresponded to a decrease in one year old fish (R^2=0.11, *P*=0.037, inverse first order polynomial; Fig. 7). An increase in sand corresponded to an increase in one year old fish (R^2=0.28, *P*=0.002, quadratic; Fig. 7). An increase in sand and silt corresponded to a decrease in one year old fish (R^2=0.04, *P*=0.43, inverse 2nd order polynomial; Fig. 7). An increase in gravel corresponded with a slight increase in two year old fish densities (R^2=0.25, *P*=0.04, linear; Fig. 8). In increase in sand corresponded to a slight decrease in densities (R^2=0.24, *P*=0.04, linear; Fig. 8). An increase in silt corresponded to a decrease in two year old densities R^2=0.19, *P*=0.597, linear; Fig 8). Two year old fish were distributed evenly by densities over a wide range in gravel and sand. Age three fish were found present in two grabs on the sand wave. Two fish were found in the same grab in a sample comprised of 70% sand and the second instance was a fish found in 37% sand (Fig. 9)

CPUE and average fish length

Two groups of fish can be observed when looking at average fork length. The majority of the samples can be separated into a group comprising of fish with average fork length of 80mm.

This average size group is comprised of grabs with high numbers of fish. The alternative average size group found in samples has an average fork length of over 100mm. This average size group is typically found in grabs with low numbers of fish. Overall as CPUE increased, average fork length decreased (R^2=0.80, P<0.001, exponential decay, Fig. 10).

DISSCUSSION

SJC sand wave field proved to be consistently occupied through space and time by PSL, confirming this location as a successful PSL habitat occupied through time from 2006, 2011, and fall 2012 (Greene et al., 2011). In 2006, 2010 and 2012, the wave field was dominated by one year old fish (Rood, 2010). On the outskirts of the sand wave field the substrate composition was locally variable, composed of high concentrations of gravel and relatively lower sand concentrations. The middle of the wave is consistently comprised of high concentrations of sand and small concentrations of gravel. The local variation on the north and south edges of the sand wave field may be explained by peak to trough variability. The outcome of the crest and trough velocity difference may be more dramatized on the out skirts of the sand wave fields, where bigger particles accumulate over time.

These sediment deposition patterns within the sand wave field provided different habitat choices for the PSL. An increase in CPUE in the center of the sand wave may be explained by the presence of optimal and spatially consistent substrate. A decrease in gravel concentrations was a significant driver in increased sand lance abundance; it is important to note the ability to occupy higher percentages of gravel. There was no significant difference in CPUE with variation with in the optimal habitat ranging from very coarse to fine sand which is thought to be the range for ideal PSL habitat, although coarse sand demonstrated a strong positive linear relationship with CPUE. These results suggest that other factors besides grain size including, oxygen availability, diel cycles, tidal cycles and seasonal trends may be driving differences in CPUE.

The strong positive relationship between course sand and density of PSL suggest grain size may act as a good predictor for habitat in this location of the SJC sand wave field. It is also possible that coarse sand has a strong relationship with CPUE because there were higher percentages of this sand fraction in the sample. No relationship between other sand grain sizes was observed suggesting smaller grain sizes may increase PSL decrease oxygen circulation. There was an exponential decreased in PSL density with a small increase in silt, suggesting silt to act as an environmental restrictor on PSL (Pinto et al., 1984)

The relationships between average fork length, substrate and age class distribution with substrate builds insight and raises questions regarding the PSL life history. There is evidence that one year old sand lance were more reliant on optimal sand habitat whereas two year old fish do not have as strong requirements for substrate as the one year old fish. This optimal sand is found in the middle of the wave with high concentrations of PSL. There may be advantages for smaller fish living in the middle of the wave including greater opportunity to join passing schools for feeding. The two year old PSL were found occupying substrate with high percent gravel, found on the edges of the sand wave field. The more diverse distribution of the two year old fish suggest these fish to be more individualist after their 1st year. The edge of the sand waves may provide a benefit for increased feeding opportunity because decreased crowding pressure from the water column. The two year old PSL may able to balance the cost of occupying non optimum substrate with decreased crowding pressure and optimal feeding opportunities.

