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Establishing Foraminifera Based Biofacies within Shallow Marine Deposits, Carpinteria Slough, CA. Implications for southern California Sea-Level Studies

A Thesis submitted in partial satisfaction of the
requirements for the degree Master of Science
in Earth Science

by

John Michael Bentz

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September 2016

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June 2016

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Abstract

Establishing Foraminifera Based Biofacies within Shallow Marine Deposits, Carpinteria Slough, CA. Implications for southern California Sea-Level Studies

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Foraminiferal assemblages are useful for producing high resolution sea-level curves, interpreting ancient marine and coastal sediments, and reconstructing past climates. However, their use for these purposes is dependent on knowing the environmental controls on their distribution, which varies regionally. In this study, I document the environmental variables controlling the distribution of foraminifera in Carpintaria Slough in southern California. The foraminiferal assemblages were determined at 29 sample locations within the marsh. Assemblages were complimented by measurements of elevation, pore-water salinity, pore-water pH, and grain size. Total organic carbon was also measured in 16 of these samples.

Three distinct biofacies were identified using Q-mode cluster analysis. Four species of foraminifera were shown to have statistically different mean abundances between the three biofacies zones, through the implementation of one-way analysis of variance tests (ANOVA). Zone 1 is defined by mean abundances of *Miliammina fusca* comprising between 30 and 60% of the entire sample. Zone 2 is defined by mean abundances of *Elphidium excavatum* comprising between 0 and 2% of any sample, and *Ammonia parkinsonian* comprising between 2 and 4% of any sample. Zone 3 is defined by a mean abundance of *Balticammina pseudomacscerens* comprising between 45 and 50% of any sample.

Correlation analysis, principle component analysis, and ordinary least squares linear regressions suggest that the distributions of foraminiferal species in Carpinteria Slough are linked to the environmental variables of elevation and salinity. Principle component analysis demonstrates that the percent of total variance in assemblage data is explained by elevation (33.68%), salinity (16.52%), pH (12.49%), and median grain size (12.42%). Although, the link between environmental variables and foraminiferal assemblages lacks definitive correlations, a final ANOVA, based upon elevation, is able to separate the foraminiferal data into two elevation zones. Zone A consists of all elevations below 0.83m and Zone B consists of all elevations above 0.83m. Therefore, foraminifera from southern California marshes provide limits to the refining of past relative sea-levels at the sub-meter scale.

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INTRODUCTION

Southern California is home to more than 20 million residents in coastal counties alone (Heberger et al., 2009). Human impacts on climate and the resulting sea-level rise have increased concerns of inundation among coastal communities. As much as 1.4 meters of sea-level rise are expected across the globe during the next century, assuming a constant medium to high rate of fossil fuel consumption (Cayan et al., 2009). One meter of sea-level rise would cost the city of San Francisco $48 billion (in 1990 USD) due to the damage of industrial, commercial, and residential buildings (Gleick and Maurer, 1990). Similarly, southern California coastal cities will be financially impacted by not only direct loses brought on by inundation, but also through the construction of infrastructure maintenance programs to mitigate a rise in sea level (Gleick and Maurer, 1990).

One way to better understand how sea-level rise might affect modern coastlines is to study the impact of past sea-level rise on the California coast. However, relatively few studies have examined past sea-level change in southern California in part due to the complicated relationship between eustatic sea-level rise, tectonic activity, and the difficulties associated with dating coastal sediments (Reynolds and Simms, 2015). Despite prior efforts, methods for reconstructing high-resolution sea-level curves have not been developed for southern California (Reyolds and Simms, 2015; Scott and Medioli, 1978).

Early sea-level studies utilized ‘sea-level index points’ to estimate the amount of sea-level change (Shennan, 1982). A sea-level index point is defined as any indicator in the sedimentary record that provides constraints on the elevation the sediment was deposited in relation to sea level (Shennan, 1982). Salt marsh foraminifera provide reliable 'index points' and elevation constraints on formerly undifferentiated coastal deposits (Scott and Medioli, 1978). In some cases, foraminifera have the potential to reconstruct local RSL with an accuracy of ± 5cm (Scott and Medioli 1978, 1980a).

Before modern foraminiferal assemblages can be used to reconstruct past sea levels along any specific stretch of coastline, the controls on their distribution must be established. The pioneering work of Scott and Medioli (1978), which has been built upon extensively over the last four decades, suggests that the main environmental control on marsh foraminiferal assemblages is elevation above mean sea level (MSL) (Kemp et al., 2009; Edwards et al., 2002; Leorri et al., 2008; Gehrels 1994; Hayward et al., 1999; Scott et al., 1996; Callard et al., 2011). However, other studies caution that other factors such as salinity, pH, total organic carbon (TOC), and grin size also control foraminiferal abundance and diversity in some settings (de Rijk, 1995; de Rijk and Troelstra, 1997, 1999). Taken together, these studies suggest that foraminiferal assemblages are determined by a multitude of environmental factors including not only elevation, but also salinity, pH, total organic carbon (TOC), and grain size (de Rijk and Troelstra, 1997). Thus before using foraminifera to reconstruct past sea level, the role of elevation in controlling their distribution must be established at each site.

The majority of prior salt marsh foraminifera sea-level research has been conducted on the eastern seaboard of North America and Europe, with only three salt marsh foraminifera studies along the western coast of North America (Hawkes et al, 2011; Guibalt et al., 1996; Jonasson and Patterson, 1992). No contemporary studies have investigated the environmental parameters governing the modern distribution of salt marsh foraminifera in southern California. The purpose of this study is to determine which environmental parameters govern the modern distribution of foraminifera in the Mediterranean climate of southern California.

In order to answer this question, I catalogued the modern foraminiferal assemblages and environmental variables governing their distribution in Carpinteria and Goleta Sloughs. This modern training set will aid the use of foraminifera in refining sea-level curves and documenting subsidence in southern California.

BACKGROUND

Prior Work in Southern California

Phleger (1962) was the first to study foraminifera within southern and Baja California salt marshes. In addition to documenting which species occurred in the semi-arid salt marshes of Baja California, Phleger (1962) also noted their general zonation with regard to vegetation and elevation. However, Phleger (1962) did not precisely measure the elevation ranges of each species of foraminifera, nor the ratio of species with respect to sea-level datums, two key parameters needed to use foraminifera to analyze past sea-level change.

Scott (2011) conducted foraminiferal studies within San Diego lagoons, in which elevation and foraminiferal abundances were determined; however, his study focused on subtidal lagoons, not the intertidal salt marsh sediments needed for refining sea-level curves. An earlier study by Scott and Medioli (1986) did document foraminiferal species abundances in relation to elevation above MSL along the pacific North American coast. However, neither this study nor other studies examined the environmental controls on the distribution of foraminifera within southern California salt marshes. Due to the different climate and oceanographic conditions among the Pacific Northwest and southern California coast, their salt marshes likely display different foraminiferal assemblages.

Controls on Salt Marsh Foraminifera

Elevation

The majority of salt marsh foraminifera studies, starting with Scott and Medioli (1978), suggest that the main environmental control on foraminifera zonation is elevation with respect to mean sea level (MSL) (Kemp et al., 2009; Edwards et al., 2002; Leorri et al., 2008; Gehrels 1994; Hayward et al., 1999; Scott et al., 1996; Callard et al., 2011). Scott and Medioli (1978) were the first to quantify assemblage changes with respect to GPS measurements. Since this study, other work has divided the marsh into faunal zones with respect to sea-level datums (Horton et al., 1999; Hayward et al., 2004; Horton and Culver, 2008; Hawkes et al., 2010).

Salinity

Several recent studies demonstrate that pore water salinity may also be a controlling environmental parameter in salt marsh benthic foraminiferal assemblages and faunal zones (de rijk, 1995; de Rijk and Troelstra, 1997; Horton and Culver, 2008). Historically salinity measures are taken from surface waters overlying the sample collection site, which fails to take into account the salinity within the pore water in which the foraminifera live (Scott et al., 1991; Phleger, 1955). Furthermore, surface waters and pore waters are different due to the difference in factors such as rainfall, groundwater seepage, and evaporation (de Rijk, 1995; de Rijk and Troelstra, 1997). Thus before assuming elevation is the dominant control on foraminifera zonation, the role of salinity in controlling their distribution must be taken into account.

Organic Matter

Organic carbon is food for foraminifera and modulates the pH of pore water near sample locations (Scott et al., 1991). Nitrogen in salt marsh sediments controls how much microorganisms can metabolize decomposed organic matter (Lee and Anderson, 1991). Therefore, studies of salt marsh ecology also account for the link between TOC and the Carbon to Nitrogen (C/N) ratios in controlling foraminiferal abundances (de Rijk and Troelstra, 1997; Patrick, 1990; Valiela and Teal, 1979; Phleger, 1955, 1960a, 1960b; Lessen, 2005).

Grain size

Salt marsh foraminiferal assemblages are dominated by agglutinates, which build their tests from sediment ranging from 2-20 μm in diameter (de Rijk and Troelstra, 1997). The absence of sediments within the 2-20 μm size range could limit the abundance of agglutinates (de Rijk and Troelstra, 1997). In addition, grain-size distributions provide insight into the depositional energy experienced throughout the marsh, which could also affect foraminiferal assemblages through relocation by strong currents (Hjulstrum, 1939; Phleger, 1955; Scott et al., 1991; Scott et al., 2011).

pH

Historical studies of salt marsh foraminiferal distributions neglect the correlation between pore water pH and foraminiferal assemblages (Murray and Alve, 1999). Foraminfera are either composed entirely of calcium carbonate or use calcium carbonate to bind sediment particles together in the formation of their test. Therefore, low pH may result in the dissolution of foraminifera and bias their abundances (Murray and Alve, 1999).

Season

Murray (1991) suggests that the time of year in which sampling occurs may bias foraminiferal abundances and distributions due to the potential for blooms of foraminifera in the spring and summer months. Spring and summer are the periods of highest primary productivity in southern California (Kahru and Kudela, 2009).

Study Areas

Carpinteria Marsh (34°24.0’N 119°31.5’W), the largest extant salt marsh in southern California, is located roughly 20 km east of Santa Barbara along the Santa Barbara Channel (Ferren, 1985; Wilson et al., 2013; Fugro West Inc., 2004) (Figure 1). Carpinteria Slough is structurally located within the subsiding Carpinteria Basin, an E-W syncline verging to the north, which is subsiding at a rate of 1.2±0.4 mm/yr (Jackson and Yeats, 1982; Simms et al., 2016). The Rincon Creek Fault to the south segments the Carpinteria Basin from a rocky reef located immediately offshore (Ferren, 1985). The freshwater creeks flowing into the marsh include Franklin and Santa Monica Creeks, although historical records show that before the development of the Carpinteria area, Carpinteria Creek, Arroyo Paredon, and a fifth unnamed creek also drained into a more extensive version of the marsh (Ferren, 1985; Page et al., 1995). Tidal input and drainage primarily occurs through the tidal inlet, which sits at the southern margin of the marsh, with additional tidal flow occurring through a constructed cobble sill near the tidal inlet (Sadro et al., 2007).

The 230-ha marsh is composed of a network of tidal channels incised into a vegetated marsh, unvegetated mudflat, and a sandy tidal inlet. The slough has three mini basins. The two eastern mini basins are separated from the western mini basin by an artificial road. Channels within the eastern half of the marsh are channelized and dredged, resulting in a highly altered tidal flushing of the marsh plain (Sadro et al., 2007). The western half of the marsh, mini basin 3, contains a much more complex array of tidal channels and creeks, which are largely un-altered (Sadro et al., 2007). Therefore, we focused this study on mini basin 3, the most natural, unmodified marsh environment.

Table 1

	Carpinteria Slough	Santa Barbara	Santa Monica
MHHW	0.85	0.729	0.808
MHW	0.63	0.489	0.578
MSL	0.23	-0.051	-0.012
MLW	-0.09	-0.581	-0.592
MLLW	-0.16	-0.901	-0.892
MTL	0.27	-0.041	-0.002

Table 1. Tidal datums modified from Sadro et al., (2007). All elevations are in meters in relation to modern day Mean Sea Level.

Goleta Slough (Figure 1) also lies along the Santa Barbara coastline. It is bordered to the east by More Mesa and to the west by the campus of the University of California Santa Barbara (34◦, 25’, 1’’ N 119◦, 50’, 14’’ W). Six major streams drain into Goleta Slough, and all outflow occurs through a narrow, ephemeral tidal inlet (Lohmar et al, 1980). The tidal inlet only experiences open marine communication following the breaching of a sandspit during periods of high winter rainfall. The opening of the tidal inlet produces an open estuarine environment in which tidal processes reach up into the six feeder creeks. However, during the summer months and dry years Goleta Slough is an enclosed basin in which tidal influences do not reach the marsh plain.

Figure 1

Figure 1. Modified after ESRI Landviewer. Surface map showing the relative positions of four studied estuaries along the coast of southern California. Carpinteria Slough is the focus of this study.

Goleta Slough represents the late stage infilling of a once much larger estuarine embayment (Lohmar et al, 1980). Historic accounts of Goleta Slough support the connection between both modern day Goleta Slough and neighboring Deveraux Slough (34◦, 25’, 1’’ N 119◦, 50’, 14’’ W) (Stone, 1982). When combined, these sloughs covered over 46 km^2. Today the modern extent of Goleta Slough is only 1.3 km^2(Lohmar et al, 1980). Both Goleta and Deveraux Sloughs occupy a structural depression enhanced by stream erosion during the last glacial maximum, 20 ka (Lohmar et al, 1980). Following European settlement of Santa Barbara and Goleta, increased sediment supply due to agricultural practices and the construction of the Santa Barbara Airport resulted in a significant reduction in the size of the once larger estuarine system (Stone, 1982; Lohmar, 1980).

The More Ranch fault separates the marine terrace upon which the University of California Santa Barbara (UCSB) campus is built from Goleta Slough. The More Ranch Fault is a reverse fault, which has uplifted UCSB's campus 14 meters above modern sea level (Gurrola et al, 2014). Throw on the More Ranch fault results in subsidence of Goleta Slough at a rate of 0.4±0.3mm/yr (Melosh and Keller, 2013; Simms et al., 2016). Gurrola et al. (2014) calculated an uplift rate for the marine terrace underlying UCSB's campus of 1.6 m/ka, based upon the elevation of the 48 ka UCSB marine terrace.

Mugu Lagoon (34°06'07"N 119°05'52"W) is located along the Oxnard plain, roughly 50 kilometers east of Santa Barbara (Figure 1). The 130-ha marsh began taking form in the mid-Pleistocene as the Oxnard plain was uplifted and the local watersheds were diverted to the northwest (Onuf, 1987; Warme, 1971). The lagoon now consists of two main channels, Callegous Creek and an unnamed creek. Mugu Lagoon is presently home to the Point Mugu Naval Base and, as home to the United States Navy, has undergone dredging of the main channels and stabilization of the tidal inlet. Although the marsh is anthropogenically altered, the regional uplift has provided a high gradient coastline and a marsh that exhibits great elevation heterogeneity (Warme, 1971).

Sweetwater Marsh National Wildlife Refuge (32°38'25'' N 117°06'40'' W) is located on the east side of south San Diego Bay (Figure 1). This 128-ha marsh is the largest undisturbed wetland in San Diego Bay (Langis et al., 1991). It is located on the delta of the Sweetwater River. Due to the recent development of nearby interstates, ship channels, and the Living Coast (National Wildlife Building and Fish and Wildlife Service office), the marsh is much smaller in area than it was before the settlement of San Diego Bay (Langis et al., 1991). Despite being located in a highly modified area, Sweetwater Marsh offers a wide variety of marsh environments and is the southernmost marsh investigated in this study (Figure 1).

METHODS

Field Methods

I collected surface sediment samples in the winter of 2016 for micropaleontological analysis, and sediment characterization from 29 sites in Carpinteria Slough (Figure 2). The 29 sites were collected along one long linear transect (CS_BM) as well as a series of short transects creating a grid of samples (CS_ES). Samples were taken in the winter of 2016 to minimize the bloom in foraminifera species in the spring and summer (Murray, 1991; Scott and Medioli, 1980).

The primary transect, CS_BM, taken from Carpinteria Slough is a roughly linear transect that spans shallow intertidal mudflat to high vegetated marsh. Sample sites along the transect were chosen based on changes in vascular plant abundance and floral species changes, as well as other visual indicators of elevation gain (Figure 2). Because Legendre (1993) suggests that the linear transect method is suspect to autocorrelation an additional 17 samples, CS_ES, were taken from a wide swath of the marsh adjacent to the linear transect (Kemp et al., 2009) (Figure 2). The additional samples were taken from similar elevation ranges as the linear transect, but differ in vegetation cover and other environmental variables.

At each station 10cm^3 (10cm^2 by 1cm thick) of surface sediment was procured with a 1cm diameter syringe by taking 10, 1cm diameter plugs. A volume of 10 cm^3 allows for comparison with similar foraminifera studies (Scott and Medoli, 1980; De Rijk, 1995). Each sample was diluted in 70% ethanol, buffered in seawater, and stained with the protein-specific rose Bengal to preserve the sample and enable the identification of living constituents (Horton and Culver, 2008; Pak, Dotti personal communication). Rose Bengal will stain any protoplasm bright red, therefore any living tissue will be stained red and differentiated from the unstained, dead populations (Murray, 1991). All samples were refrigerated at 45° F to prevent dissolution of foraminifera. A GPS measurement was taken at each sample station (Topcon Station: elevation error ± .05 m), to determine the elevation of each sample site. Each sample was also accompanied by measurements of salinity, pH, and grain size. In addition, a subset of 16 samples from CS_ES include TOC measurements.

At each sample site I dug a 30cm hole, allowing the pore waters to seep into the hole and collect at the base (de Rijk, 1995). Using a pipet the water collected at the base of the hole was extracted and salinity was measured using an Extech portable salinity refractometer. Two salinity measurements were taken and averaged from each station.

pH measurements were taken in the field with an Oakton pH 100 Series portable pH meter using the same holes as the salinity measurements. The pH meter was first calibrated using standard pH buffers of 4.01 and 10.01 pH. The Oakton pH meter automatically corrects for temperature in the field. When pore-water contained too little volume to test the pH via the pH meter probe, pH strips were used. This occurred in two of the high marsh samples.

TOC was analyzed on sediment samples in the UCSB Marine Science Analytical Lab. Before analysis each sample was weighed and treated with sulfurous acid to remove any inorganic carbon contained within the samples (Verado et al., 1990).

Grain-size analysis was conducted on sediments using a CILAS Laser Particle Size Analyzer. Pretreatment for grain-size analysis followed the methods of Kirby et al., (2014). After removing the organic material from the sample using hydrogen peroxide, sodium hexametaphosphate was added to the sample as a dispersive agent. Each measurement was replicated to ensure that the grain-size outputs were consistent. The replicate grain-size measurements were averaged to provide the input for statistical analyses.

Two 10cm long push cores, PC_01 and PC_02, were taken from Carpinteria Slough during the spring of 2016. The two push cores were used to identify foraminifera's infaunal capabilities, and the push cores were taken at a time of year when foraminiferal blooms are expected, which provides the greatest opportunity to find infaunal foraminifera alive (Figure 6). PC_02 was obtained from the intertidal mudflat in the location of CS_BM_02, and PC_02 was obtained from the vegetated marsh in the location of CS_ES_022. Each push core sample was examined at 1cm intervals for stained foraminifera (living specimens at depth).

Samples were also initially collected and analyzed from Goleta Slough, Mugu Lagoon and Sweetwater Marsh. However, these three marshes do not contain a wide variety of marsh environments, and it was found that the original processing procedures for the samples at Mugu Lagoon and Sweetwater Marsh resulted in the loss of on foraminiferal species, *Miliammina fusca.* As such their data are not included in the faunal zonation portion of this study. However, the problem was fixed for the samples taken in Carpinteria Slough and Goleta Slough.