The understanding and characterization of the optimum PSL substrate and habitat of the SJC wave field facilitates the ability to better monitor the population of the wave field in the future. Using the middle of sand wave fields for future short term and long term monitoring projects will help eliminate questions about the variability created by substrate differences of PSL during sampling. However, it is also important to remember that sand lance, especially the two year olds from this study are capable of occupying "non ideal" habitat described in lab experiments and that patchiness does exist in fish densities along the wave. The patters observed provide insight and bring up many questions regarding the PSL life history and survival strategies. The high concentration of one year old PSL in comparison to low concentrations of two year old fish bring up question about the spatial and temporal variation of the life history of the PSL as it is thought that PSL become sexually mature at 2 years (Greene, 2006 FHL). In the future it would be useful for a three year intensive sampling project on sand wave fields over small scale and annual time periods to help understand the differences in age class distribution. It would be also be useful to monitor multiple wave fields at the same time to get an idea of the variability of life history and population stages from wave to wave.

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FIGURES

Table 1. Sample Locations and dates around the SJC sand wave field. * Indicates samples not usable because of a fowled closer of the Van Veen grab. Samples used for sediment analysis and fish analysis were taken from fully “closed” grabs.

Latitude	Longitude	Drop	Date	Time	Open/Close grab
48.51773	-122.948	C1.1	9/28/2012	?	Close
48.51237	-122.952	C1.2	9/28/2012	?	Close
48.5104	-122.953	C2.1	10/10/2012	1440	Close
48.50983	-122.955	C2.2	10/10/2012	1440	Close
48.52278	-122.952	C2.3	10/10/2012	1440	Open
48.52738	-122.954	C2.4	10/10/2012	1440	Open
48.52293	-122.954	C3.1	10/17/2012	1334	Close
48.52273	-122.954	C3.2	10/17/2012	1344	Close

48.511	-122.953	C3.3	10/17/2012	1357	Close
48.51103	-122.953	C3.4	10/17/2012	1400	Close
48.50812	-122.955	C3.5	10/17/2012	1407	Close
48.50222	-122.954	C3.6	10/17/2012	1415	Close
48.52203	-122.954	C4.1	10/23/2012	1350	Close
48.5222	-122.952	C4.1*	10/23/2012	1345	Open
48.52193	-122.956	C4.2	10/23/2012	1355	Close
48.51262	-122.956	C4.3	10/23/2012	1407	Close
48.5103	-122.955	C4.4	10/23/2012	1424	Close
48.5114	-122.959	C4.4*	10/23/2012	1415	Open
48.50025	-122.954	C4.5*	10/23/2012	1439	Open
48.50115	-122.953	C4.5*	10/23/2012	1434	Open
48.51022	-122.95	C5.1	10/25/2012	735	Close
48.51168	-122.949	C5.1*	10/25/2012	735	Close
48.51162	-122.954	C5.10	10/25/2012	1303	Close
48.5137	-122.949	C5.10*	10/25/2012	1255	Open
48.51005	-122.953	C5.2	10/25/2012	751	Close
48.50882	-122.953	C5.3	10/25/2012	756	Close
48.50782	-122.954	C5.4	10/25/2012	758	Close
48.50658	-122.954	C5.5	10/25/2012	802	Close
48.50965	-122.951	C5.6	10/25/2012	1226	Close
48.51167	-122.954	C5.7	10/25/2012	1237	Close
48.50957	-122.95	C5.7*	10/25/2012	1229	Open
48.51248	-122.953	C5.8	10/25/2012	1241	Close
48.51188	-122.959	C5.9	10/25/2012	1245	Close
48.52168	-122.951	C6.1	10/30/2012	1317	Close
48.52172	-122.951	C6.2	10/30/2012	1320	Close
48.5129	-122.954	C6.3	10/30/2012	1330	Close
48.513	-122.955	C6.4	10/30/2012	1335	Close
48.5086	-122.955	C6.5	10/30/2012	1412	Close
48.50167	-122.955	C6.5*	10/30/2012	1351	Open
48.50205	-122.954	C6.5*	10/30/2012	1346	Open
48.50765	-122.952	C6.5*	10/30/2012	1400	Open
48.50787	-122.953	C6.5*	10/30/2012	1405	Open
48.50818	-122.954	C6.5*	10/30/2012	1408	Open
48.52137	-122.95	C7.1	11/7/2012	1244	Close
48.5212	-122.95	C7.2	11/7/2012	1248	Close
48.51255	-122.954	C7.3	11/7/2012	1258	Close
48.51153	-122.955	C7.4	11/7/2012	1301	Close
48.52017	-122.952	C8.1	11/14/2012	1214	Close
48.52163	-122.953	C8.1*	11/14/2012	1204	Open
48.52217	-122.953	C8.1*	11/14/2012	1207	Open
48.52098	-122.952	C8.2	11/14/2012	1218	Close
48.52058	-122.952	C8.2*	11/14/2012	1216	Open
48.51658	-122.952	C8.3	11/14/2012	1226	Close
48.51685	-122.953	C8.4	11/14/2012	1229	Close
48.51078	-122.953	C8.5	11/14/2012	1240	Close
48.51103	-122.953	C8.5*	11/14/2012	1236	Open

48.50808	-122.954	C8.6	11/14/2012	1249	Close
48.50828	-122.954	C8.6*	11/14/2012	1246	Open
48.52147	-122.959	A1.1	10/21/2012	1734	Close
48.52035	-122.954	A1.2	10/21/2012	1754	Close
48.50637	-122.956	A1.3	10/21/2012	1819	Close
48.51478	-122.956	A2.1	11/1/2012	812	Close
48.51348	-122.958	A2.3	11/1/2012	843	Close
48.51323	-122.956	A2.4	11/1/2012	855	Close
48.52087	-122.951	A3.1	11/8/2012	1918	Close
48.51278	-122.954	A3.2	11/8/2012	1943	Close
48.50895	-122.954	A3.3	11/8/2012	2005	Open

Table 2. Grain size fraction classification.

Grain size	Grain size diameter (mm)	phi
Gravel	2	-1
Very coarse sand	1	0
Coarse sand	0.5	1
Fine + medium sand	0.125	3
Silt and very fine sand	<.125	<3

Table 3. Percent difference in sieve methods.

Sieve Size (mm)	% difference of techniques
2	11.5509906
1	6.6794433
0.5	12.47089181
0.125	19.47320794
<.125	58.84837159

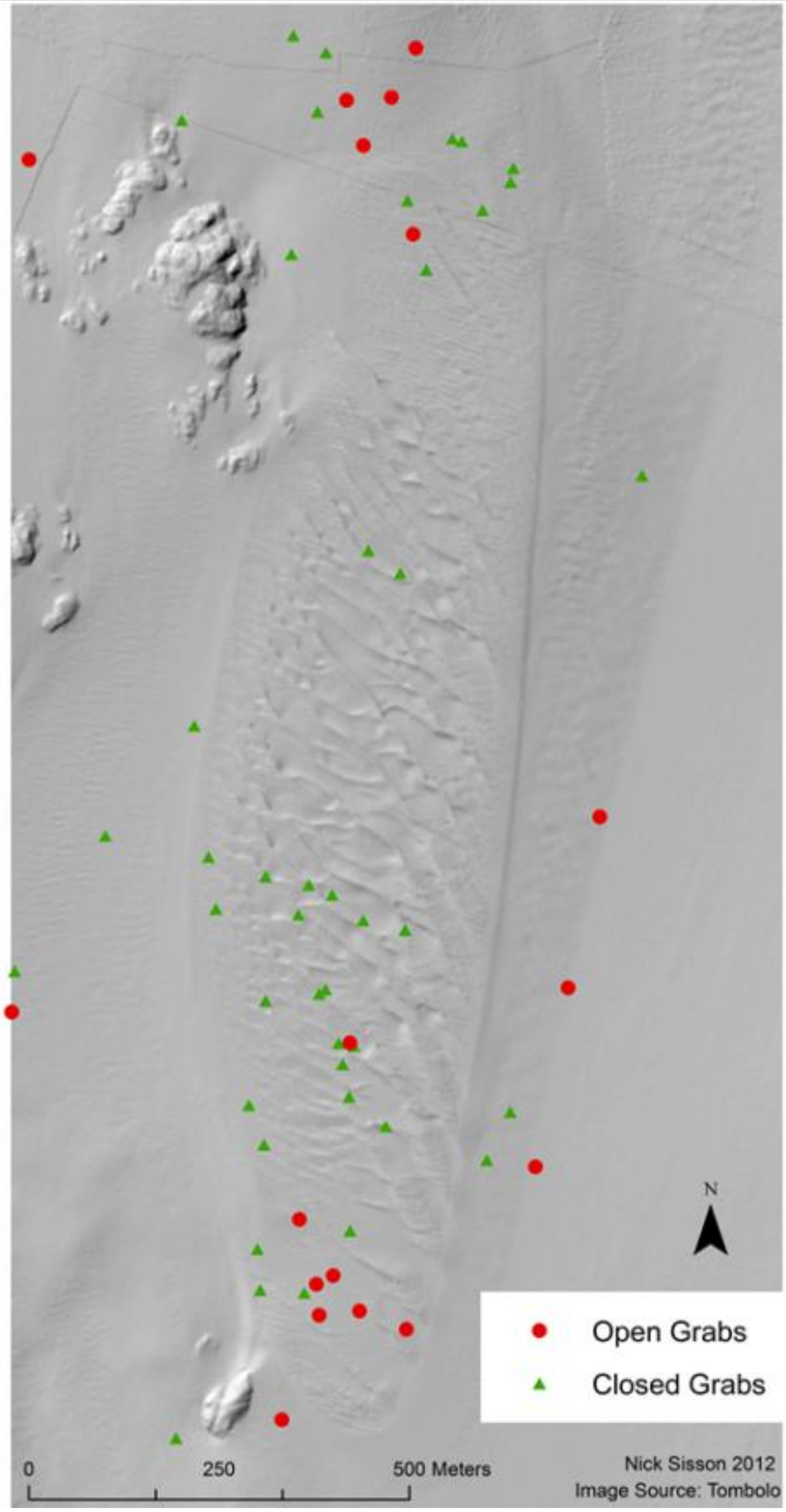

Figure 1. Location of sample sites around San Juan Channel sand wave field, courtesy of Nick Sisson

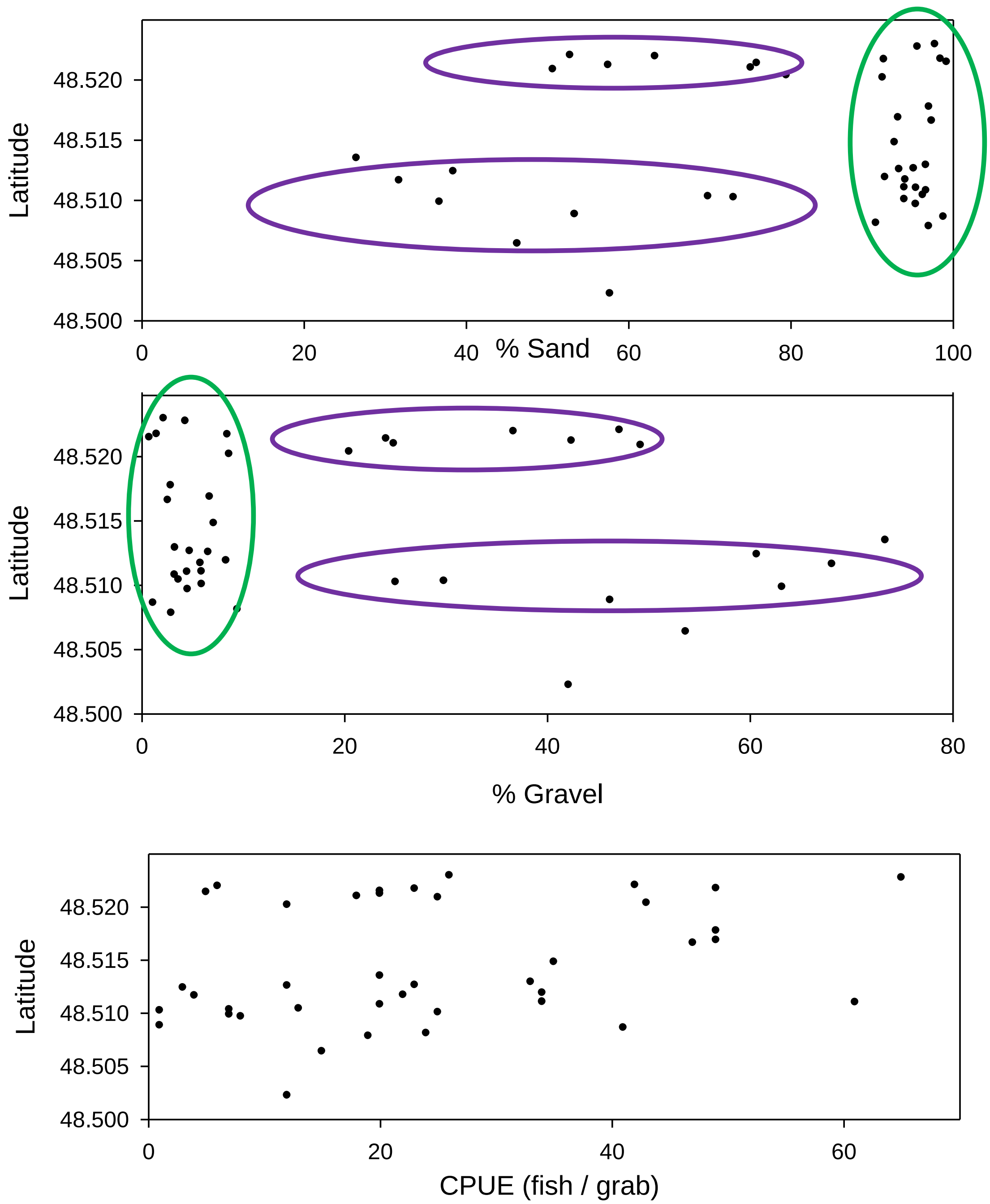

Figure 2. Distribution of sand, gravel and CPUE with latitude.