Figure 2

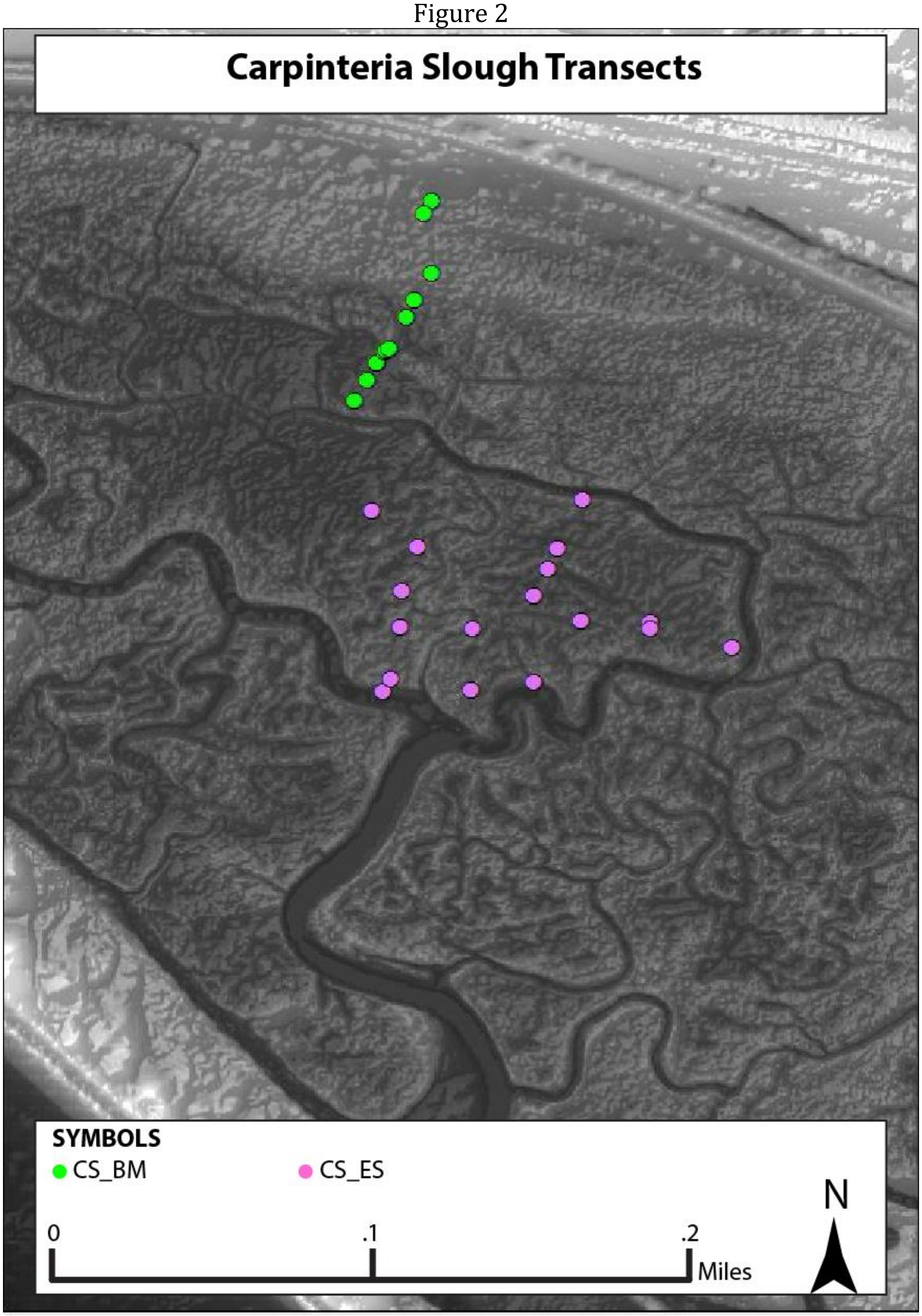


Figure 2. ArcMap DEM overlain by the sample locations of the two transects taken in Carpinteria Slough. Green dots represent stations along the CS_BM transect, and pink dots represent stations along the CS_ES transects.

Micropaleontological Analysis

Surface sediments were sieved to isolate particles between 63 and 500 microns (Scott and Medioli, 1980; de Rijk, 1995; Kemp et al., 2009; Murray, 1991). The sediment remaining was buffered in seawater to preserve the foraminiferal constituents. Aliquots of the sieved sample were pipetted onto a petri dish with a 5x5 grid. Foraminiferal constituents of each aliquot were counted under projected light and a binocular microscope (picked when possible, some foraminifera are very fragile and break upon pressure from paintbrushes). When possible, at least 300 individual foraminifera were picked per sample to establish statistically significant samplings (Leorri et al., 2008; Murray, 1991). In this study, no distinction was made between the adult and juvenile forms of foraminifera. Pamela Buzas-Stephens at the University of Colorado, Boulder, aided in the species identification in each sample. Each sample count was normalized to 5 ml of sediment, allowing for numerical comparisons between samples.

Dead assemblages of foraminifera are more representative than living assemblages because they are the result of the annual buildup of foraminifera, in which seasonality and the taphonomic loss of species do not play a large part in determining the overall assemblage ratios (Schoenfield, 2012; Horton and Culver, 2008). Also, unlike modern salt-marsh foraminifera, dead assemblages account for preferential degradation and dissolution due to test compositional differences (Murray, 1982; Horton and Culver, 2008). I focused only on the dead, unstained, assemblages in an attempt to accurately portray paleoenvironments.

Statistical Analysis

Bivariate correlation analysis, which uses a Pearson correlation coefficient (r) with a 2-tailed test of significance, was used to create a correlation matrix in Matlab (using the corrcoef function) to quantify the environmental variables that statistically control the mean abundance of foraminifera species within Carpinteria Slough. The variables in the analysis consist of all of the environmental variables analyzed in this study: elevation (m above MSL), salinity (ppt), pH, median grain size (mm), percent Carbon, percent Nitrogen, Carbon to Nitrogen ratio, vegetation density, and *Cerethedia californica* density (Appendix A).

Three sets of ANOVA's (Analysis of Variance) were run in Matlab (using the anova1) function to distinguish the similarity between groups of data. The first two ANOVA's compared the variance in mean species abundances based on two groupings of samples. Before running the first two ANOVA's all species percent data was transformed via an arcsin square root transformation following the methods of Kemp et al., (2011). The third ANOVA compared the variance in elevation based on groups of samples defined by cluster analysis.

Figure 3

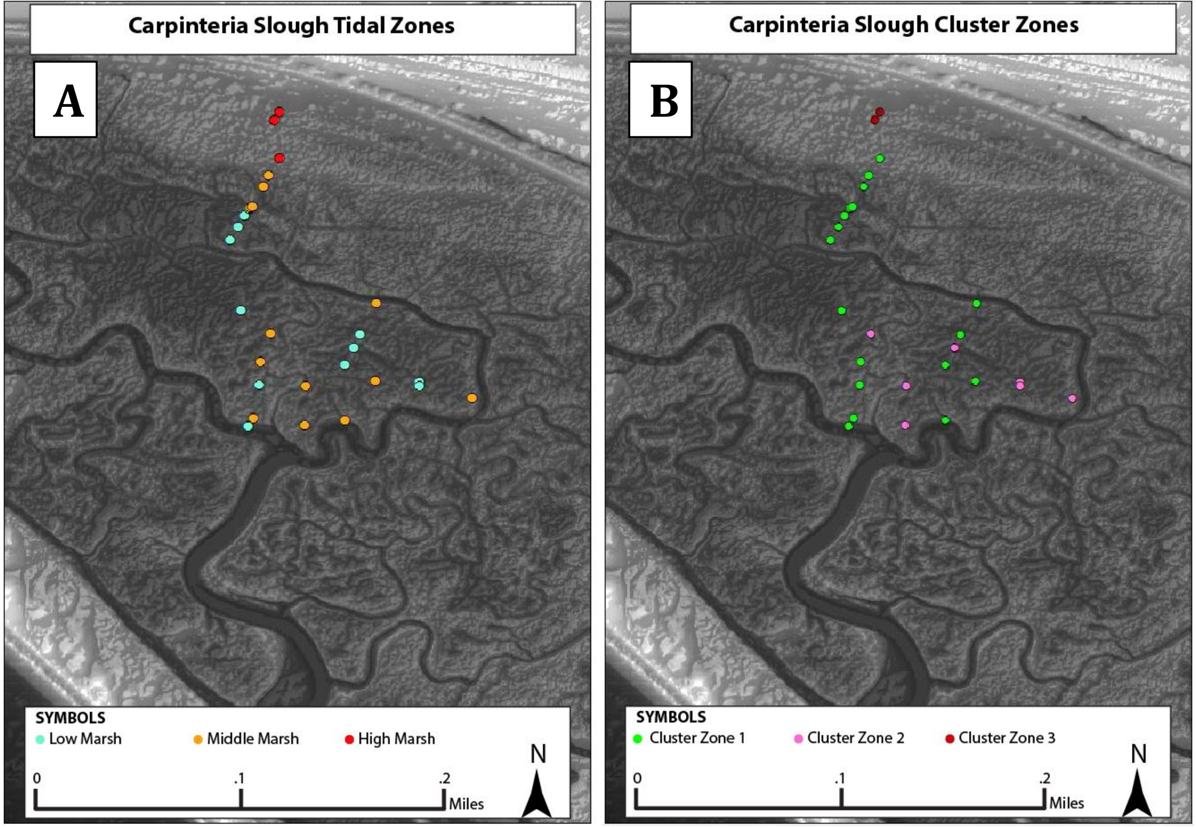


Figure 3. **A**: ArcMap DEM of Carpinteria Slough overlain by sample locations broken down into three groups based upon the samples elevations in relation to tidal datums. Low marsh (blue dots) samples have elevations below MHW; Middle Marsh (orange dots) samples have elevations between MHW and MHHW; High marsh (red dots) samples have elevations above MHHW.
B: ArcMap DEM of Carpinteria Slough overlain by overlain by sample locations broken down into three groups based upon the cluster analysis dendogram. Cluster Zone 1 (green dots); Cluster Zone 2 (pink dots; Cluster Zone 3 (red dots).

Hierarchical agglomerative single link cluster analysis helped in dividing the samples into groups defined by the similarity (Euclidean distance) of foraminiferal constituents within the 29 samples from Carpinteria Slough. All foraminifera species percentages were used as data points, from which the Euclidean distance coefficient between each data point were calculated. Q-mode cluster analysis (run in SYSTAT 13) was used to divide the Carpinteria Slough samples into groups, without considering the predictive abilities of elevation.

The fourth statistical test employed was Principle Component Analysis (PCA), using the ecological statistics software package, SYSTAT 13. Three different PCAs were performed on the Carpinteria Slough data. The first PCA evaluated the four major environmental variables of elevation, salinity, pH, and median grain size via a correlation based PCA. A second round of PCA included both the species data and the environmental data to better determine how the dominant environmental variables explain the species data. The third round of PCA consisted of four independent PCA runs, each one isolating an individual environmental variable, and analyzing the correlations between taxonomic data and each individual environmental variable.

Polynomial and linear regressions were also employed, using SYSTAT 13, to aid in determining which environmental variable best predicts the abundance of species. Polynomial regressions were first used to gauge the linearity of the species data within Carpinteria Slough. For data shown to behave in a primarily linear fashion, multiple linear regressions, using the Ordinary (OLS) Least Squares Method, were used to plot each individual species against all environmental variables.

OLS regressions were run to analyze the predictive capabilities of environmental variables against each foraminiferal species, as well as the predictive capabilities of the two principle components (extracted from the first round of PCA) against each foraminiferal species. 20 OLS regressions were performed, 10 regressions plotting each individual species against all environmental variables, and 10 regressions plotting each individual species against the two principle component factors. Principle component factors, taken from the PCA run only on environmental variables, can be treated as independent variables. As such, the factors may better predict the data than any of the independent environmental variables.

RESULTS

Foraminifera

Table 2

Sample ID	Density/5ml	Diversity
CS_BM_012	80	5
CS_BM_011	427	8
CS_ES_025	499	5
CS_ES_0000	48	4
CS_ES_001	343	4
CS_ES_002	653	7
CS_ES_003	340	5
CS_ES_0004	895	5
CS_ES_0006	1266	5
CS_ES_0009	10	2
CS_ES_00011	1710	5
CS_ES_00014	299	4
CS_ES_00017	1590	6
CS_ES_00018	1830	6
CS_ES_00019	2940	7
CS_ES_00020	2675	6
CS_ES_00021	928	7
CS_ES_00022	2680	6
CS_ES_00023	994	6
CS_BM_01	938	6
CS_BM_02	1172	6
CS_BM_03	623	7
CS_BM_04	642	5
CS_BM_05	886	7
CS_BM_06	1138	3
CS_BM_07	1950	6
CS_BM_08	1260	6
CS_BM_09	1156	6
CS_BM_010	952	5

Table 2. Table showing the density of dead tests per 5ml of sediment picked, and the number of species present at each sample location.

Foraminifera were found in all 29 samples from Carpinteria Slough. Densities of foraminifera ranged from 9 tests/5ml in the channel bottom to 2940 tests/5ml in the vegetated marsh (Table 2). Species diversities ranged from 2 species in the channel bottom sample to 8 species per sample in the vegetated marsh.

A total of 11 species of foraminifera were identified (Appendix A, Plates I-IV). One of the species was within the genus *Textularia.* The *Textularia* species was not speciated and comprised less than 1% of the species within any sample, so it was not included in the statistical analyses. The 10 species of foraminifera that comprised the majority of foraminifera found within Carpinteria Slough are in order of abundance: *(Mf) Miliammina fusca* 43%*; (Ti) Trochammina inflata* 18%*; (Jm) Jadammina macscerens* 13%*; (Qsp) Quinqueloculina species* 12%*; (Hw) Halphragromides wilberti* 5%*; (Ap) Ammonia parkinsonian* 2%*; (Bp) Balticammina pseudomacscerens* 2%*; (Ee) Eplhidium excavatum* 2%*; (Pf) Protoschista findens* 1%*;* and *(Psp) Polysaccammina species* <1%*.* These ten species of foraminifera varied in abundance and ratios amongst all sample sites (Figure 4). *M. fusca* and *T. inflata* are observed at 26 of the 29 study locations, while *B. pseudomacscerens* and *Polysaccammina sp.* are only present in 2 of the samples (Figure 4). *Mf* dominated the density in the majority of samples. See Appendix for a listing of all foraminiferal counts observed in this study.

Transects

CS_BM (Figure 4) is dominated by three species: *Mf, Ti,* and *Bp*. *Mf* comprises the majority of the dead assemblage in all but 4 samples. *Mf* comprises over 75% of all samples in the intertidal mudflat, i.e. elevations lower than MHW that lack vegetation. As elevation increases *Ti* and *Bp* emerge as major contributors to the total dead population of foraminifera (Figure 4). *Ti* makes up 45% of the dead populations in the vegetated middle marsh sample sites, ie elevations between MHW and MHHW, whereas *Bp* comprises 55% of the dead populations in the high marsh salt grass sample sites, ie elevations greater than MHHW (Figure 4). *Ap* and *Ee* do not comprise greater than 20% of any sample, nor do they show distinct patterns as to where they live along the CS_BM transect.

Figure 4

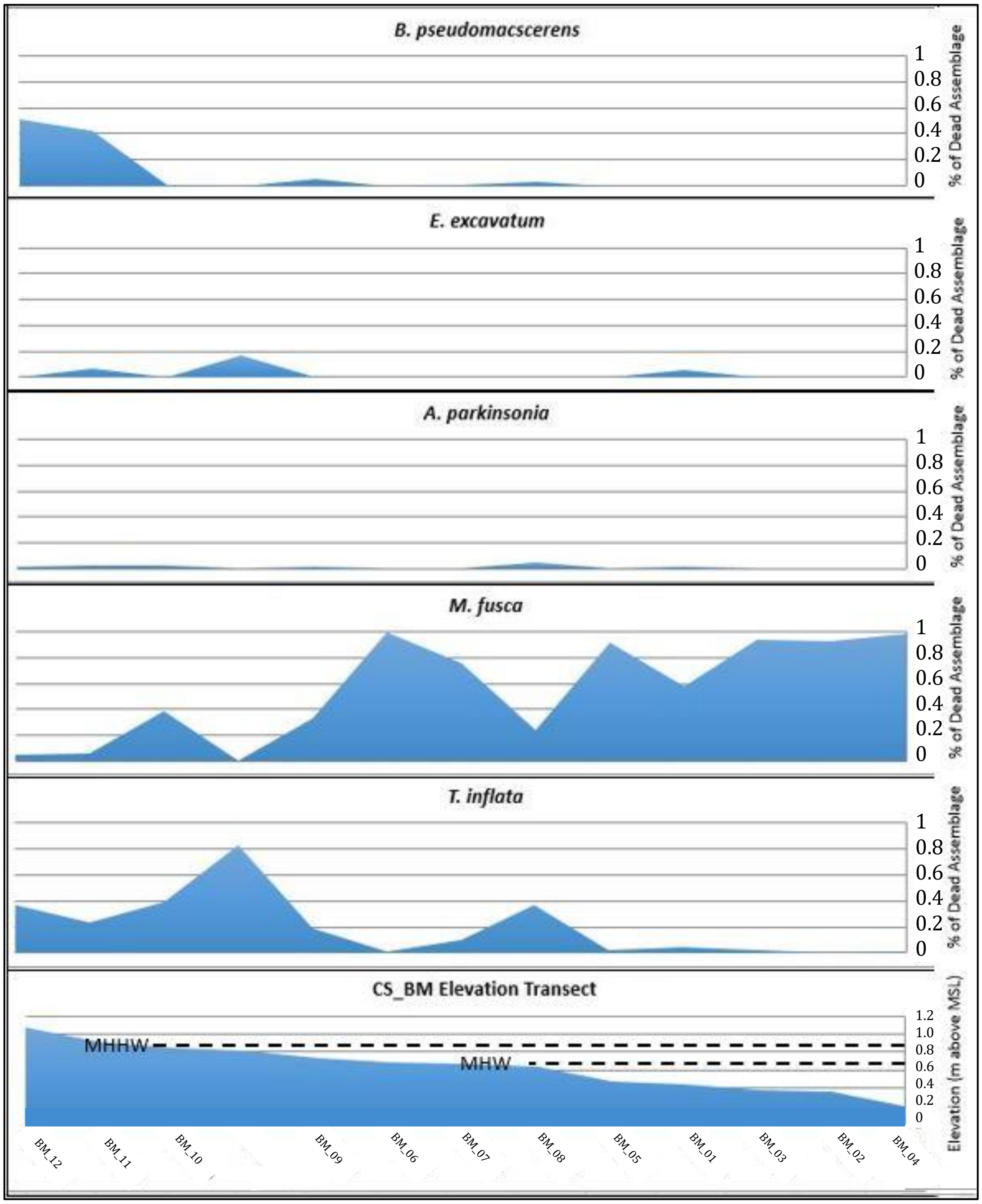


Figure 4. Elevation profile for the CS_BM transect (bottom pannel). The relative % of dead assemblage for the species of: *(T. inflata) Trochammina inflata; (M. fusca) Miliammina fusca; (A. parkinsonia) Ammonia parkinsonia; (E. excavatum) Elphidium excavatum; (B. pseudomacscerens) Balticammina pseudomacscerens,* are plotted above the elevation profile. Bottom Panel is the elevation profile through CS_BM from the intertidal mudflat (right side) to the high salt marsh (left side). Tidal datums (dashed lines) overlay the elevation profile.

The CS_ES transect (Figure 5) displays a patchier distribution of foraminifera than does CS_BM. CS_ES is not a linear transect and CS_ES spans a smaller range of elevations than CS_BM. *Ti,* while sporadic, is the dominant species within the dead assemblage, and appears to generally increase in percent as elevation increases. *Mf* is also a major contributor of dead specimens, but unlike *Ti, Mf* distribution shows no trends within CS_ES. *Ap* and *Ee* comprise small percentages of the dead assemblage, and they exhibit no distinct pattern in their abundance relative to elevation . *Bp* is not present in any of the CS_ES samples.