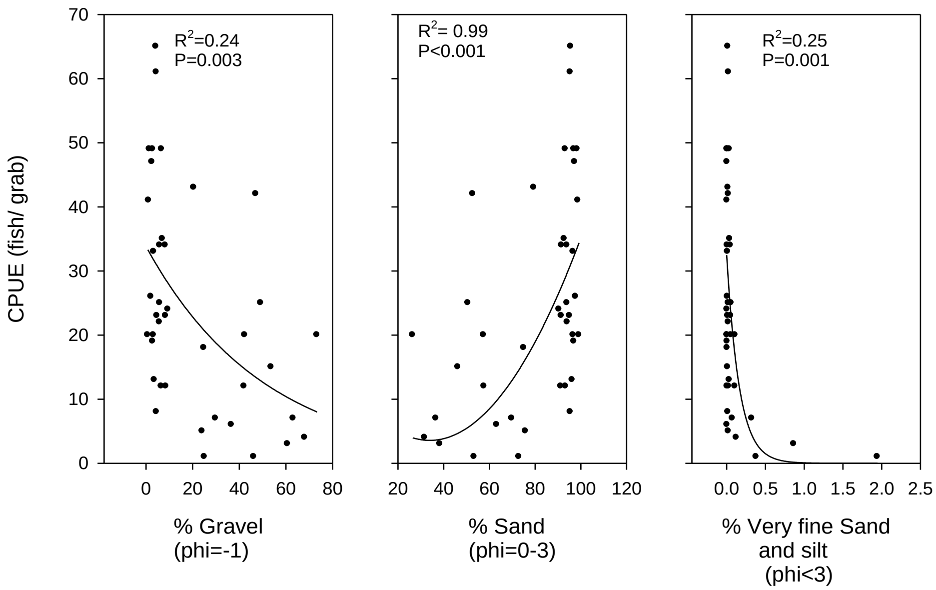

Figure 3. CPUE in respect to sediment composition.

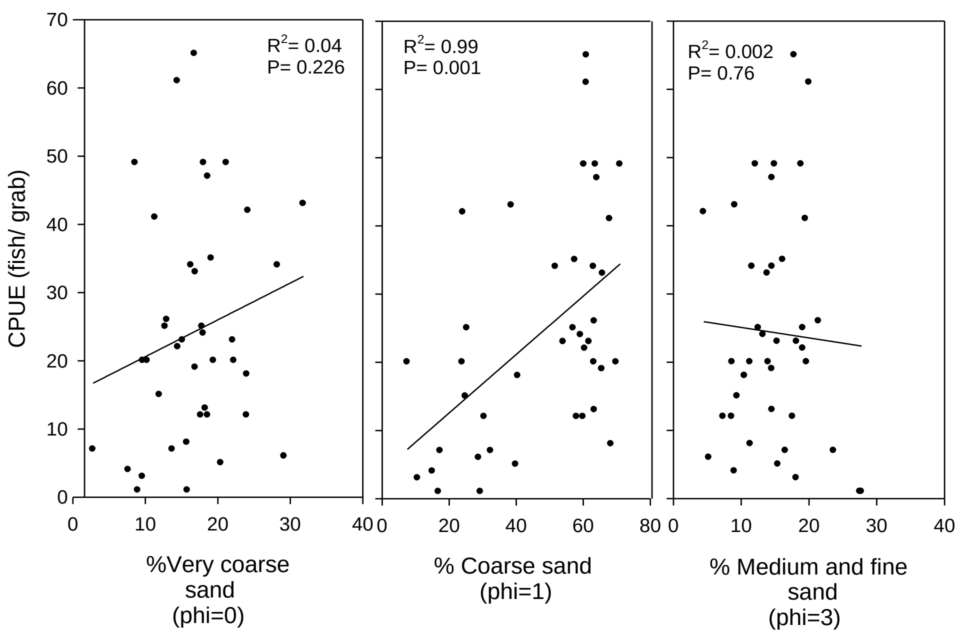

Figure 4. CPUE in respect to differing sand grain sizes.