Figure 5

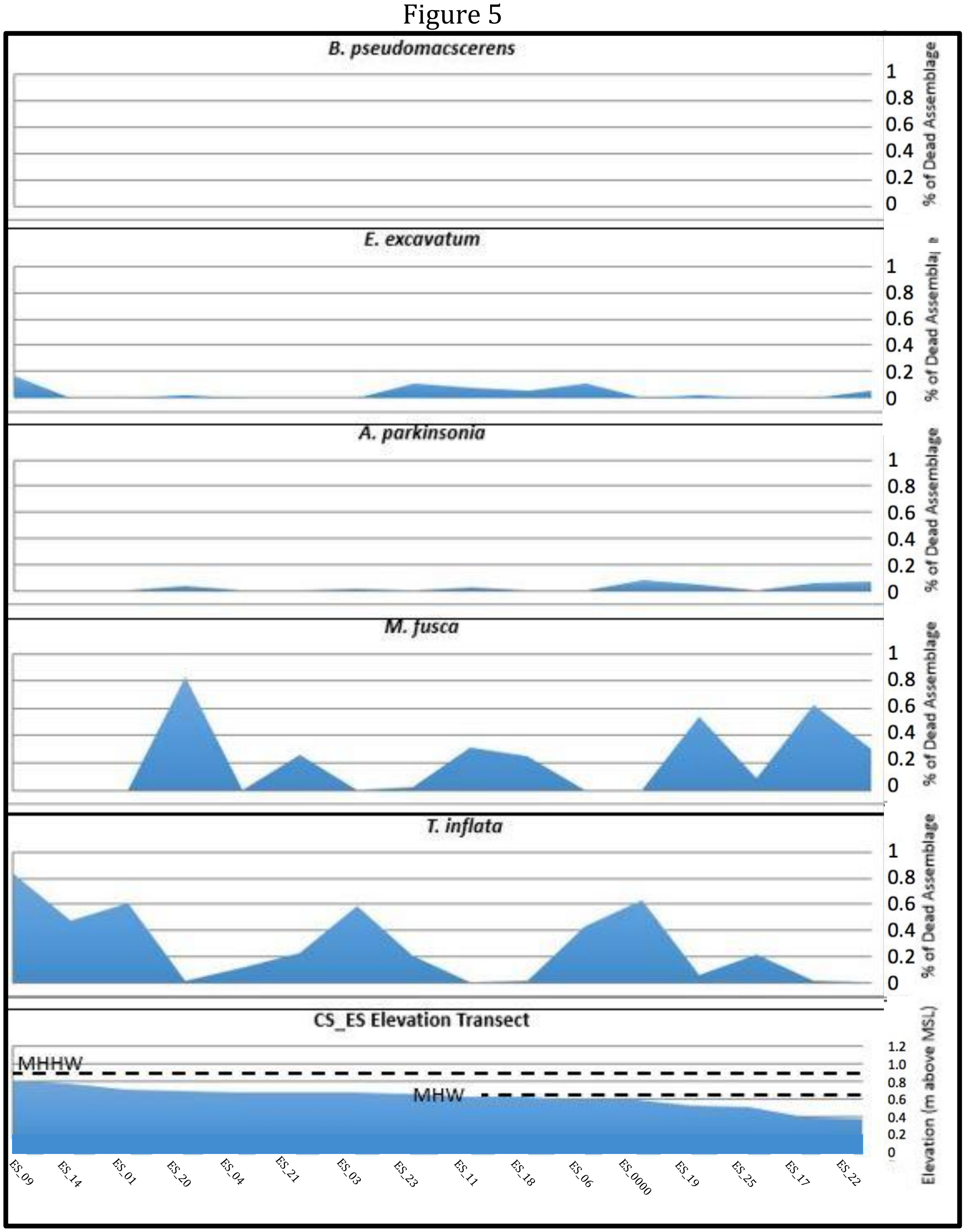


Figure 5. Elevation profile for the CS_ES transect (bottom pannel). The relative % of dead assemblage for the species of: *(T. inflata) Trochammina inflata; (M. fusca) Miliammina fusca; (A. parkinsonia) Ammonia parkinsonia; (E. excavatum) Elphidium excavatum; (B. pseudomacscerens) Balticammina pseudomacscerens,* are plotted above the elevation profile. Bottom Panel is the elevation profile through CS_BM from the intertidal mudflat (right side) to the high salt marsh (left side). Tidal datums (dashed lines) overlay the elevation profile.

Seasonality

Table 3

Sample ID	Stained Total	Sample ID	Stained Total
CS_ES_0000	0	CS_BM_01	0
CS_ES_001	5	CS_BM_02	0
CS_ES_002	3	CS_BM_03	0
CS_ES_003	12	CS_BM_04	0
CS_ES_0004	43	CS_BM_05	0
CS_ES_0006	28	CS_BM_06	0
CS_ES_0009	0	CS_BM_07	0
CS_ES_00011	61	CS_BM_08	0
CS_ES_00014	5	CS_BM_09	0
CS_ES_00017	27	CS_BM_010	0
CS_ES_00018	56	CS_BM_012	0
CS_ES_00019	12	CS_BM_011	0
CS_ES_00020	5	CS_ES_00022	33
CS_ES_00021	7	CS_ES_00023	86
CS_ES_025	22		

Table 3. Table showing the total raw count of living specimen from each sample location in Carpinteria Slough.

Stained foraminifera found within samples indicate live foraminifera at the time of collection, winter of 2016. The living population of foraminifera from the CS_ES sample sites was dominated by *Quinqueloculina sp.* (Table 3). However, CS_BM contained no living foraminifera.

Infaunal Capabilities

Two push cores were taken to determine the depth of living foraminifera. PC_01, taken from the intertidal mudflat, contained no stained foraminifera at any depth interval, which is consistent with the results from the CS_BM samples. PC_02, taken from the vegetated marsh, contained 11 stained *Qsp* specimens in the upper 1 cm and zero stained specimen below the top 1 cm of sediment.

Figure 6

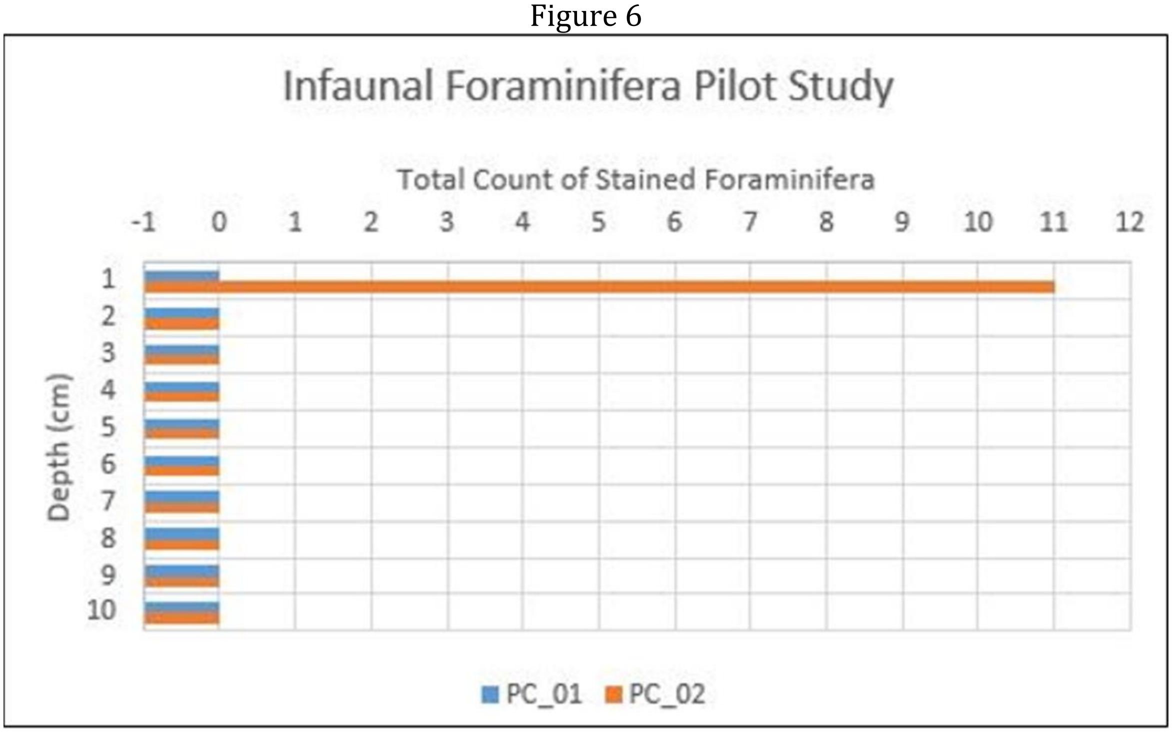


Figure 6. Bar plot showing the total count of stained (living) foraminifera down to 10cm depth in two push cores. Only PC_02 has living foraminifera and the living foraminifera are concentrated in the uppermost 1cm.

The absence of living foraminifera below 1cm indicates that foraminifera, namely *Qsp,* in Carpinteria Slough are not living at depths greater than 1cm and sampling methods focused on the upper centimeter of sediment are representative of average modern conditions.

Physical Variables

Elevation

Carpinteria Slough elevations ranged from 0.20m above MSL to 1.08 m above MSL (Figure 7). Carpinteria Slough sample stations are dominated by low marsh elevations of 0 m to 0.63 m (13 out of 29 samples); and middle marsh elevations of 0.63 m to 0.85 m (14 out of 29 samples), while only two sample stations, BM_11 and BM_12, lie above the MHHW elevation of 0.85 m above MSL (Table 1; Figure 7).

Figure 7

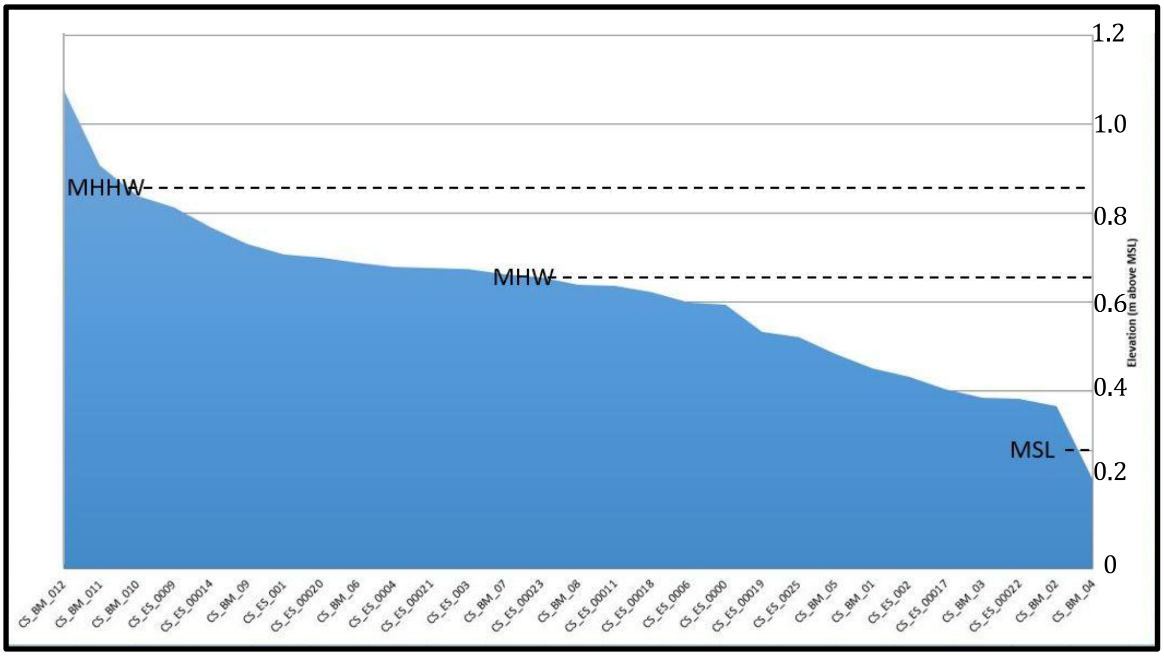


Figure 7. Elevation profile for all Carpinteria Slough data points (sorted from high to low). Superimposed are the tidal datums for Carpinteria Slough. (MSL) mean sea level; (MHW) mean high water; (MHHW) mean high high water.

The primary transect, CS_BM, is a linear transect spanning from the intertidal mudflat to the high marsh salt grasses (Figure 2). It sampled the highest and lowest elevations found in the marsh. The CS_ES grid of samples, which was taken to ensure no linear autocorrelation in the CS_BM data, spans a wide area of vegetated marsh but has less vertical relief than CS_BM. CS_ES elevations range from 0.38m in the center of a small tidal channel to 0.77m along the tidal channel levee (Figure 7). 9 of 17 CS_ES samples lie above the MHW level, and are flooded less frequently than the 3 tidal flat samples taken in CS_BM, which lie below MSL. Along CS_ES many subtle topographic highs and lows exist created by a dendritic drainage pattern of tidal channels flooded during the average high tide. The tidal channels keep the nearby soil moist, while at low tides the vegetated marsh area along CS_ES is completely drained and exposed.

Salinity

Table 4

Sample ID	Environment	Salinity (ppt)	Sample ID	Environment	Salinity (ppt)
CS_ES_0000	Sand Bar	36	CS_BM_01	Mudflat	50
CS_ES_001	Sand Berm	75	CS_BM_02	Mudflat	43
CS_ES_002	Veg. MM	40	CS_BM_03	Mudflat	42
CS_ES_003	Veg. LM	53	CS_BM_04	Mudflat	43
CS_ES_0004	Veg. MM	52	CS_BM_05	Mudflat	41
CS_ES_0006	Veg. MM	45	CS_BM_06	Mudflat	41
CS_ES_0009	Veg. LM	40	CS_BM_07	Veg. MM	45
CS_ES_00011	Veg. MM	46	CS_BM_08	Veg. MM	40
CS_ES_00014	Veg. MM	57	CS_BM_09	Veg. MM	49
CS_ES_00017	Veg. MM	38	CS_BM_010	Veg. MM	80
CS_ES_00018	Veg. LM	40	CS_BM_012	Veg. HM	110
CS_ES_00019	Veg. LM	40	CS_BM_011	Veg. HM	100
CS_ES_00020	Veg. MM	61	CS_ES_00022	Veg. MM	40
CS_ES_00021	Veg. MM	56	CS_ES_00023	Veg. MM	46
CS_ES_025	Veg. LM	40			

Table 4. Salinity measurements in (ppt) parts per thousand, for all sample locations in Carpinteria Slough. Veg. (Vegetated); LM (Low Marsh); MM (Mid Marsh); HM (High Marsh).

Pore-water salinity varied between 20 and 110ppt in Carpinteria Slough (Table 4). The greatest salinity of 110 ppt was measured in the high marsh salt grass, where the soil was dry enough to make the salinity measurement difficult. Aside from the other high marsh sample, the next highest salinities (80 ppt and 70 ppt) were found in a vegetated marsh with no proximal tidal channels. Both CS_BM and CS_ES contained samples with salinities exceeding 70ppt. The lowest salinities (36 ppt) were observed in tidal channels as well as low elevations proximal to large tidal channels. No salinities below the open marine salinity of the Santa Barbara Channel (36ppt) were found in Carpinteria Slough, suggesting little freshwater input to the marsh environments during our sampling times.

Total Organic Carbon

Table 5

Sample ID	% Carbon	%Nitrogen	C/N
CS_ES_0000	1.00%	0.11%	9.28
CS_ES_001	4.94%	0.57%	8.72
CS_ES_002	3.54%	0.32%	11.1
CS_ES_003	5.54%	0.55%	10.1
CS_ES_0004	8.34%	0.72%	11.6
CS_ES_0006	5.43%	0.56%	9.73
CS_ES_0009	2.80%	0.26%	10.6
CS_ES_00011	6.43%	0.65%	9.83
CS_ES_00014	3.04%	0.27%	11.3
CS_ES_00017	4.13%	0.47%	8.83
CS_ES_00018	5.09%	0.52%	9.78
CS_ES_00019	5.61%	0.64%	8.71
CS_ES_00020	3.37%	0.37%	9.14
CS_ES_00021	7.57%	0.72%	10.6
CS_ES_00022	3.54%	0.32%	11.1
CS_ES_00023	4.41%	0.57%	7.70

Table 5. Table of all CHN tests run on Carpinteria Slough sediment samples. (% Carbon) weight percent Carbon; (% Nitrogen) weight percent Nitrogen; (C/N) Carbon to Nitrogen ratio.

Overall TOC values rarely exceeded 5% throughout the study area (Table 5). One sample location (CS_ES_004) had a TOC value of 8.34%, which was the highest recorded TOC value in Carpinteria Slough. It was found in a *Spartina sp.* vegetated middle marsh environment proximal to a small tidal channel. The lowest TOC value of 1% was found in a sandy tidal channel (Table 4, 5). In general, 6 samples taken from elevations between MHW and MHHW contained the highest average TOC (5.16%), while the 10 samples taken from elevations below MHW contained the lowest average TOC of 3.86%.

Grain Size

Table 6

Sample ID	Median Grain Size	Percent Sand	Percent Silt	Percent Clay
CS_BM_012	34.199	19.802	70.822	9.376
CS_BM_011	10.954	0.000	80.117	19.883
CS_ES_025	30.436	15.245	74.233	10.522
CS_ES_0000	18.193	3.137	82.396	14.467
CS_ES_001	8.571	0.057	72.677	27.266
CS_ES_002	9.071	0.119	73.445	26.436
CS_ES_003	9.894	0.226	75.645	24.129
CS_ES_0004	8.671	0.000	73.883	26.117
CS_ES_0006	14.874	5.795	76.749	17.456
CS_ES_0009	12.840	1.092	79.210	19.698
CS_ES_00011	10.287	0.260	77.172	22.568
CS_ES_00014	10.526	0.196	78.328	21.476
CS_ES_00017	9.071	0.119	73.445	26.436
CS_ES_00018	8.430	0.029	73.044	26.927
CS_ES_00019	76.832	55.632	37.633	6.736
CS_ES_00020	10.080	0.271	76.539	23.190
CS_ES_00021	8.485	0.091	73.452	26.457
CS_ES_00022	10.967	0.243	77.768	21.989
CS_ES_00023	10.887	1.383	77.464	21.153
CS_BM_01	9.647	0.024	76.560	23.416
CS_BM_02	9.326	0.058	75.278	24.664
CS_BM_03	9.894	0.226	75.645	24.129
CS_BM_04	9.652	0.000	76.486	23.514
CS_BM_05	9.165	0.180	75.185	24.635
CS_BM_06	10.318	0.288	76.777	22.935
CS_BM_07	12.251	0.501	79.852	19.648
CS_BM_08	21.972	9.233	76.505	14.262
CS_BM_09	8.434	0.248	75.338	24.414
CS_BM_010	26.732	23.604	63.687	12.709

Table 6. Table showing all 29 Carpinteria Slough samples' grain size data.

In general, the sediment texture of Carpinteria Slough samples was fine-grained. Silt was the dominant grain size class comprising 74% of the samples (Table 6). One channel sample (CS_ES_0019) was composed of predominantly fine sand, and no samples contained greater than 28% clay.

CS_BM, while composed largely of samples taken within the intertidal mudflat, displayed ratios of sand, silt, and clay comparable to CS_ES. Both CS_BM and CS_ES were dominated by silt-sized particles, 75% and 73% respectively. However, CS_BM did not contain samples dominated by sand because CS_BM did not bisect any large tidal channels; whereas CS_ES contained one sand dominated sample taken within a large tidal channel (Figure 2).

pH

Table 7

Sample ID	pH	Sample ID	pH
CS_ES_025	7.06	CS_BM_01	6.68
CS_ES_0000	7.99	CS_BM_02	7.31
CS_ES_001	7.43	CS_BM_03	6.94
CS_ES_002	7.12	CS_BM_04	6.79
CS_ES_003	6.99	CS_BM_05	7.1
CS_ES_0004	6.81	CS_BM_06	6.65
CS_ES_0006	7.03	CS_BM_07	6.12
CS_ES_0009	7.52	CS_BM_08	7.56
CS_ES_00011	6.9	CS_BM_09	7.03
CS_ES_00014	7.02	CS_BM_010	6.87
CS_ES_00017	7.23	CS_BM_012	7.01
CS_ES_00018	7.01	CS_BM_011	6.93
CS_ES_00019	7.71	CS_ES_00022	7.02
CS_ES_00020	6.94	CS_ES_00023	6.82
CS_ES_00021	6.83		

Table 7. Table showing all 29 Carpinteria Slough samples' pH.

Across all samples in Carpinteria Slough, pH varied little, with the lowest value of 6.65 and the highest value of 7.71 (Table 7). The average pH of CS_ES samples was 7.12 while the average pH observed along CS_BM was 6.91. While the spread of pH is minimal throughout the marsh, CS_BM pH values are slightly depressed compared to CS_ES.

Regional Results

Samples were also collected from Atascadero Creek (Goleta Slough tributary), Mugu Lagoon, and Sweetwater Marsh. While foraminiferal assemblages from all estuarine locations were comprised of similar species of foraminifera, the elevations of the other sample sites did not span the same range of tidal datums as did the elevations in Carpinteria Slough. The environmental variables of pH, salinity, grain size, and TOC were only measured from the 4 samples within Atascadero Creek. All Atascadero Creek samples were located within an intertidal mudflat environment, which was the only estuarine environment present in the creek. Three foraminiferal species comprised the majority of the dead assemblage, *Mf* (69%), *Ap* (16%) , and *Psp* (10%) (Appendix B). While most environmental variables from Atascadero Creek were consistent with the environmental variable results from intertidal mudflat samples in Carpinteria Slough, the salinity in Atascadero Creek was on average 4 ppt higher than the average salinities observed in all samples from Carpinteria Slough, and 12 ppt higher than the intertidal mudflat samples from Carpinteria Slough (Appendix B).

Goleta Slough contained low, middle, and high marsh environments, but access to the pristine parts of the marsh is restricted by the Santa Barbara Airport. Mugu Lagoon was bisected by fewer tidal channels than Carpinteria Slough and Sweetwater Marsh. Mugu Lagoon contained no intertidal mudflat environments, and was dominated by sparsely vegetated middle to high marsh. Sweetwater Marsh, while bisected by many tidal channels, also only contained middle to high marsh, but the vegetation was denser than Mugu Lagoon, due to more frequent tidal inundations.

Statistical Results

Foraminiferal species distributions in intertidal salt marshes are controlled by one or several environmental factors (Scott and Medioli, 1978; Scott and Medioli, 1980; de Rijk 1995; de Rijk and Troelstra, 1997; Murray, 1991; Kemp et al., 2011; Edwards et al., 2004). Elevation and salinity are the two most cited environmental factors controlling foraminiferal species distributions (Scott and Medioli, 1978; Scott and Medioli, 1980; de Rijk 1995; de Rijk and Troelstra, 1997; Murray, 1991; Kemp et al., 2011; Edwards et al., 2004). In Carpinteria Slough, it is not clear what variables are exerting the most control on foraminiferal distributions. Pearson R^2 values suggest that both salinity and elevation correlate with several of the foraminiferal species, although the correlations between elevation, salinity and taxa are only statistically significant for species *Bp, Mf,* and *Ap* (Figure 9). Many taxa correlate positively with other taxa, suggesting that some foraminifera are often found together (Figure 8).

Figure 8

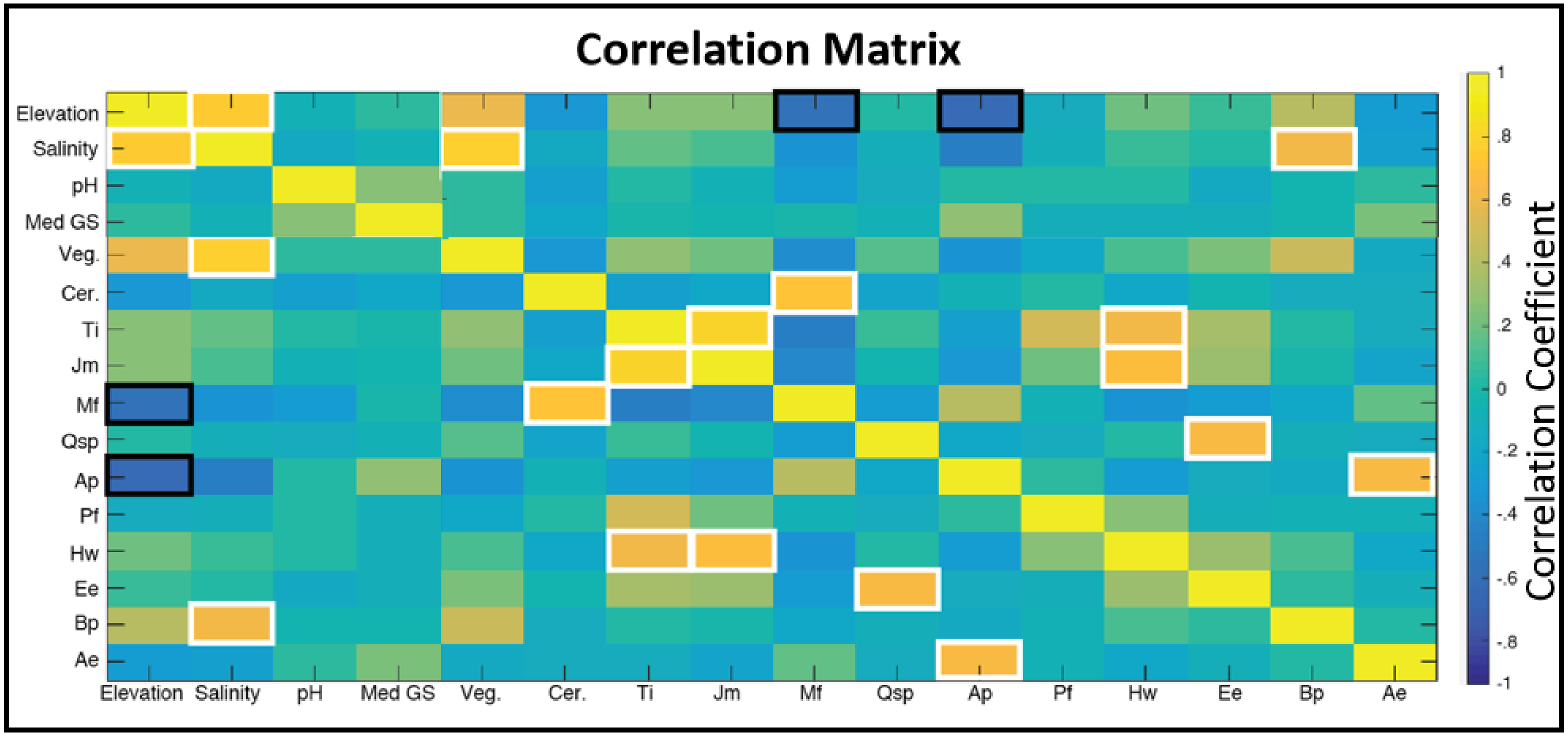
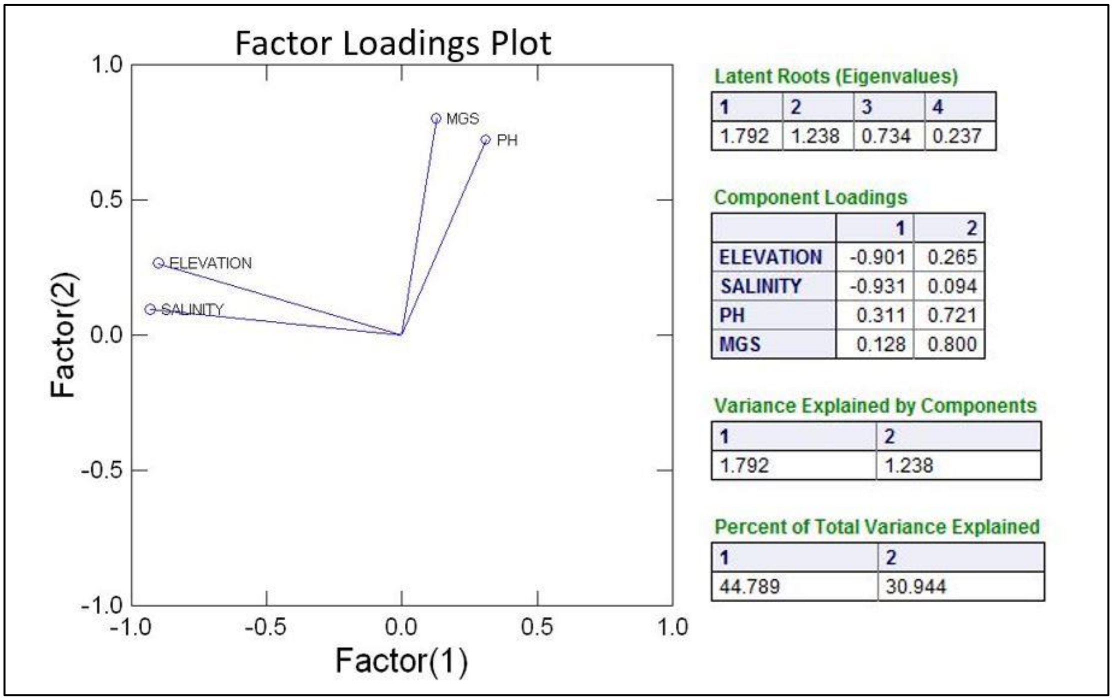


Figure (8). Correlation matrix of Pearson R^2 values. (med GS) Median Grain Size; (Veg.) amount of vegetation cover; (Cer.) density of living Cerithedia californica; *(Ti) Trochammina inflata; (Jm) Jadammina macscerens; (Mf) Miliammina fusca; (Qsp) Quinqueloculina species; (Ap) Ammonia parkinsonia; (Pf) Protoschista findens; (Hw) Halphragromides wilberti; (Ee) Eplhidium excavatum; (Psp) Polysaccammina species.* All positive correlations exceeding .75 are highlighted by a white box. All negative correlations less than -.75 are highlighted by a black box

Figure 9



Latent Roots (Eigenvalues)

1	2	3	4
1.792	1.238	0.734	0.237

Component Loadings

	1	2
ELEVATION	-0.901	0.265
SALINITY	-0.931	0.094
PH	0.311	0.721
MGS	0.128	0.800

Variance Explained by Components

1	2
1.792	1.238

Percent of Total Variance Explained

1	2
44.789	30.944

Figure 9. A factor loadings plot (left panel) showing the correlation between environmental variables and the two main principle components. Environmental Variables are: Elevation; Salinity; pH; (MGS) median grain size. Explanation of the Eigenvalues and component loadings (right panel).

PCA and Ordinary Least Squares regressions were employed in tandem to test for a relationship between taxa and environmental variables that the more simplistic correlation test could not detect. The scores (Factor (1) and Factor (2)) from the PCA run on environmental variables were analyzed in OLS regression as independent variables (Figure 9) (Table 6). Factor (1), which is comprised of both elevation and salinity, predicts the species abundance for four species, while Factor (2), i.e. grain size, only significantly predicts one species, *Bp.* However, *Bp* is better predicted by elevation and salinity than grain size (Table 8). Elevation alone predicts the abundances of *Ti, Ap,* and *Mf,* but does so with less confidence than does Factor (1).

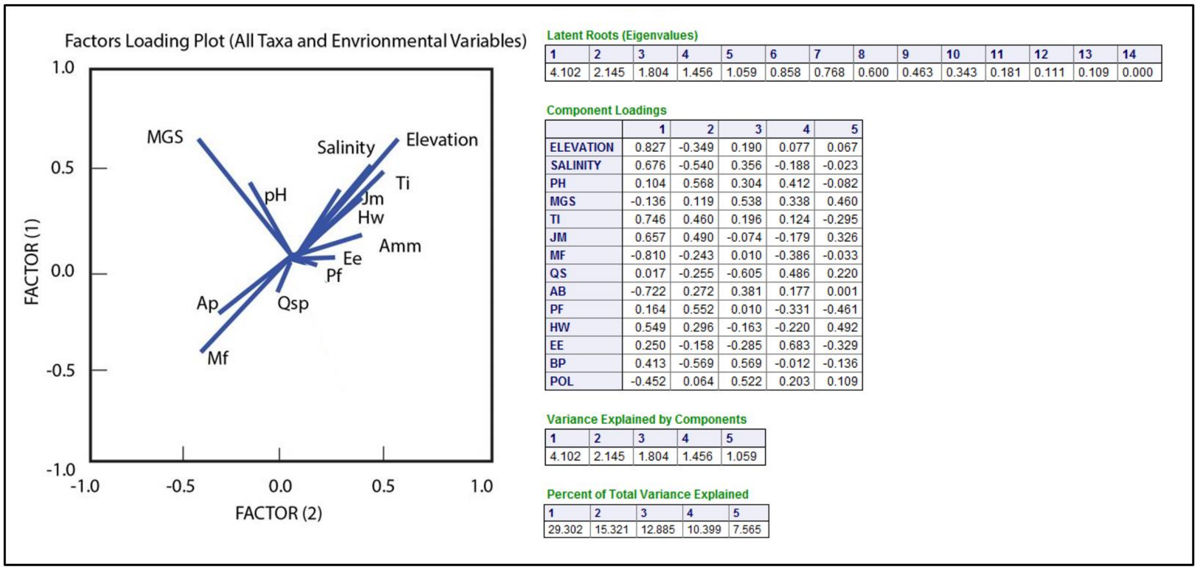
Table (8)

	Ti	Jm	Mf	Qs	Ab	Pf	Hw	Ee	Bp	Pol
ELEVATION	0.034	0.345	0.034	0.574	0.039	0.703	0.167	0.214	0.542	0.3
SALINITY	0.616	0.515	0.79	0.26	0.488	0.984	0.751	0.239	0	0.008
PH	0.003	0.342	0.061	0.416	0.333	0.452	0.747	0.866	0.792	0.643
MGS	0.314	0.409	0.952	0.857	0.423	0.979	0.744	0.909	0.003	0.283
Factor(1)	0.04	0.171	0.01	0.899	0	0.529	0.186	0.504	0	0.152
Factor(2)	0.034	0.384	0.067	0.445	0.44	0.822	0.793	0.984	0.145	0.58

Table 8. 'P-values' (probability that a variable predicts species values at a 95% confidence level) plotted for each foraminiferal species against each environmental variable. Factor(1) and Factor(2) refer to the first two principle components produced from the initial PCA. Highlighted values indicate statistically significant results.

The predictive capabilities of elevation and salinity and the inability of grain size to predict the abundance of taxa is important for two reasons. First, as revealed by the correlation matrix, salinity and elevation exert greater control on foraminiferal assemblages than any other environmental variable. Secondly, the second round of PCA demonstrated the importance of focusing only on one grain size metric (MGS). Originally, the second PCA was run using all grain-size metrics as environmental variables. However, due to the autocorrelation between the metrics, grain size was identified as PC1 in the second PCA. Grain size's appearance as PC1 is not indicative of grain size controlling the taxa in Carpinteria Slough, rather it is an artifact of the correlation between multiple grain size metrics, and as such I only focused on the grain size metric of median grain size (MGS) in the OLS Regression, which again distinguished elevation and salinity as the primary controllers on the foraminiferal assemblages (Figure 10).

Figure 10



Latent Roots (Eigenvalues)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
4.102	2.145	1.804	1.456	1.059	0.858	0.768	0.600	0.463	0.343	0.181	0.111	0.109	0.000

Component Loadings

	1	2	3	4	5
ELEVATION	0.827	-0.349	0.190	0.077	0.067
SALINITY	0.676	-0.540	0.356	-0.188	-0.023
PH	0.104	0.568	0.304	0.412	-0.082
MGS	-0.136	0.119	0.538	0.338	0.460
TI	0.746	0.460	0.196	0.124	-0.295
JM	0.657	0.490	-0.074	-0.179	0.326
MF	-0.810	-0.243	0.010	-0.386	-0.033
QS	0.017	-0.255	-0.605	0.486	0.220
AB	-0.722	0.272	0.381	0.177	0.001
PF	0.164	0.552	0.010	-0.331	-0.461
HW	0.549	0.296	-0.163	-0.220	0.492
EE	0.250	-0.158	-0.285	0.683	-0.329
BP	0.413	-0.569	0.569	-0.012	-0.136
POL	-0.452	0.064	0.522	0.203	0.109

Variance Explained by Components

1	2	3	4	5
4.102	2.145	1.804	1.456	1.059

Percent of Total Variance Explained

1	2	3	4	5
29.302	15.321	12.885	10.399	7.565

Figure 10. A factor loadings plot (left panel) showing the correlation between environmental variables and the taxonomic data with the PC1 and PC2 making up the y and x axes respectively. Environmental Variables are: Elevation; Salinity; pH; (MGS) median grain size. Explanation of the Eigenvalues and component loadings (right panel).

Similarly, a third round of individual PCA's, designed to show the degree to which taxonomic data is explained by the four major environmental variables, demonstrated that elevation and salinity were again the major controlling factors on taxonomic data (Table 9). Elevation explained the most variance in taxonomic data at 33.68% of variance explained, and salinity explained 16.52% of the taxonomic variance with pH and MGS also explaining 12.49% and 12.42% of the taxonomic variance respectively.

Table (9)

	Percent of Total Variance Explained
Elevation	33.68%
Salinity	16.52%
pH	12.49%
MGS	12.42%

Table 9. Relative percent of variance explained within the taxonomic data (right column) for four environmental variables (left column).

Due to the connection between elevation and species abundances I ran an Analysis of Variance Test (ANOVA) looking at the variance among species abundances in different marsh zones. The sample location elevations overlap tidal datums calculated by Sadro et al. (2007) (Table 1), breaking the marsh into elevations below MHW (low marsh), elevations between MHW and MHHW (middle marsh), and elevations above MHHW (high marsh). The low, middle and high marsh environments, acted as the zones in which the ANOVA tested if species abundances varied significantly. The tide-based ANOVA's (Figure 11) showed that two species have significantly different mean abundances between the three groups (Table 10). *Ti* abundances in the high were different from their abundances in both low and middle marsh environments, and *Ap* abundances in the low marsh were different from their abundances in both middle and high marsh environments (Figure 11). As such, the first ANOVA was only able to differentiate the marsh into two very broad biofacies, dependent on two foraminiferal species.

Table (10)

	SS	**df**	**MS**	**F**	**prob>F**
Ti	1.0694	2	0.53469	1.26	0.3015
Jm	0.14579	2	0.07289	0.36	0.7028
Mf	2.321	2	1.16052	1.21	0.3131
Qs	0.3043	2	0.15215	0.34	0.7115
Ab	0.46245	2	0.23123	8.08	0.0019*
Pf	0.07927	2	0.03964	1.59	0.2233
Hw	0.11909	2	0.05954	0.62	0.5442
Ee	0.01549	2	0.00775	0.1	0.9065
Bp	2.74065	2	1.37033	22.05	2.52E-06*
Pol	0.05621	2	0.0281	3.7	0.0386

Table 10. ANOVA results based upon tidal groupings (low, middle and high marsh). (SS) sum of squares; (df) degrees of freedom; (MS) mean squares; (F) F statistic; (prob>F) probability greater than F at the 95% confidence level. * indicates species whose probability greater than F is statistically significant.

Figure (11)

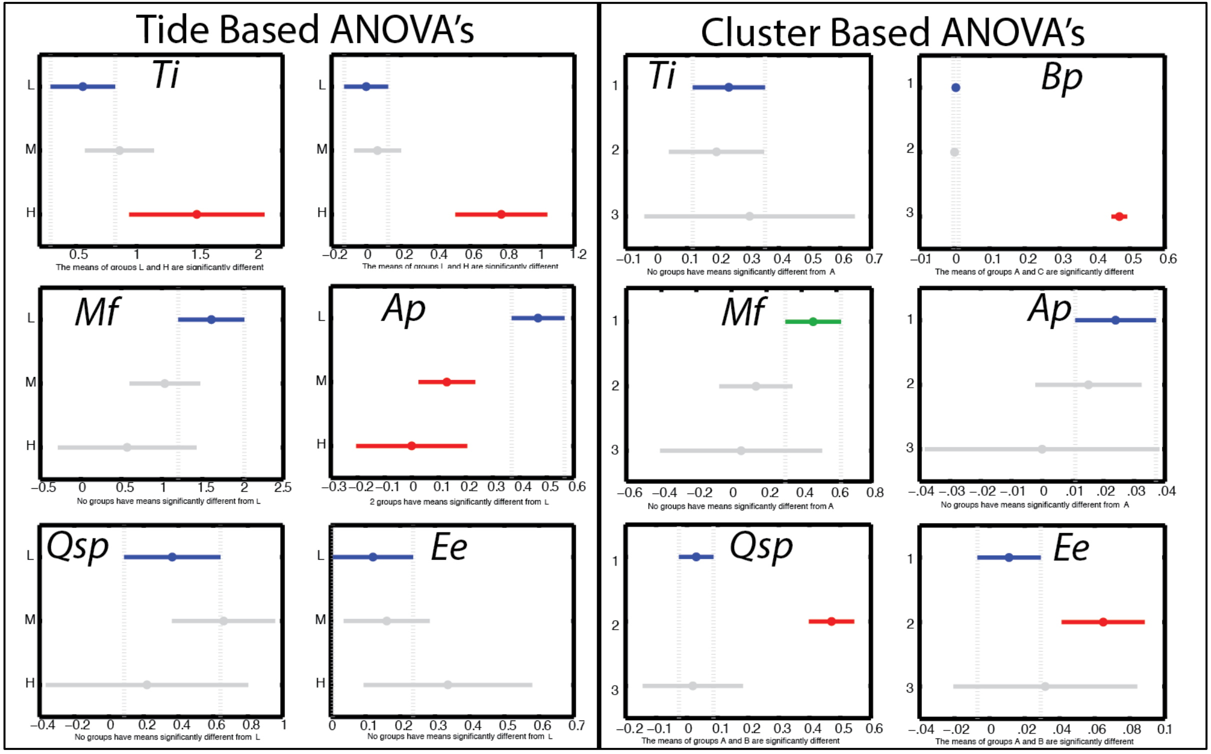


Figure 11. Each box represents an individual species of foraminifera, only showing the results of the six most distinctive species in Carpinteria Slough: *(Ti) Trochammina inflata; (Bp) Balticammina pseudomacscerens; (Mf) Miliammina fusca; (Ap) Ammonia parkinsonian; (Qsp) Quinqueloculina species; (Ee) Elphidium excavatum.* The Y axis represents the groups of foraminifera defined by tidal datums: (L) Low Marsh; (M) Middle Marsh; (H) High marsh. The x-axis represents the mean abundances of the foraminifera (after an arcsin square root transformation). Each box has a caption explaining the variance of species data amongst the three marsh environments.