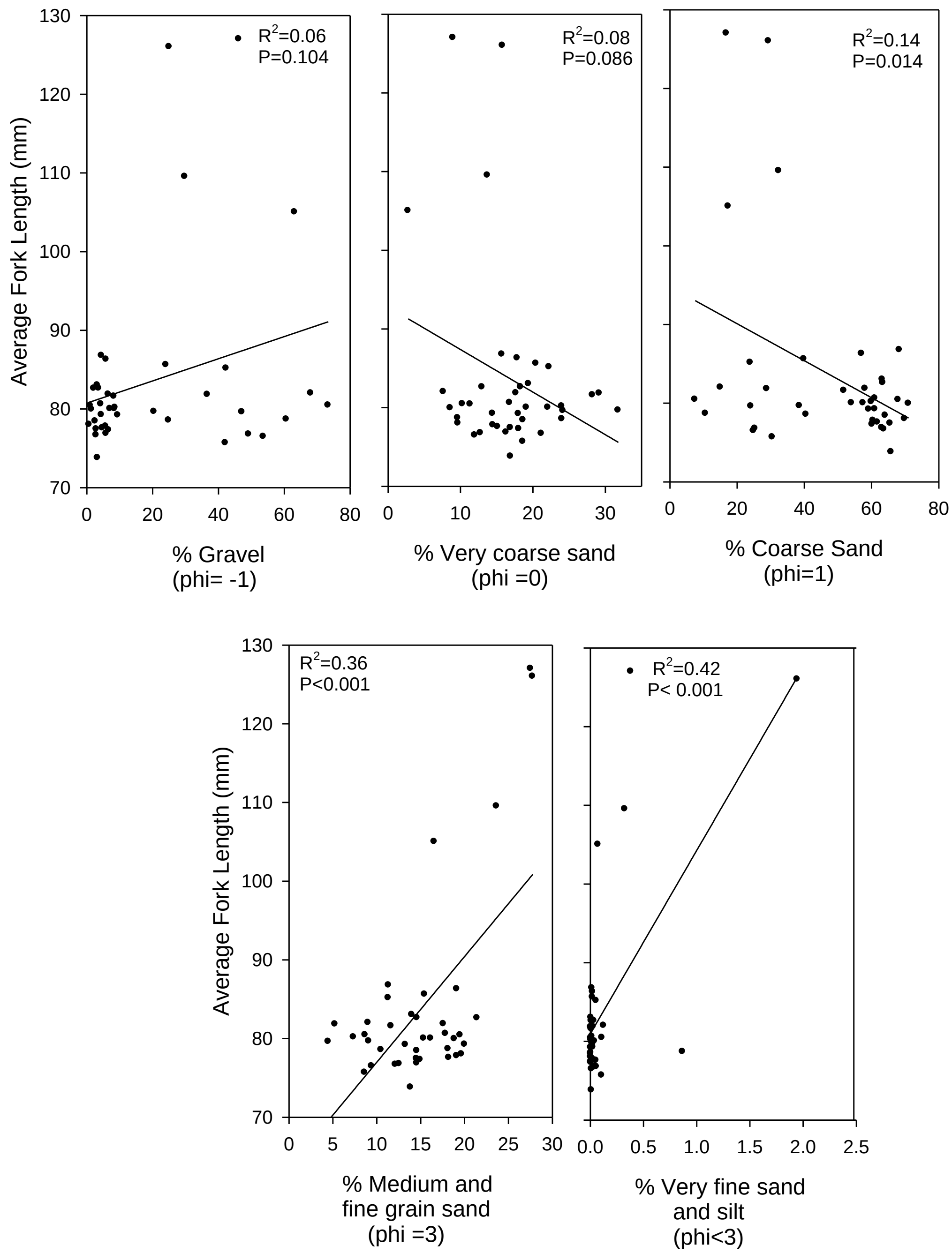

Figure 5. Average fish length samples in response to substrate composition.