While elevation appears to exert the dominant control on species abundance, I took a second approach, separate from elevation, to break apart the salt marsh into biofacies. Cluster analysis based on the similarity between foraminiferal assemblages at each sample site allowed for breakup of the sample sites into zones, without taking into account the elevation of the samples. Q-mode cluster analysis of the taxa revealed three distinct cluster zones (Figure 12).

Figure 12

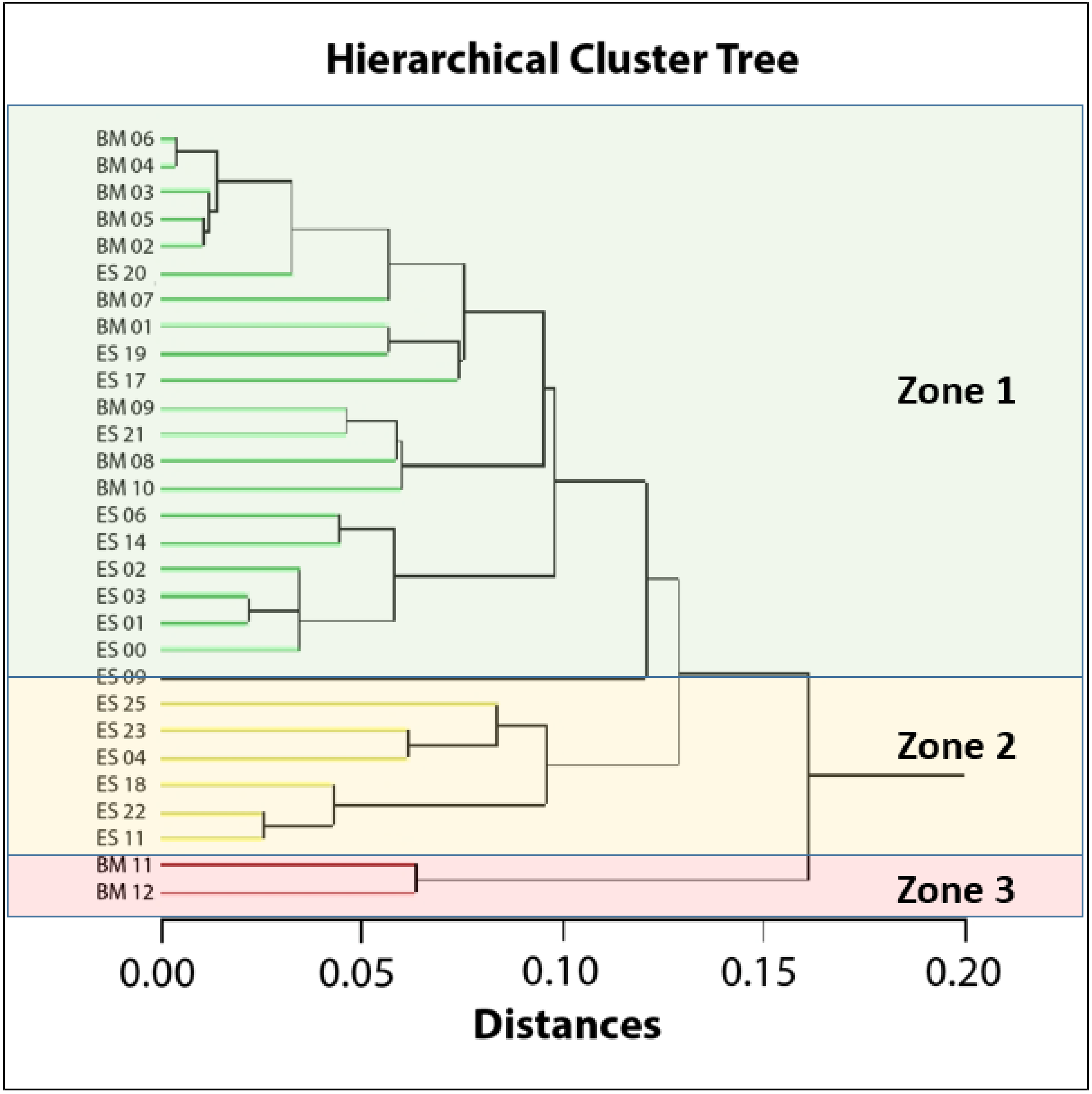


Figure 12. Dendogram of Carpinteria Slough sample data. Green represents Zone 1, Yellow represents Zone 2, and Red represents Zone 3. The closer the samples are to one another the more similar are the two samples.

In order to quantify what the driving foraminiferal constituents producing the three cluster analysis zones, a second round of ANOVA's was conducted to investigate the species' mean abundance differences among the three cluster zones (Table 11; Figure 11). Four species, as opposed to the two species in the first round of ANOVA's, displayed significantly different mean abundances between the three marsh zones (Figure 11). Zone 1 is defined by high abundances of *Mf.* Zone 2 is defined by two species with significantly different mean abundances from zones 1 and 3, *Ee* and *Ap.* A significantly higher mean abundance of *Bp* compared to zones 1 and 2 defines Zone 3. Thus, the ANOVA based on cluster zones allows for the partitioning of Carpinteria Slough into 3 biofacies zones, each defined by its foraminiferal constituents and their individual species' mean abundances.

Table(11)

	SS	**df**	**MS**	**F**	**prob>F**
Ti	0.01981	2	0.00991	0.16	0.8545
Jm	0.04192	2	0.02096	1.49	0.2444
Mf	0.75217	2	0.37608	3.31	0.0526**
Qs	1.03775	2	0.51887	36.48	2.84E-08*
Ap	0.00128	2	0.00064	0.82	0.4514
Pf	0.00075	2	0.00038	0.84	0.4426
Hw	0.0041	2	0.00205	0.56	0.5788
Ee	0.01506	2	0.00753	5.14	0.0131*
Bp	0.40668	2	0.20334	779.34	6.24E-24*
Pi	0.00112	2	0.00056	9.54	0.0008*

Table 11. ANOVA results based upon cluster groupings (Zone A, Zone B, and Zone C). (SS) sum of squares; (df) degrees of freedom; (MS) mean squares; (F) F statistic; (prob>F) probability greater than F at the 95% confidence level. * Indicates species whose probability greater than F is statistically significant. ** Indicates that the probability of *Mf* is very close to the statistical significance threshold.

Figure 13 displays the relationship between the cluster zones and the species data in graphical form. The species ratios are an important component of differentiating the biofacies zones. Zone 1 is dominated by high percentages of primarily *Mf* and to a lesser degree *Ti* (Figure 13). Zone 3 is dominated by high percentages of *Bp.* And Zone 2 is more complicated, relying on relatively small abundances of *Mf, Ti,* and *Bp,* in conjunction with a larger abundance of *Ap* and *Ee* (Figure 13)*.* Based on the dendogram, it may be possible to break Zone 1 into three subgroups, Zone 1a, in which *Mf* is in high abundance and *Ti* abundances are small. Zone 1b contains sporadic *Mf* values and a much higher percentage of *Ti.* Zone 1c contains approximately equal percentages of *Mf* and *Ti* with a higher than normal abundance of *Ee.*

Figure 13

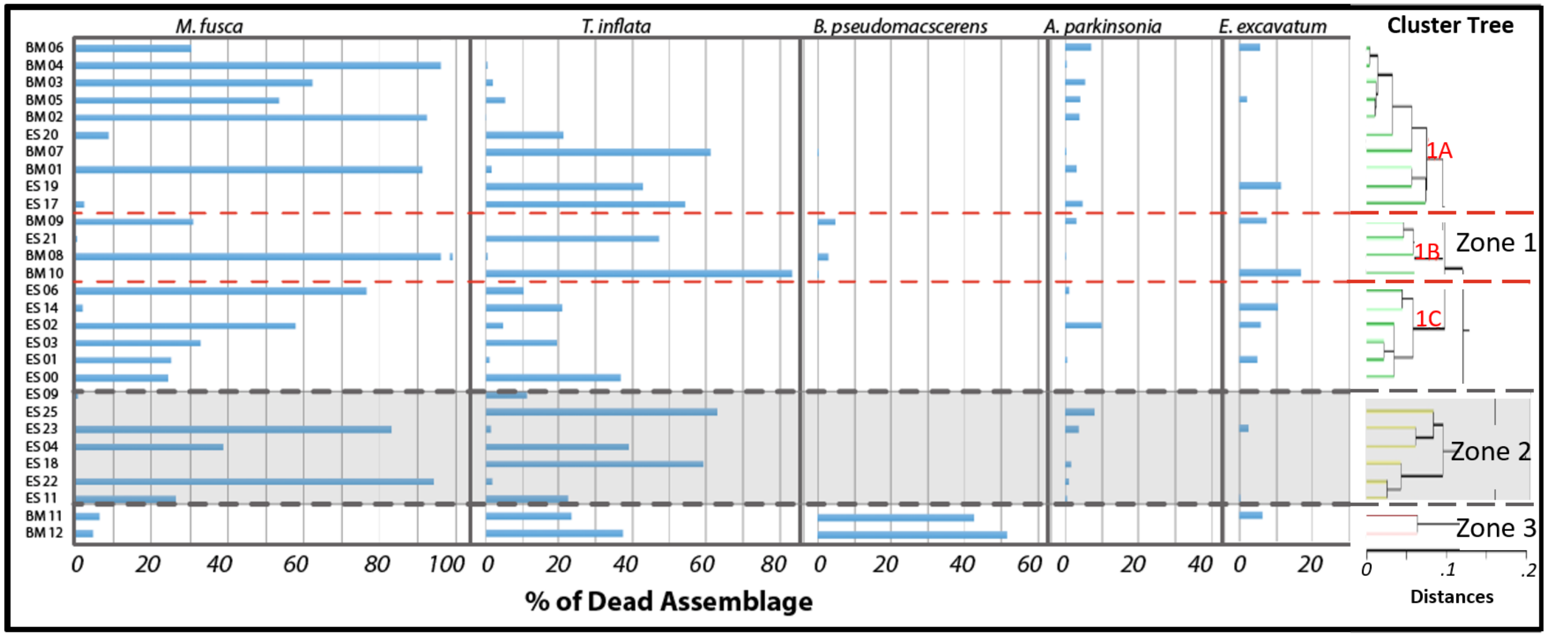


Figure 13. Schematic illustrating biofacies zones, as defined by cluster analysis, and the species data that informed the cluster analysis. Only the species of *Trochammina inflata*, *Miliammina fusca*, *Balticammina pseudomacscerens*, *Ammonia parkinsonia*, and *Elphidium excavatum* are displayed. Zone 1 can be subdivided based upon the dashed red lines, subdividing Zone 1 into Zones 1A, 1B, and 1C.

In the hopes of distinguishing elevation patterns within the cluster defined biofacies zones, I ran a third round of ANOVA's focusing on the mean elevations among the three cluster zones (Figure 14). Two ranges of elevations correlate with the three cluster zones (Figure 14). All elevations below 0.83m comprise elevation Zone A, which contains both cluster Zones 1 and 2. Elevation Zone B contains all samples above 0.83m, i.e. only samples within cluster Zone 3 (Figure 14).

Figure 14

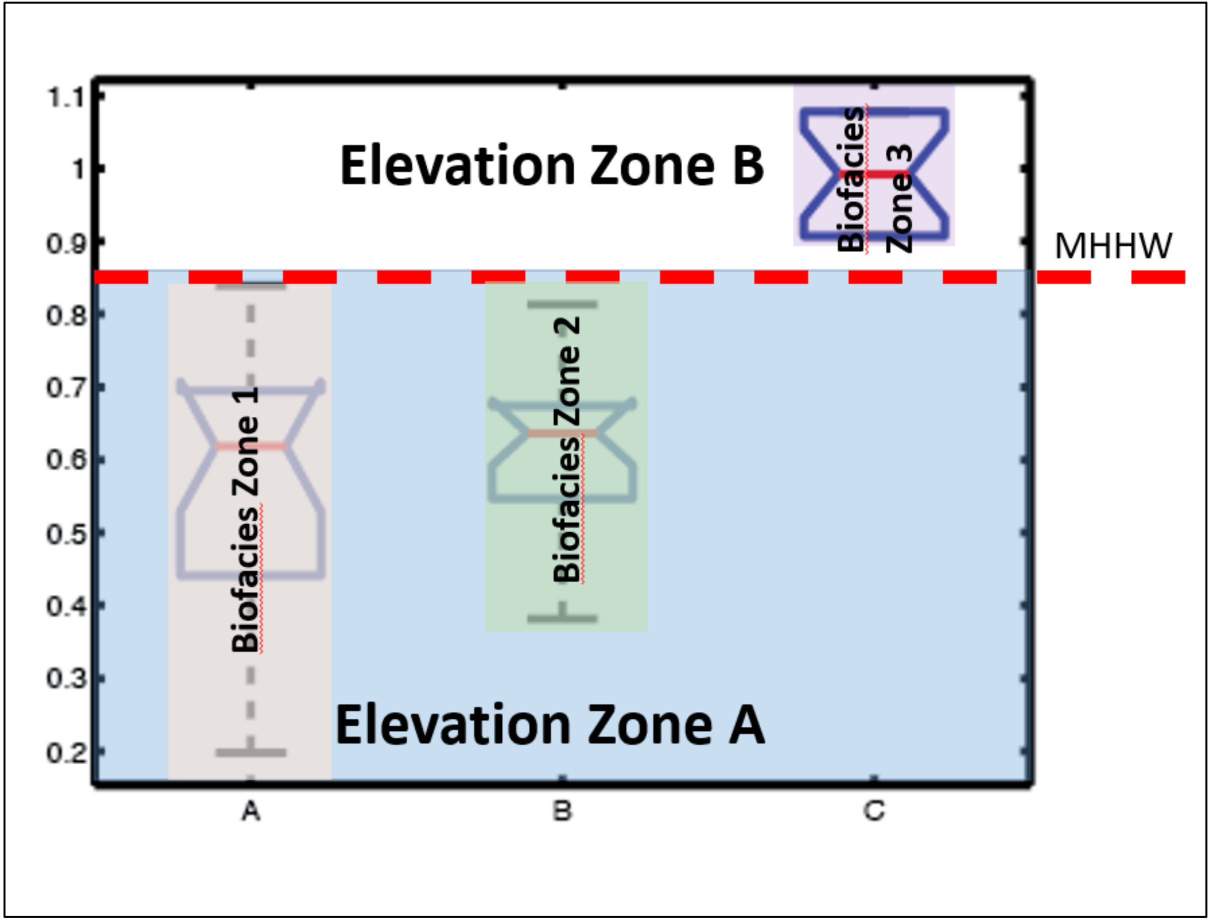


Figure 14. Elevation ANOVA output displaying the mean elevations of cluster defined biofacies (Zone 1 in orange; Zone 2 in green; Zone 3 in purple). The red dashed line signifies the MHHW elevation. Elevation Zone A is the blue box, and the white box is Elevation Zone B.

DISCUSSION

Biofacies and Transfer Function Implications

Cluster analysis allows for the separation of the marsh into three biofacies and 2 elevation zones (Figure 14). Zone A contains all elevations below 0.83m above MSL, and Zone B is comprised of all elevations greater than .83m above MSL, which also coincides with all elevations higher than MHHW (Figure 14). Thus, creating a sea-level transfer function based on foraminiferal assemblages in Carpinteria Slough is possible, but may not be as high resolution as reconstructed in foraminiferal studies elsewhere, due primarily to Carpinteria Slough's patchy lower to middle marsh foraminiferal assemblages (Kemp et al., 2009; Edwards et al., 2002; Leorri et al., 2008; Gehrels 1994; Hayward et al., 1999; Scott et al., 1996; Callard et al., 2011).

The patchiness of foraminifera observed within elevation Zone A may stem from anthropogenic forcings in southern California, which are potentially greater than the disturbances to other salt marsh locales in which high precision foraminifera-based, sea-level transfer functions are created. Carpinteria Slough's boundaries are not fluid to change with sea level and sediment supply, but rather set in place by the faults that bound its seaward margin and the modern development on the landward edge of the marsh (Simms et al., 2016). As such, Carpinteria Slough is much smaller than many salt marshes along the east coast of North America (Table 12). In general, southern California's smaller salt marshes are confined due to active tectonics, which often preclude large coastal plains and encourage the juxtaposition of mountains adjacent to the ocean, as well as the extensive anthropogenic modification of the California coast, including the infilling of natural salt marshes (Ferren, 1985). The building of houses, industrial complexes, and railroads significantly reduced the size of Carpinteria Slough as well as other southern California salt marshes, and as such humans are responsible for 'marsh squeeze' in which the historic extent of the salt marshes has diminished dramatically due to human modifications (Southern California T-Sheet Atlas) (Figure 15).

Table (12)

Marsh Name	City, State	Size (ha)	Reference
Carpinteria Slough	Carpinteria, CA	230	Ferren (1985)
Mugu Lagoon	Oxnard, CA	130	Warme (1971)
Sweetwater Marsh	San Diego, CA	128	Langis et al., (1991)
Great Marshes	Barnstable, MA	1360	de Rijk and Troelstra (1997)
Georgia Bight Backbarrier Marshland	Georgia Coastline	150000	Frey and Basan (1985)

Table 12. Camparisson in size (hecta acres (ha)) between southern California study areas, the Great Marshes, and the connected back barrier marshland along the Georgia coast.

Figure 15

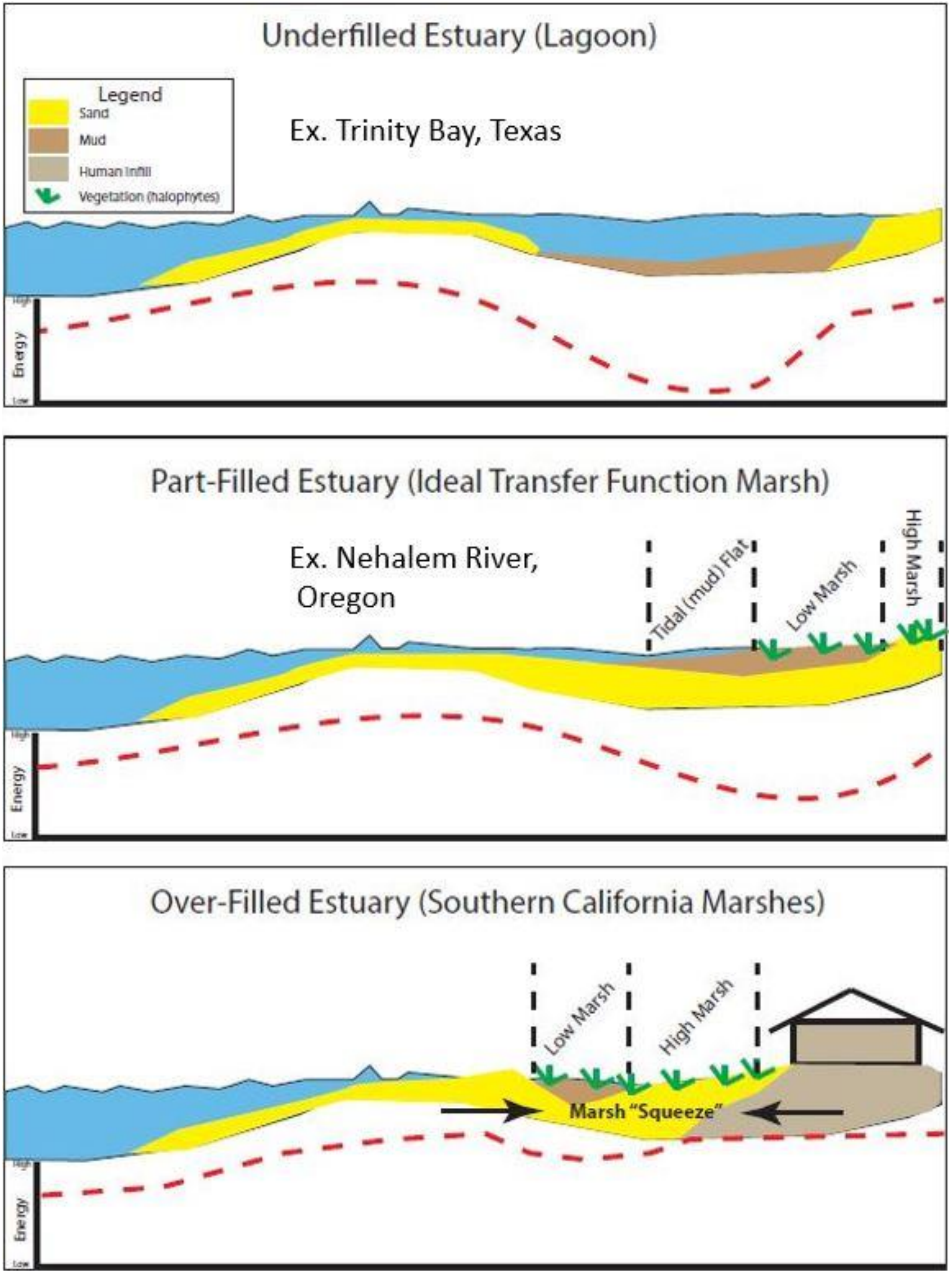


Figure 15. Schematic illustrating the effects of 'Marsh Squeeze'. Note the red dotted line, which represents relative energy (current velocities) observed along the marsh profile, and how it the energy line is proposed to change as a result of 'Marsh Squeeze'.

Marsh squeeze, in and of itself, does not explain why Carpinteria Slough biofacies are not directly linked to elevation, but it could play a pivotal role in the modification of forminifera zones within the marsh. Increased sediment supply, in conjunction with marsh squeeze, may be responsible for notable salt marsh morphological changes over the last 150 years. Ejarque et al., (2015) demonstrated that a southern California coastal lake experienced increased sedimentation rates of up to 300% since the settling of southern California by the Spanish due to associated land use changes. Reynolds (2015) found a 50% increase in sedimentation rates within Carpinteria Slough since Spanish settlement of California. Due to the fact that a marsh experiencing marsh squeeze in combination with an increase in sedimentation rates will aggrade more quickly than an unmodified marsh, it stands to reason that the smaller, tectonically controlled salt marshes in southern California would experience exacerbated rates of marsh squeeze as a result of the local increases in sedimentation rates.

One sedimentary environment rare in Carpinteria Slough and non-existant in both Sweetwater Marsh and Mugu Lagoon is intertidal mudflats. Other studies along the west coast document salt marshes with large, broad, well-defined intertidal mudflats (Hawkes et al., 2011). Paleo-reconstructions of California's coast, based upon historical records from the 1800's suggest that southern California salt marshes contained large intertidal mudflats (Southern California T-Sheet Atlas) (Figure 16). Modern southern California salt marshes often contain only a portion of the once broad mudflats depicted in the historical records (Southern California T-Sheet Atlas) (Figure 16). Not only are facies shifts evident from historical data, but it is also plausible that ancient marshes experienced a more gradual increase in elevation from the tidal inlet to the high marsh. In theory, a broad salt marsh would produce a wide variety of energy regimes throughout the marsh, differing based on a location's proximity to fluvial or marine inputs. With a gradual increase in elevation, tidal inundation frequencies would depend only on the elevation of a location above MSL. The differing energy environments would not only allow for a wider variety of sedimentary facies, but also produce a marsh whose biofacies are more dependent on elevation (Phleger, 1962; Scott and Medioli, 1980; de Rijk, 1995).

The aggradation of salt marsh environments may result in the shrinking of southern California intertidal mudflats as well as altered tide and land interactions. Sadro et al., (2007) suggest that Carpinteria Slough behaves much like a bathtub with a bad drain, filling up with water during high tide, but not draining completely during low tides, resulting in a mean low water level (MLW) roughly 0.2 m above the average MLW along the open Santa Barbara coastline. Sadro et al., (2007) also suggests that areas in Carpinteria Slough undergo variable tidal inundation times based not solely on elevation differences throughout the marsh, but also due to complex marsh morphologies associated with large sandy berms that can either prevent inundation by acting as a dam to the incoming tidal waters, or enhancing inundation when acting as a clogged drain and slowing the outflow of tidal waters and inducing ponding.

Figure 16

Figure 16. T-sheet data displaying the environments as observed in 1852 overlaying the modern conditions in San Diego Bay. Note that Sweetwater Marsh, outlined in red, once contained large swaths of intertidal mudflats (beige), and contains no intertidal mudflat in the modern. Figure modified after Southern California T-Sheet Atlas Figure B39.

CONCLUSIONS

1- Q-mode cluster analysis separated the foraminiferal assemblage data into 3 distinct biofacies (Zones 1, 2, and 3) based upon the similarity of foraminiferal constituents at each sample location. Zone 1 is defined by mean abundances of *Miliammina fusca* comprising between 30 and 60% of the entire sample. Zone 2 is defined by mean abundances of *Elphidium excavatum* comprising between 0 and 2% of any sample, and *Ammonia parkinsonian* comprising between 2 and 4% of any sample. Zone 3 is defined by a mean abundance of *Balticammina pseudomacscerens* comprising between 45 and 50% of any sample. Similarly, Zone 1 can be subdivided into Zones 1a, b, and c using cluster analysis. Cluster analysis was the only statistical test able to segment the foraminiferal data into distinct groups.

2- Principle component analysis demonstrates that the percent of total variance in assemblage data is explained by the environmental factors of elevation (33.68%), salinity (16.52%), pH (12.49%), and median grain size (12.42%). ANOVAs and OLS regressions also indicate that of the environmental variables investigated: elevation, salinity, pH, and grain size; only elevation and salinity exert control on foraminiferal assemblages. However, the correlation between foraminifera and the environmental variables is only significant for the species of *Mf, Ab, Ee,* and *Bp.*

3- A one-way ANOVA of elevation based upon the three biofacies zones of foraminifera defined by cluster analysis divide the marsh into two elevation zones (Zone A, which contains all elevations below 0.83m, and Zone B, which contains all elevations above 0.83m). The segmentation of elevation data based upon foraminiferal assemblages allows for the refinement of southern California sea-level and subsidence curves with up to 0.83m resolution.

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Appendix A
Taxonomic Notes

Order FORAMINIFERIDA Eichwald
Suborder TEXTULARINA Delge and Herouard
Superfaimily ASTRORHIZACEA Brady
Family SACCAMMINIDAE Brady
Genus *Polysaccammina* Scott

Polysaccammina species Scott

Polysaccammina species Scott, 1976, vol.6, no.4, p.319-320; pl.2, figs. 1-4; p.315, text figs. 4a-c.

Taxonomic description: Test free, finely arenaceous with pseudochitinous base; globular chambers, irregularly shaped, in uniserial arrangement but sometimes irregularly developed; with terminal aperture; test is flexible at sutures; earlier chambers appear to collapse; sutures distinct and depressed; arenaceous outer layer is not continuous between chambers.

Superfamily RZEHAKINACEA Cushman
Family RZEHAKINIDAE Cushman
Genus *Miliammina* Heron-Allen and Earland

Milliamina fusca (Brady)

Quinqueloculina fusca Brady, 1870, ser. 4, vol. 6, p. 286; pl.11, figs 2-3.

Taxonomic description: Although this species is coiled on a quinqueloculine plan, the finely agglutinated wall shows it to be alituolacean. Specimens immersed in concentrated nitric acid do not disintegrate. This is due to presence of a thick organic lining holding the detrital grains together although Loeblich and Tappan (1964), following Heron-Allen and Earland, believe the cement to be siliceous. The terminal aperture has a small tooth. Average length of 0.4 mm.This very euryhaline species colonizes hyposaline lagoons, estuaries, and tidal marshes.

Superfamily LITUOLACEA de Blainville
Family HALPHRAGRAGMOIDIDAE Mayne
Genus *Halphragromides* Cushman

Halphragromides wilberti Anderson

Halphragromides wilberti Anderson, 1953, vol. 4, pt. 1, p.21; pl 4, figs 7a, b.

Taxonomic description: An involute, slightly inflated, smooth species of Haplophragmoides with eight or nine chambers gradually increasing in size as added. Small umbilicus on each side filled with the lobed ends of the chambers. Sutures distinct, slightly depressed, straight to sigmoid at an angle of approximately 40 degrees to each other. Aperture not present but foramen of penultimate chamber visible as a low, peripheral slit at the basal suture beneath a lip; wall tectinous with very fine silt grains. Amber to brownish-white in color with smooth, glossy finish.Maximum diameter of 0.53 mm.

Superfamily TROCHAMMINACEA Schwager
Family TROCHAMMINIDAE Schwager
Subfamily TROCHAMMININAE Schwager
Genus *Trochammina* Parker and Jones

Trochammina inflata (Montagu)

Nautilus inflatus Montagu, 1808, p. 81; pl. 18, fig. 3.

Taxonomic description: Trochospiral test. Spiral side is flat with a gently depressed sutures. The umbilical side has deeply depressed sutures between the inflated chambers. The umbilicus is deep. The interiomarginal aperture is confined to the umbilical side; it is narrow and bordered by a lip. The thin wall is finely agglutinated and brown. Average diameter is 0.4 mm.

Jadammina macrescens Brady

Trochammina macscerens (Montagu) var. *macscerens* Brady, 1870, ser. 4, vol. 6, p. 290-1, pl. 11, figs. 5 a-c.

Taxonomic description: *Jadammina* is distinguished from *Trochammina* by its primary equatorial aperture and cribrate openings. The wall is very thin and flexible when wet so the chambers commonly collapse when the specimen is dried. Average diameter is 0.3 mm.

Superfamily ROTALIACEA Ehrenberg
Family ROTALIDAE Ehrenberg
Genus *Ammonia* Brunnich

Ammonia parkinsoniana (d'Orbigney)

Rosalina parkinsoniana d'Orbigny, 1839, p.99; vol.8; pl.4, figs. 25-27.

Taxonomic description: Biconvex test is trochospirally coiled. On the spiral side the earlier sutures become thickened and imperforate but the later ones are deeply depressed, imperforate, and ornamented with tubercules. The periphery is rounded. On the umbilical side the sutures are depressed and have thickened imperforate tubercular growths particularly at their umbilical extremities. The umbilicus is sometimes occupied by a calcite boss. Aperture is an interiomarginal slit. Average greatest diameter 0.4 mm, but the size range is variable.

Family ELPHIDIIDAE Galloway
Subfamily ELPHIDIINAE Galloway
Genus *Elphidium* de Montfort

Elphidium excavatum (Terquem)

Polystomella excavatum Terquem, 1875, vol. 19, p. 429; pl.2, figs. 2a, b.
Taxonomic description: The planispirally coiled test is compressed , involute, with 8-9 chambers in the outer whorl. Deeply depressed sutures are crossed by a few, irregular retral processes and ornamented with tubercles. The umbilici bear imperforate calcite bosses and are also ornamented with tubercles. The aperture is an interiomarginal row of pores with assocated tubercles. Average diameter is 0.3 mm.

Superamily MILIOLIDEA Ehrenberg
Family HAUERINIDAE Schwager
Subfamily HAUERININAE Schwager
Genus *Quinqueloculina* Terquem

*Quinqueloculina sp***.** Terquem
*Quinqueloculina sp***.** Terquem, 1876, vol. 2, p. 82, pl. 11, figs. 8 a-c.

Taxonomic description: Test is coiled on a quinqueloculine plan. Test wall is porcellaneous and imperforate. Aperture is an elongate terminal slit with a stout simple tooth. Sutures are slightly depressed. The oblong outline and triangular cross section are characteristic. Average length ranges from 0.7-1.5 mm.
An inner shelf species.

Superfamily TEXTULARIOIDEA Ehrenberg
Family THOMASINELIDAE Thomasinellidae Loeblich & Tappan
Genus *Protoschista* Eimer & Fickert

Protoschista findens (Parker)
Protoschista findens Costello, 2001, vol. 50, p. 60-75.

Taxonomic description: The rectilinear series of six chambers increases slowly in size, becoming progressively smoother and flatter, and the ultimate chamber has two apertures, each on a slight neck.

Superfamily TROCHAMMINOIDEA Schwager
Family TROCHAMMINIDAE Schwager
Subfamily POLYSTOMAMMININAE Brönnimann & Beurlen
Genus *Balticammina* Brönnimann, Lutze & Whittaker

Balticammina pseudomacrescens Brönnimann, Lutze & Whittaker
Balticammina pseudomacrescens Brönnimann, Lutze & Whittaker, 1989, vol. 41, p. 167-77.

Taxonomic description: *Balticammina* is distinguished from *Trochammina* by its primary with an interiomarginal aperture and an open umbilicus. It also differs from *T. inflata* by the greater number of chambers in the final whorl and apertural and umbilical characteristics (possessing supplementary apertures opening into the wide umbilicus).

List of Species		
Number	Taxonomic name and Authority	Plate Number (this work)
1	*Ammonia parkinsonian* (d'Orbigny 1839)	I. a-b
2	*Balticammina pseudomacscerens* (Brönnimann, Lutze & Whittaker 1989)	I. c-d
3	*Elphidium excavatum* (Terquem 1875)	II. a-b
4	*Halphragromides wilberti* (Anderson 1953)	II. c-d
5	*Jadammina macscerens* (Brady 1870)	II. e-f
6	*Miliammina fusca* (Brady 1870)	III. a-b
7	*Polysaccammina species* (Scott 1976)	III. c-d
8	*Protoschista findens* (Parker 1870)	III. e-f
9	*Quinqueloculina species* (Terquem 1876)	IV. a-b
10	*Trochammina inflata* (Montagu 1808)	IV. c-d
11	Unidentified Textularid	IV. e-f