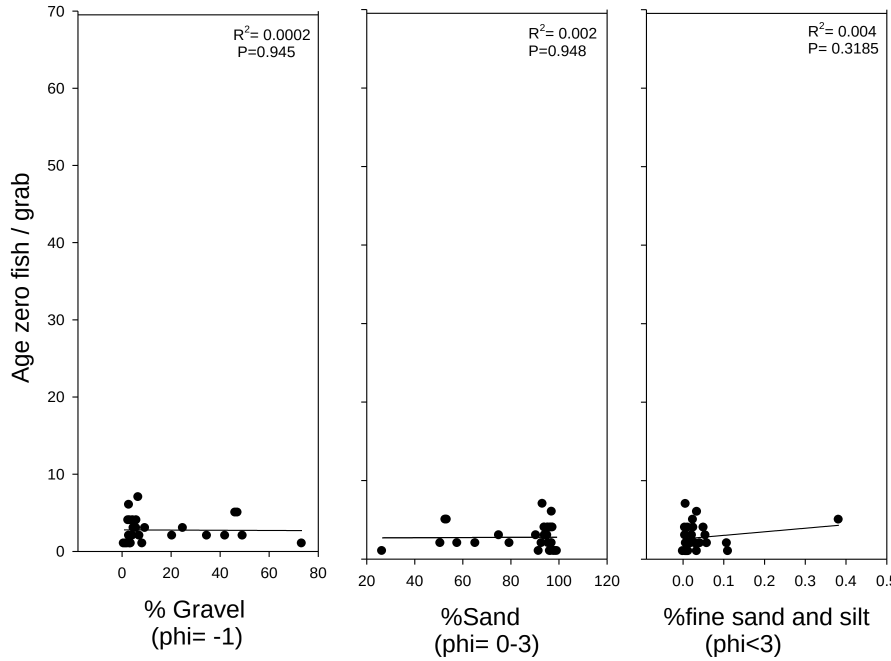

Figure 6. Densities of age zero fish in each grab in relationship to substrate.

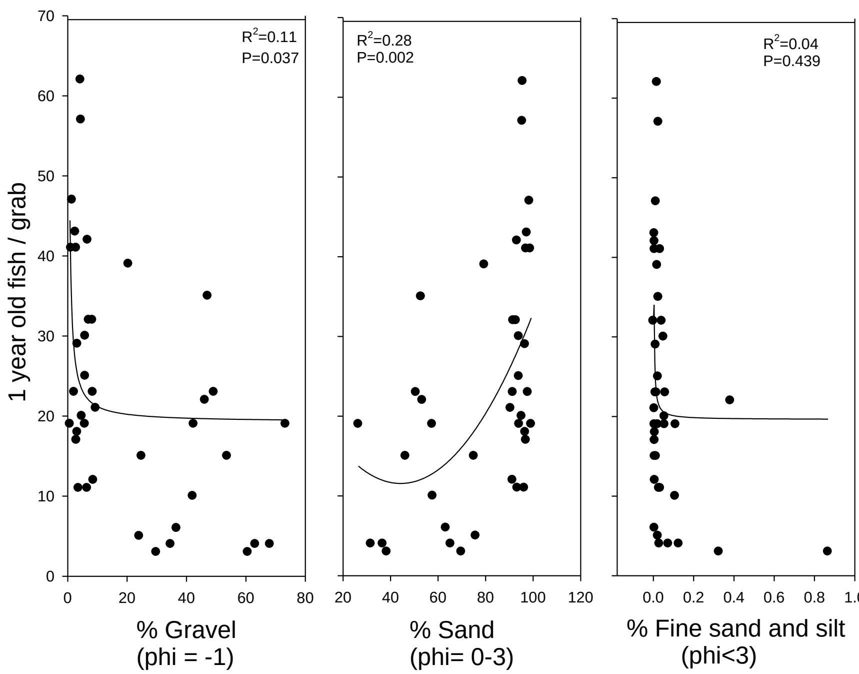

Figure 7. Densities of one year old fish in relationship to substrate characteristics.

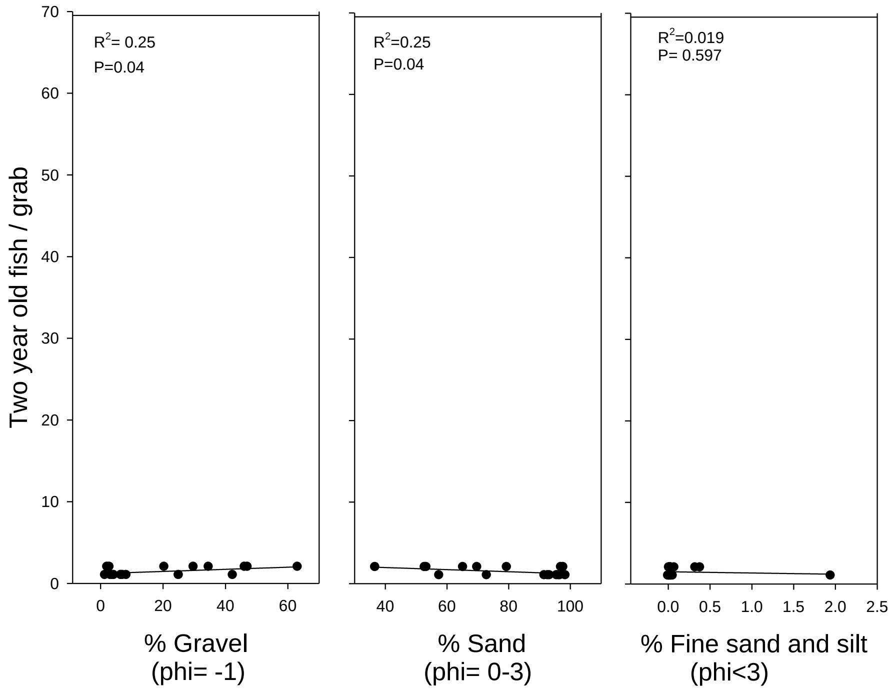

Figure 8. Densities of two year old fish in relation to substrate composition.

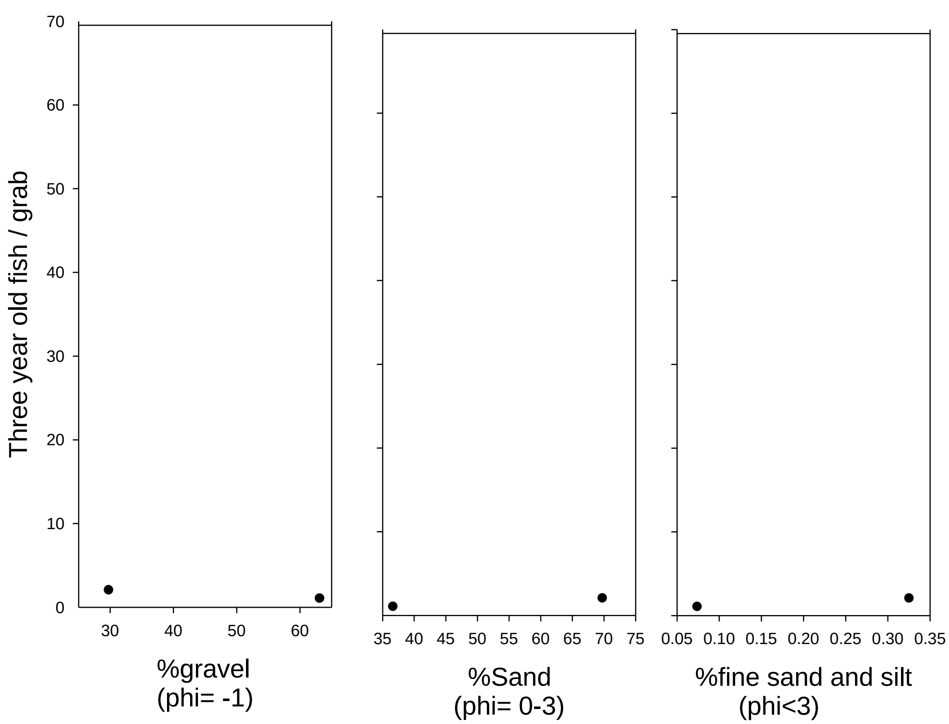

Figure 9. Densities of Three year old fish in relationship to substrate composition.

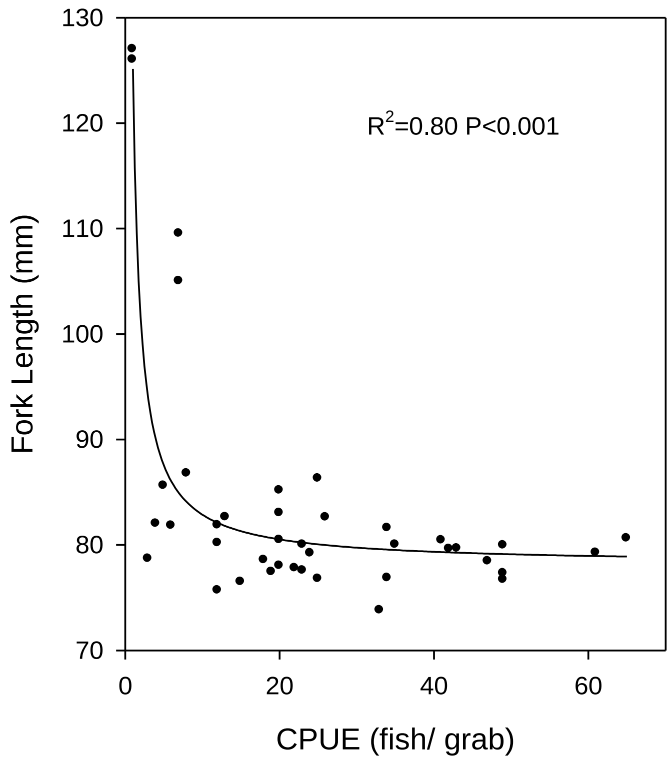

Figure 10. Average fish length in relationship to CPUE.