Plate I

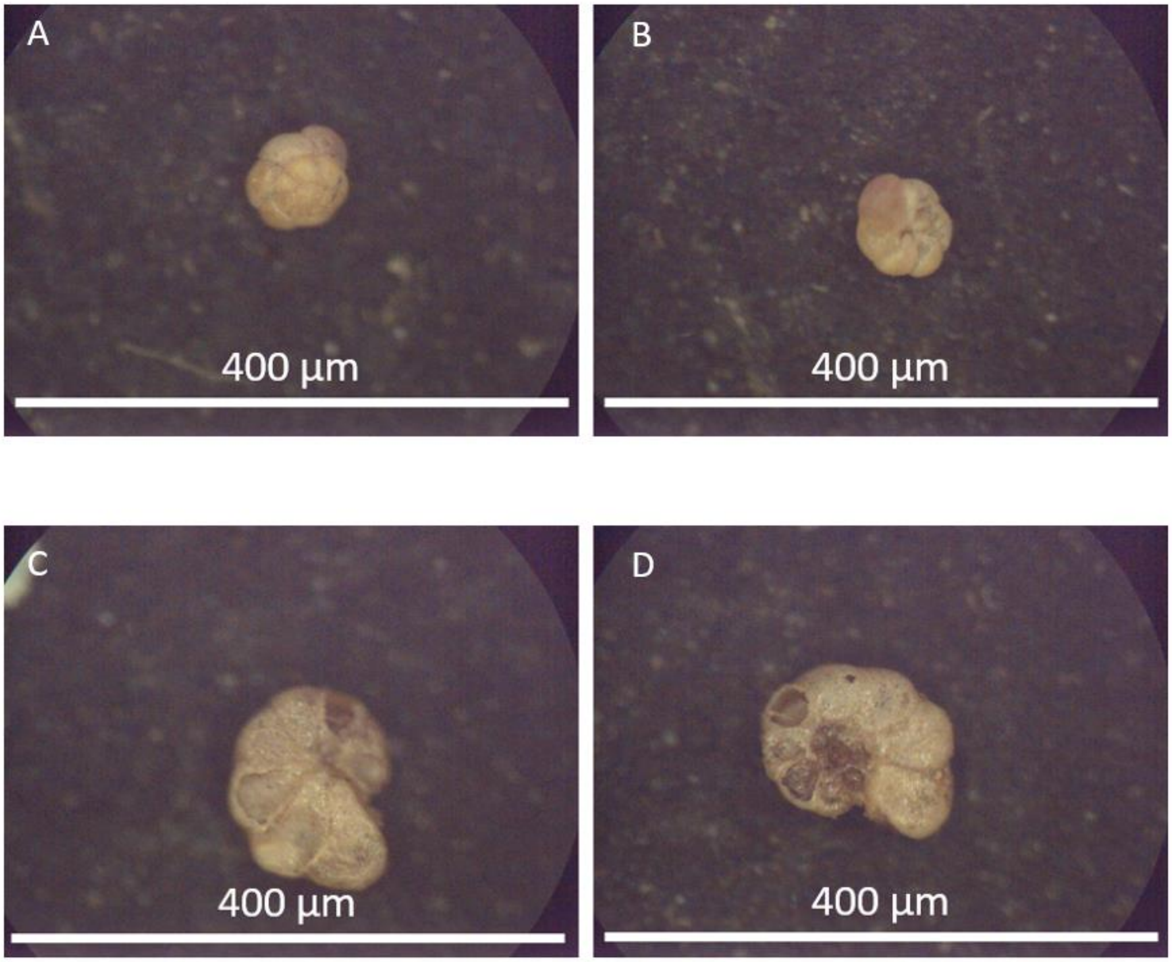


Plate II

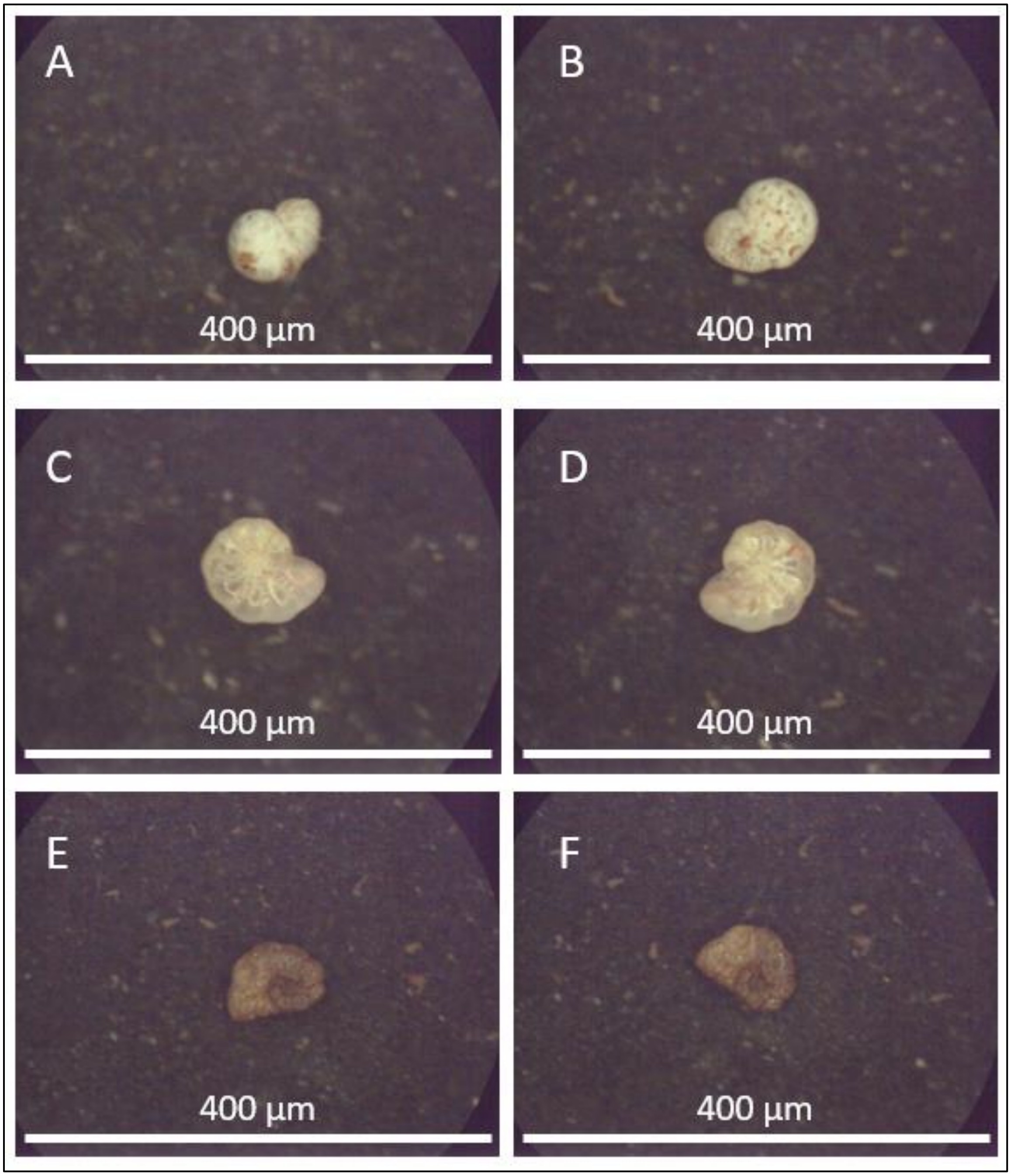


Plate III

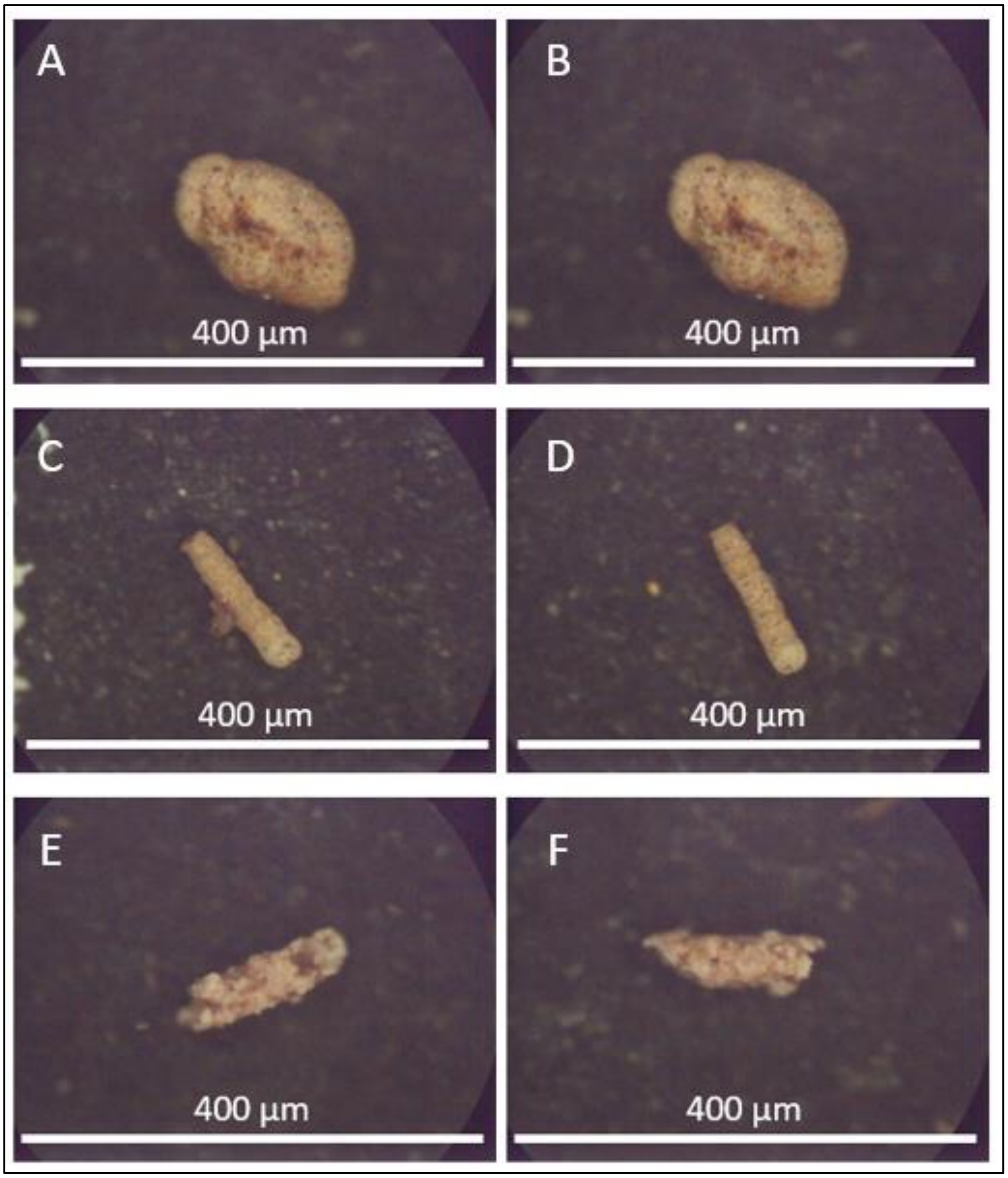
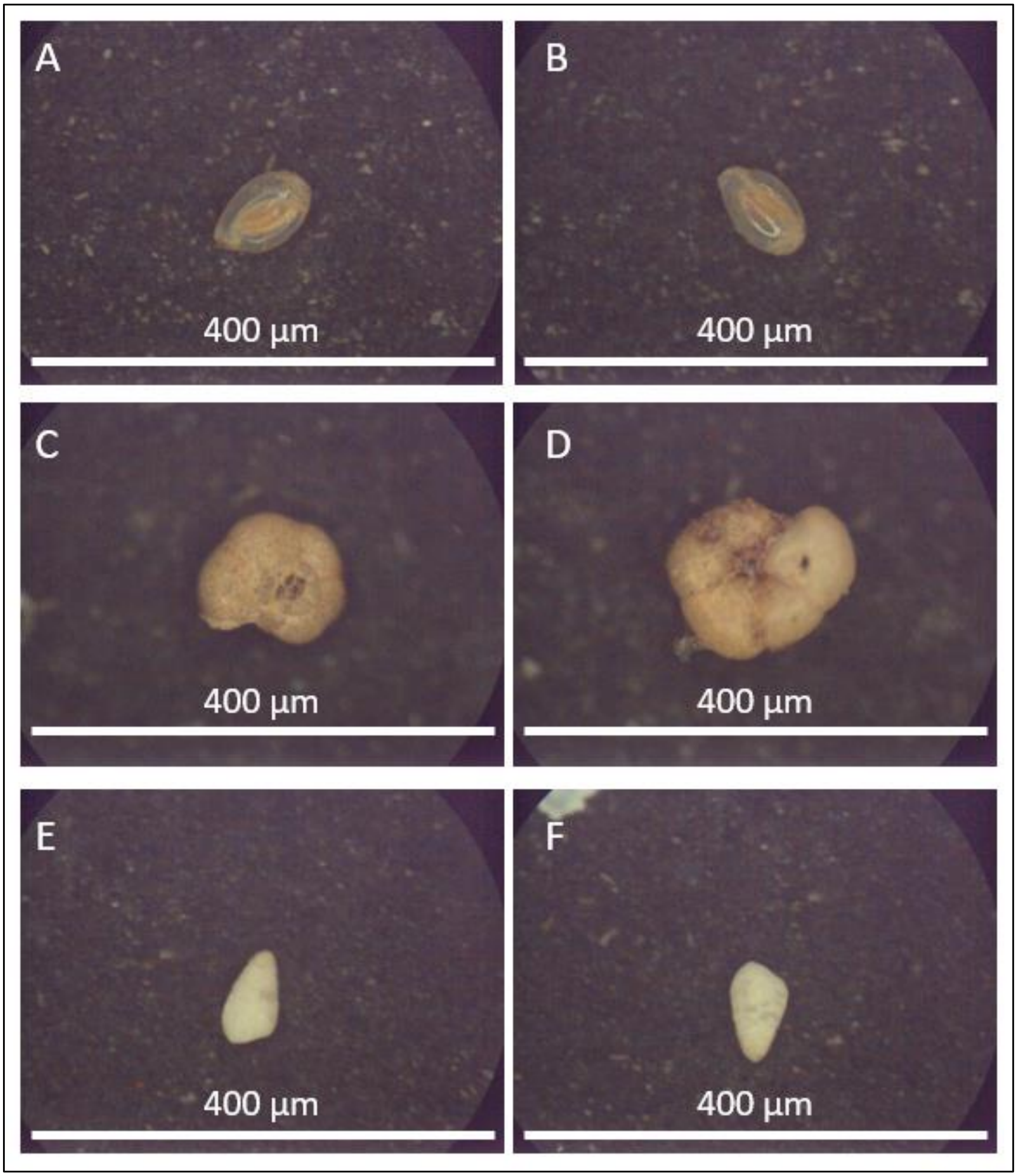


Plate IV



Foraminifera Census

Name	CS_ES_00	CS_ES_01	CS_ES_02	CS_ES_03	CS_ES_04	CS_ES_06	CS_ES_09	CS_ES_11	CS_ES_14
Ti	24	157	319	161	20	271	5	0	113
Ji	10	76	112	72	18	200	0	28	75
Mf	0	0	13	0	1	0	0	106	1
Qsp.	0	0	2	0	117	0	0	172	0
Ap	3	1	27	4	0	0	0	10	0
Pf	1	0	58	15	0	1	0	0	0
Hw	0	23	57	20	23	89	0	0	50
Ee	0	0	0	0	0	72	1	26	0
Bp	0	0	0	0	0	0	0	0	0
Pi	0	0	0	0	0	0	0	0	0
Living	0	5	3	12	43	28	0	61	5
Sed Picked (ml)	4	3.75	4.5	4	1	2.5	3	1	4
Total/5 ml	47.5	342.6667	653.3333	340	895	1266	10	1710	298.75

Name	CS_ES_17	CS_ES_18	CS_ES_19	CS_ES_20	CS_ES_21	CS_ES_22	CS_ES_23	CS_ES_25	CS_BM_01
Ti	9	2	16	6	83	0	186	74	22
Ji	3	11	38	0	125	6	56	86	92
Mf	297	46	157	356	98	82	17	30	271
Qsp.	129	114	34	18	19	141	509	149	9
Ap	26	1	12	16	2	19	0	0	47
Pf	0	0	0	0	0	0	0	0	0
Hw	13	0	31	21	43	5	32	10	0
Ee	0	9	6	11	1	15	95	0	28
Bp	0	0	0	0	0	0	0	0	0
Pi	0	0	0	0	0	0	0	0	0
Living	27	56	12	5	7	33	86	22	0
Sed Picked	1.5	0.5	0.5	0.8	2	0.5	4.5	3.5	2.5
Total/5 ml	1590	1830	2940	2675	927.5	2680	994.4444	498.5714	938

Name	CS_BM_02	CS_BM_03	CS_BM_04	CS_BM_05	CS_BM_06	CS_BM_07	CS_BM_08	CS_BM_09	CS_BM_010
Ti	1	7	4	11	3	61	185	112	186
Ji	0	2	0	2	0	68	154	137	92
Mf	497	387	630	647	451	447	122	190	185
Qsp.	4	2	0	3	0	0	24	12	12
Ap	21	4	3	22	1	6	0	0	0
Pf	0	4	2	16	0	2	0	0	0
Hw	7	5	3	8	0	0	5	100	0
Ee	0	0	0	0	0	0	0	0	0
Bp	0	0	0	0	0	1	14	27	1
Pi	9	0	0	0	0	0	0	0	0
Living	0	0	0	0	0	0	0	0	0
Sed Picked	2.3	3.3	5	4	2	1.5	2	2.5	2.5
Total/5ml	1171.739	622.7273	642	886.25	1137.5	1950	1260	1156	952

Name	CS_BM_011	CS_BM_012	AC1	AC2	AC3	AC4
Ti	70	24	58	12	2	0
Ji	22	3	8	7	0	0
Mf	19	3	307	308	486	327
Qsp.	7	1	0	0	0	3
Ap	0	0	93	80	82	82
Pf	0	0	0	0	0	0
Hw	20	0	0	0	0	0
Ee	19	0	0	0	0	0
Bp	127	33	0	0	0	0
Pi	15	0	61	126	14	14
Living	0	0	0	0	0	0
Sed Picked	3.5	4	3.5	3	3.5	2.5
Total/5ml	427.1429	80	752.8571	888.3333	834.2857	852

Environmental Variables

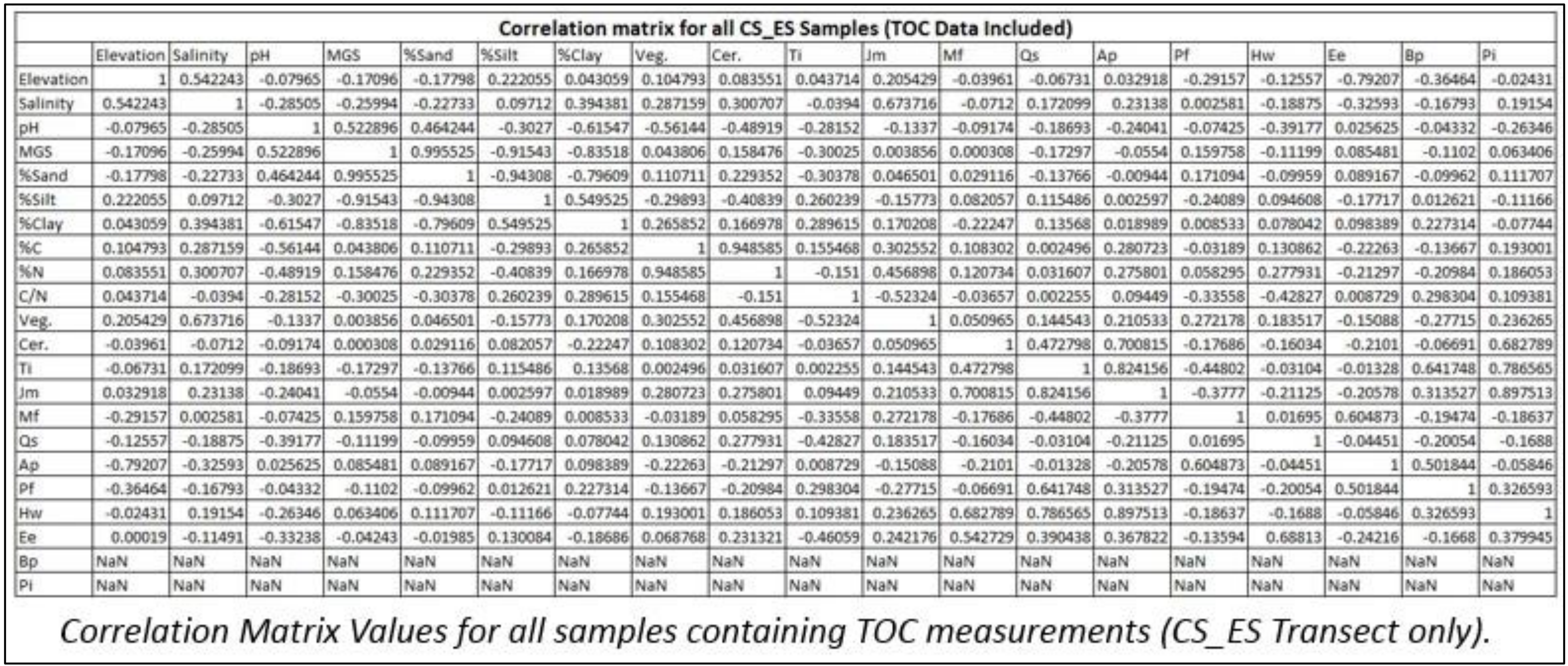
Name	CS_ES_0000	CS_ES_001	CS_ES_002	CS_ES_003	CS_ES_0004	CS_ES_0006	CS_ES_0009	CS_ES_00011	CS_ES_00014
Elevation	0.595	0.708	0.431	0.674	0.68	0.599	0.813	0.637	0.769
Sed Picked	4	3.75	4.5	4	1	2.5	3	1	4
Salinity	36	75	40	53	52	45	40	46	57
pH	7.99	7.43	7.12	6.99	6.81	7.03	7.52	6.9	7.02
Med Gsize (microns)	18.1926	8.571058	9.071214	9.894136	8.671003	14.87426	12.84004	10.28678	10.52618
%Sand	3.137291	0.056992	0.119225	0.22641	0	5.794907	1.092388	0.259811	0.195689
%Silt	82.39559	72.67744	73.44486	75.64491	73.88304	76.74888	79.21003	77.17205	78.3281
%Clay	14.46712	27.26557	26.43592	24.12868	26.11696	17.45621	19.69758	22.56814	21.47621
Weight % C	0.0100	0.0494	0.0354	0.0554	0.0834	0.0543	0.0280	0.0643	0.0304
Weight % N	0.0011	0.0057	0.0032	0.0055	0.0072	0.0056	0.0026	0.0065	0.0027
C/N	9.28	8.72	11.1	10.1	11.6	9.73	10.6	9.83	11.3
Vegetation Cover	0	3	0	0	1	1	0	0	0
Cerithedia	0	0	0	0	0	1	0	0	0

Name	CS_ES_017	CS_ES_018	CS_ES_019	CS_ES_020	CS_ES_021	CS_ES_00022	CS_ES_023	CS_ES_025	CS_BM_01
Elevation	0.403	0.623	0.534	0.7	0.676	0.382	0.656	0.521	0.451
Sed Picked	1.5	0.5	0.5	0.8	2	0.5	4.5	3.5	2.5
Salinity	38	40	40	61	56	40	46	40	50
pH	7.23	7.01	7.71	6.94	6.83	7.02	6.82	7.06	6.68
Med Gsize (microns)	9.071214	8.43013	76.83195	10.07953	8.484921	10.96728	10.88651	30.43577	9.646654
%Sand	0.119225	0.028538	55.63155	0.270676	0.091358	0.24337	1.382694	15.24469	0.023899
%Silt	73.44486	73.0442	37.63257	76.53887	73.45168	77.76795	77.46404	74.2333	76.56023
%Clay	26.43592	26.92727	6.735888	23.19045	26.45696	21.98868	21.15326	10.52201	23.41587
Weight % C	0.0413	0.0509	0.0561	0.0337	0.0757	0.0354	0.0441	NaN	NaN
Weight % N	0.0047	0.0052	0.0064	0.0037	0.0072	0.0032	0.0057	NaN	NaN
C/N	8.83	9.78	8.71	9.14	10.6	11.1	7.70	NaN	NaN
Vegetation Cover	1	0	1	2	2	0	2	0	0
Cerithedia	0	0	0	0	0	0	0	0	2

Name	CS_BM_02	CS_BM_03	CS_BM_04	CS_BM_05	CS_BM_06	CS_BM_07	CS_BM_08	CS_BM_09	CS_BM_010
Elevation	0.366	0.385	0.198	0.484	0.689	0.663	0.638	0.731	0.839
Sed Picked	2.3	3.3	5	4	2	1.5	2	2.5	2.5
Salinity	43	42	43	41	41	45	40	49	80
pH	7.31	6.94	6.79	7.1	6.65	6.12	7.56	7.03	6.87
Med Gsize (microns)	9.326308	9.894136	9.6523	9.164632	10.318	12.25105	21.97244	8.433501	26.73245
%Sand	0.057892	0.22641	0	0.180206	0.287628	0.500839	9.232597	0.247742	23.60392
%Silt	75.27838	75.64491	76.48553	75.18456	76.77748	79.85163	76.50547	75.3383	63.68698
%Clay	24.66372	24.12868	23.51447	24.63523	22.93489	19.64753	14.26193	24.41395	12.7091
Weight % C	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Weight % N	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
C/N	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Vegetation Cover	0	0	0	0	0	0	2	0	2
Cerithedia	3	3	3	3	3	1	0	0	0

Name	CS_BM_012	CS_BM_011	AC1	AC2	AC3	AC4
Elevation	1.078	0.907	0.490461	0.330461	0.222461	0.150461
Sed Picked	4	3.5	3.5	3	3.5	2.5
Salinity	110	100	55	55	55	55
pH	7.01	6.93	7.1	7.1	7.1	7.1
Med Gsize (microns)	34.19896	10.9543	107.3962	6.553836	12.13388	9.678589
%Sand	19.80197	0	65.98204	0.291668	2.004417	0.298515
%Silt	70.82179	80.11671	28.84197	66.96706	79.8646	75.86989
%Clay	9.37624	19.88329	5.175987	32.74127	18.13098	23.8316
Weight % C	NaN	NaN	0.0542	0.0252	0.0366	0.0249
Weight % N	NaN	NaN	0.0043	0.0029	0.0029	0.0023
C/N	NaN	NaN	12.7	8.76	12.6	10.7
Vegetation Cover	3	3	0	0	0	0
Cerithedia	0	0	0	0	0	0

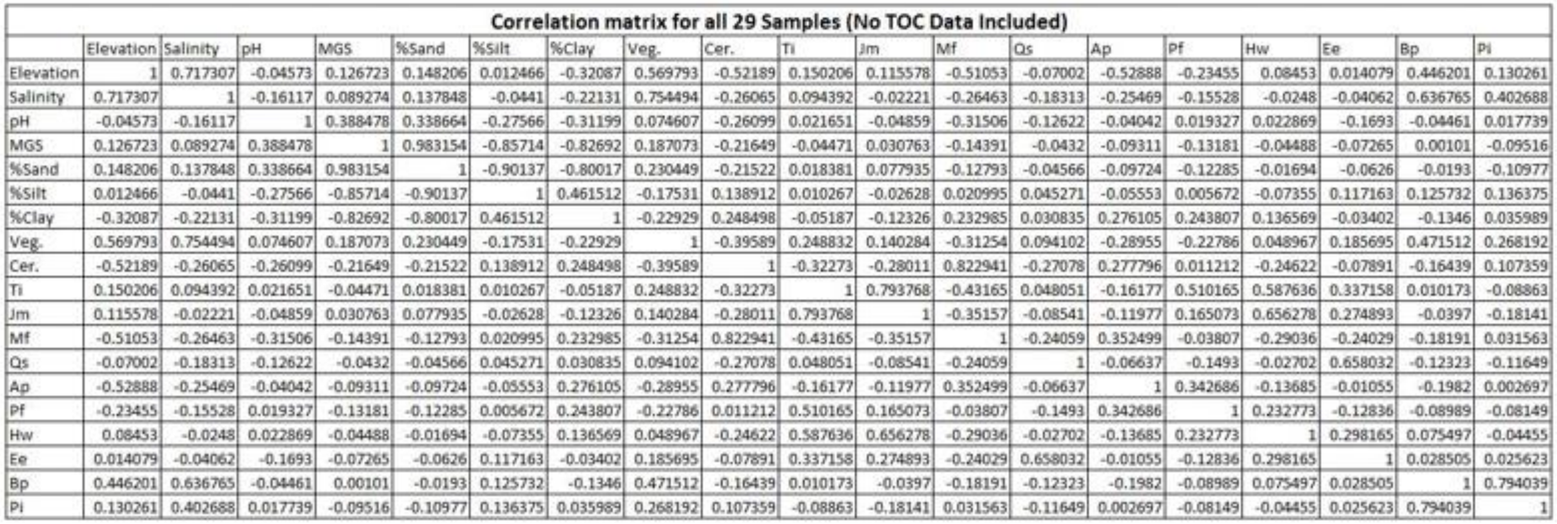
Appendix B
Statistical Results
Correlation Analysis



Correlation matrix for all CS_ES Samples (TOC Data Included)

	Elevation	Salinity	pH	MGS	%Sand	%Silt	%Clay	Veg.	Cer.	Ti	Jm	Mf	Qs	Ap	Pf	Hw	Ee	Bp	Pi
Elevation	1	0.542243	-0.07965	-0.17096	-0.17798	0.222055	0.043059	0.104793	0.083551	0.043714	0.205429	-0.03961	-0.06731	0.032918	-0.29157	-0.12557	-0.79207	-0.36464	-0.02431
Salinity	0.542243	1	-0.28505	-0.25994	-0.22733	0.09712	0.394381	0.287159	0.300707	-0.0394	0.673716	-0.0712	0.172099	0.23138	0.002581	-0.18875	-0.32593	-0.16793	0.19154
pH	-0.07965	-0.28505	1	0.522896	0.464244	-0.3027	-0.61547	-0.56144	-0.48919	-0.28152	-0.1337	-0.09174	-0.18693	-0.24041	-0.07425	-0.39177	0.025625	-0.04332	-0.26346
MGS	-0.17096	-0.25994	0.522896	1	0.995525	-0.91543	-0.83518	0.043806	0.158476	-0.30025	0.003856	0.000308	-0.17297	-0.0554	0.159758	-0.11199	0.085481	-0.1102	0.063406
%Sand	-0.17798	-0.22733	0.464244	0.995525	1	-0.94308	-0.79609	0.110711	0.229352	-0.30378	0.046501	0.029116	-0.13766	-0.00944	0.171094	-0.09959	0.089167	-0.09962	0.111707
%Silt	0.222055	0.09712	-0.3027	-0.91543	-0.94308	1	0.549525	-0.29893	-0.40839	0.260239	-0.15773	0.082057	0.115486	0.002597	-0.24089	0.094608	-0.17717	0.012621	-0.11166
%Clay	0.043059	0.394381	-0.61547	-0.83518	-0.79609	0.549525	1	0.265852	0.166978	0.289615	0.170208	-0.22247	0.13568	0.018989	0.008533	0.078042	0.098389	0.227314	-0.07744
%C	0.104793	0.287159	-0.56144	0.043806	0.110711	-0.29893	0.265852	1	0.948585	0.155468	0.302552	0.108302	0.002496	0.280723	-0.03189	0.130862	-0.22263	-0.13667	0.193001
%N	0.083551	0.300707	-0.48919	0.158476	0.229352	-0.40839	0.166978	0.948585	1	-0.151	0.456898	0.120734	0.031607	0.275801	0.058295	0.277931	-0.21297	-0.20984	0.186053
C/N	0.043714	-0.0394	-0.28152	-0.30025	-0.30378	0.260239	0.289615	0.155468	-0.151	1	-0.52324	-0.03657	0.002255	0.09449	-0.33558	-0.42827	0.008729	0.298304	0.109381
Veg.	0.205429	0.673716	-0.1337	0.003856	0.046501	-0.15773	0.170208	0.302552	0.456898	-0.52324	1	0.050965	0.144543	0.210533	0.272178	0.183517	-0.15088	-0.27715	0.236265
Cer.	-0.03961	-0.0712	-0.09174	0.000308	0.029116	0.082057	-0.22247	0.108302	0.120734	-0.03657	0.050965	1	0.472798	0.700815	-0.17686	-0.16034	-0.2101	-0.06691	0.682789
Ti	-0.06731	0.172099	-0.18693	-0.17297	-0.13766	0.115486	0.13568	0.002496	0.031607	0.002255	0.144543	0.472798	1	0.824156	-0.44802	-0.03104	-0.01328	0.641748	0.786565
Jm	0.032918	0.23138	-0.24041	-0.0554	-0.00944	0.002597	0.018989	0.280723	0.275801	0.09449	0.210533	0.700815	0.824156	1	-0.3777	-0.21125	-0.20578	0.313527	0.897513
Mf	-0.29157	0.002581	-0.07425	0.159758	0.171094	-0.24089	0.008533	-0.03189	0.058295	-0.33558	0.272178	-0.17686	-0.44802	-0.3777	1	0.01695	0.604873	-0.19474	-0.18637
Qs	-0.12557	-0.18875	-0.39177	-0.11199	-0.09959	0.094608	0.078042	0.130862	0.277931	-0.42827	0.183517	-0.16034	-0.03104	-0.21125	0.01695	1	-0.04451	-0.20054	-0.1688
Ap	-0.79207	-0.32593	0.025625	0.085481	0.089167	-0.17717	0.098389	-0.22263	-0.21297	0.008729	-0.15088	-0.2101	-0.01328	-0.20578	0.604873	-0.04451	1	0.501844	-0.05846
Pf	-0.36464	-0.16793	-0.04332	-0.1102	-0.09962	0.012621	0.227314	-0.13667	-0.20984	0.298304	-0.27715	-0.06691	0.641748	0.313527	-0.19474	-0.20054	0.501844	1	0.326593
Hw	-0.02431	0.19154	-0.26346	0.063406	0.111707	-0.11166	-0.07744	0.193001	0.186053	0.109381	0.236265	0.682789	0.786565	0.897513	-0.18637	-0.1688	-0.05846	0.326593	1
Ee	0.00019	-0.11491	-0.33238	-0.04243	-0.01985	0.130084	-0.18686	0.068768	0.231321	-0.46059	0.242176	0.542729	0.390438	0.367822	-0.13594	0.68813	-0.24216	-0.1668	0.379945
Bp	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Pi	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Correlation Matrix Values for all samples containing TOC measurements (CS_ES Transect only).

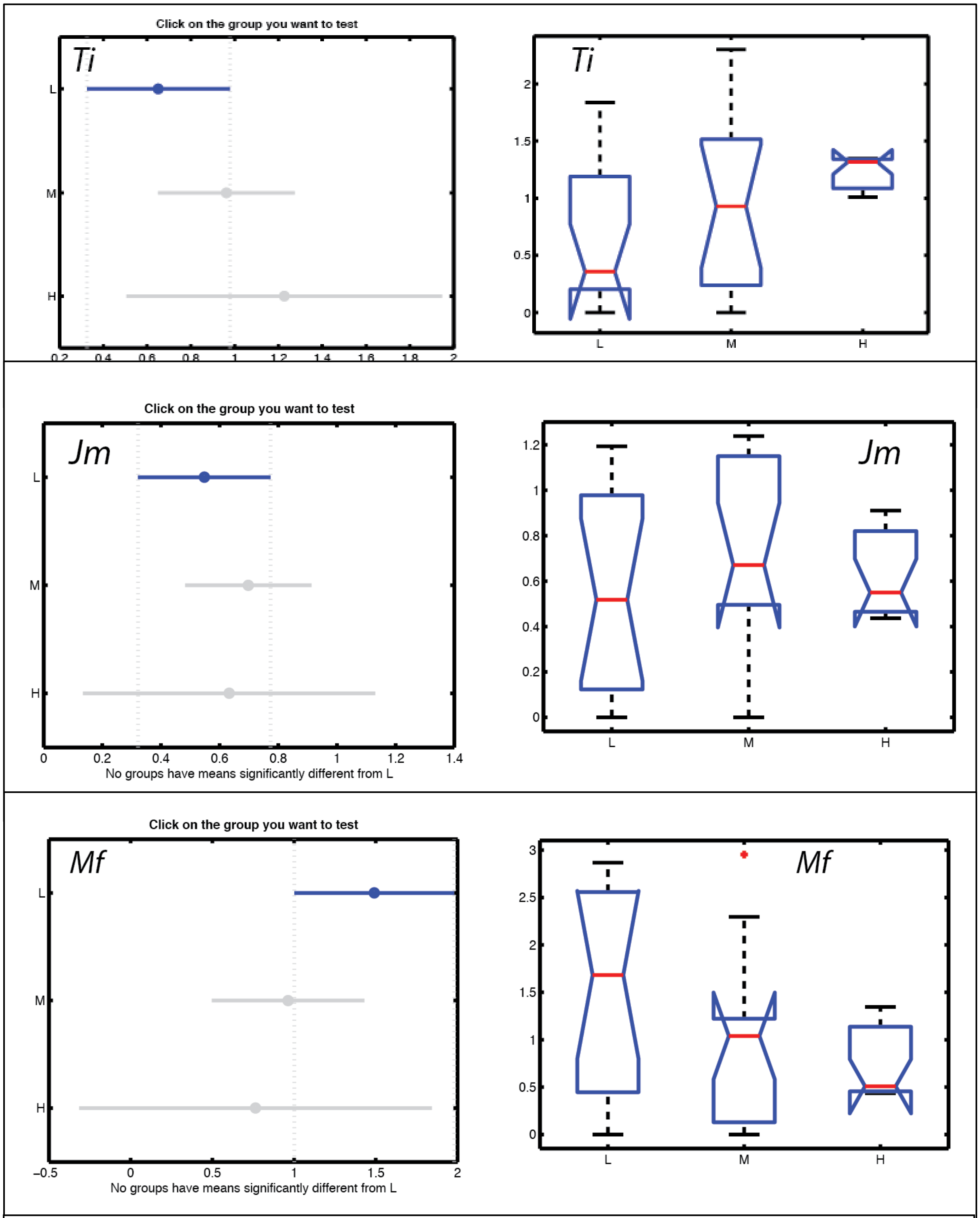


Correlation matrix for all 29 Samples (No TOC Data Included)

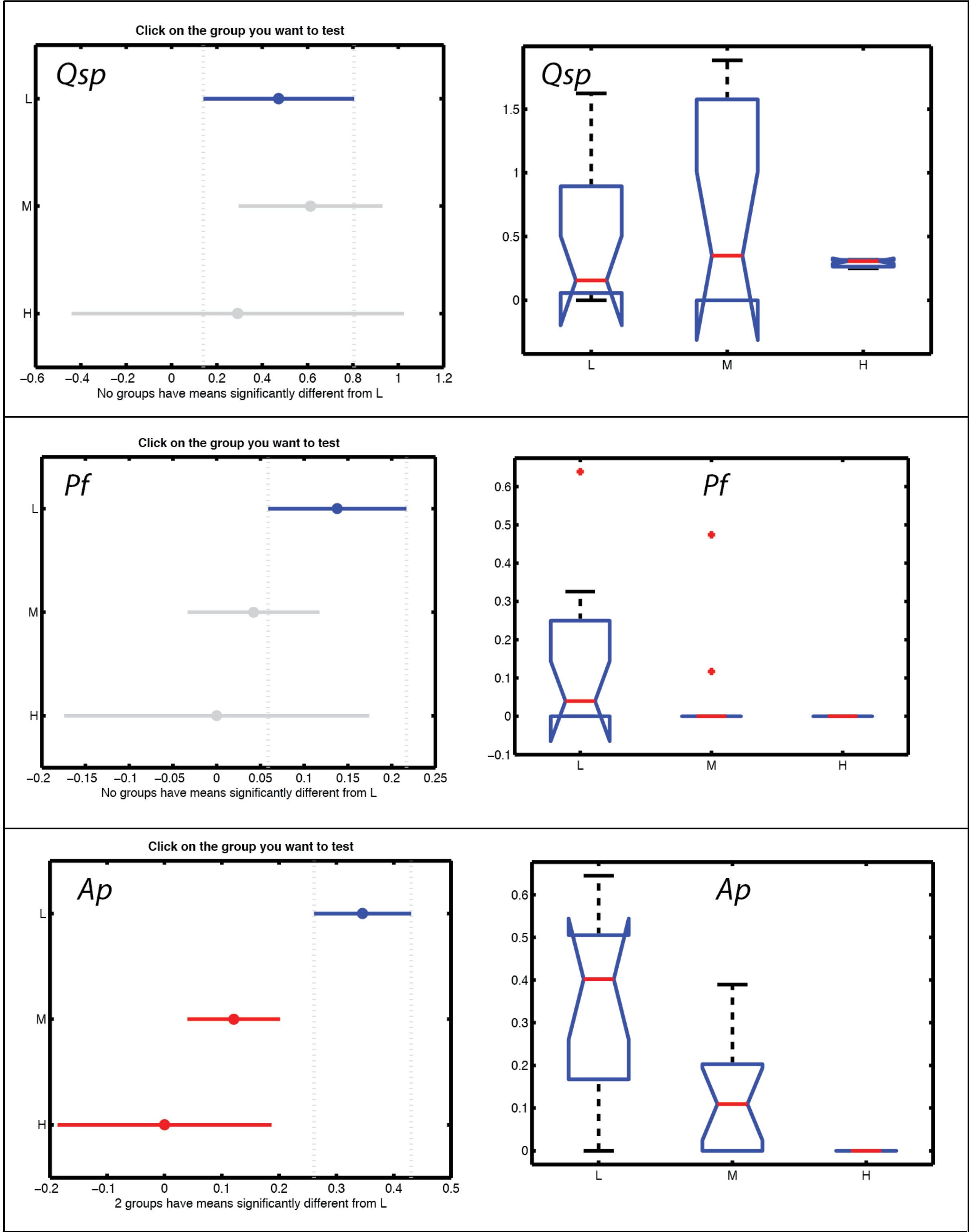
	Elevation	Salinity	pH	MGS	%Sand	%Silt	%Clay	Veg.	Cer.	Ti	Jm	Mf	Qs	Ap	Pf	Hw	Ee	Bp	Pi
Elevation	1	0.717307	-0.04573	0.126723	0.148206	0.012466	-0.32087	0.569793	-0.52189	0.150206	0.115578	-0.51053	-0.07002	-0.52888	-0.23455	0.08453	0.014079	0.446201	0.130261
Salinity	0.717307	1	-0.16117	0.089274	0.137848	-0.0441	-0.22131	0.754494	-0.26065	0.094392	-0.02221	-0.26463	-0.18313	-0.25469	-0.15528	-0.0248	-0.04062	0.636765	0.402688
pH	-0.04573	-0.16117	1	0.388478	0.338664	-0.27566	-0.31199	0.074607	-0.26099	0.021651	-0.04859	-0.31506	-0.12622	-0.04042	0.019327	0.022869	-0.1693	-0.04461	0.017739
MGS	0.126723	0.089274	0.388478	1	0.983154	-0.85714	-0.82692	0.187073	-0.21649	-0.04471	0.030763	-0.14391	-0.0432	-0.09311	-0.13181	-0.04488	-0.07265	0.00101	-0.09516
%Sand	0.148206	0.137848	0.338664	0.983154	1	-0.90137	-0.80017	0.230449	-0.21522	0.018381	0.077935	-0.12793	-0.04566	-0.09724	-0.12285	-0.01694	-0.0626	-0.0193	-0.10977
%Silt	0.012466	-0.0441	-0.27566	-0.85714	-0.90137	1	0.461512	-0.17531	0.138912	0.010267	-0.02628	0.020995	0.045271	-0.05553	0.005672	-0.07355	0.117163	0.125732	0.136375
%Clay	-0.32087	-0.22131	-0.31199	-0.82692	-0.80017	0.461512	1	-0.22929	0.248498	-0.05187	-0.12326	0.232985	0.030835	0.276105	0.243807	0.136569	-0.03402	-0.1346	0.035989
Veg.	0.569793	0.754494	0.074607	0.187073	0.230449	-0.17531	-0.22929	1	-0.39589	0.248832	0.140284	-0.31254	0.094102	-0.28955	-0.22786	0.048967	0.185695	0.471512	0.268192
Cer.	-0.52189	-0.26065	-0.26099	-0.21649	-0.21522	0.138912	0.248498	-0.39589	1	-0.32273	-0.28011	0.822941	-0.27078	0.277796	0.011212	-0.24622	-0.07891	-0.16439	0.107359
Ti	0.150206	0.094392	0.021651	-0.04471	0.018381	0.010267	-0.05187	0.248832	-0.32273	1	0.793768	-0.43165	0.048051	-0.16177	0.510165	0.587636	0.337158	0.010173	-0.08863
Jm	0.115578	-0.02221	-0.04859	0.030763	0.077935	-0.02628	-0.12326	0.140284	-0.28011	0.793768	1	-0.35157	-0.08541	-0.11977	0.165073	0.656278	0.274893	-0.0397	-0.18141
Mf	-0.51053	-0.26463	-0.31506	-0.14391	-0.12793	0.020995	0.232985	-0.31254	0.822941	-0.43165	-0.35157	1	-0.24059	0.352499	-0.03807	-0.29036	-0.24029	-0.18191	0.031563
Qs	-0.07002	-0.18313	-0.12622	-0.0432	-0.04566	0.045271	0.030835	0.094102	-0.27078	0.048051	-0.08541	-0.24059	1	-0.06637	-0.1493	-0.02702	0.658032	-0.12323	-0.11649
Ap	-0.52888	-0.25469	-0.04042	-0.09311	-0.09724	-0.05553	0.276105	-0.28955	0.277796	-0.16177	-0.11977	0.352499	-0.06637	1	0.342686	-0.13685	-0.01055	-0.1982	0.002697
Pf	-0.23455	-0.15528	0.019327	-0.13181	-0.12285	0.005672	0.243807	-0.22786	0.011212	0.510165	0.165073	-0.03807	-0.1493	0.342686	1	0.232773	-0.12836	-0.08989	-0.08149
Hw	0.08453	-0.0248	0.022869	-0.04488	-0.01694	-0.07355	0.136569	0.048967	-0.24622	0.587636	0.656278	-0.29036	-0.02702	-0.13685	0.232773	1	0.298165	0.075497	-0.04455
Ee	0.014079	-0.04062	-0.1693	-0.07265	-0.0626	0.117163	-0.03402	0.185695	-0.07891	0.337158	0.274893	-0.24029	0.658032	-0.01055	-0.12836	0.298165	1	0.028505	0.025623
Bp	0.446201	0.636765	-0.04461	0.00101	-0.0193	0.125732	-0.1346	0.471512	-0.16439	0.010173	-0.0397	-0.18191	-0.12323	-0.1982	-0.08989	0.075497	0.028505	1	0.794039
Pi	0.130261	0.402688	0.017739	-0.09516	-0.10977	0.136375	0.035989	0.268192	0.107359	-0.08863	-0.18141	0.031563	-0.11649	0.002697	-0.08149	-0.04455	0.025623	0.794039	1

Correlation Matrix Values for all 29 samples, not including the TOC measurements from CS_ES samples. This matrix corresponds to Figure 9.

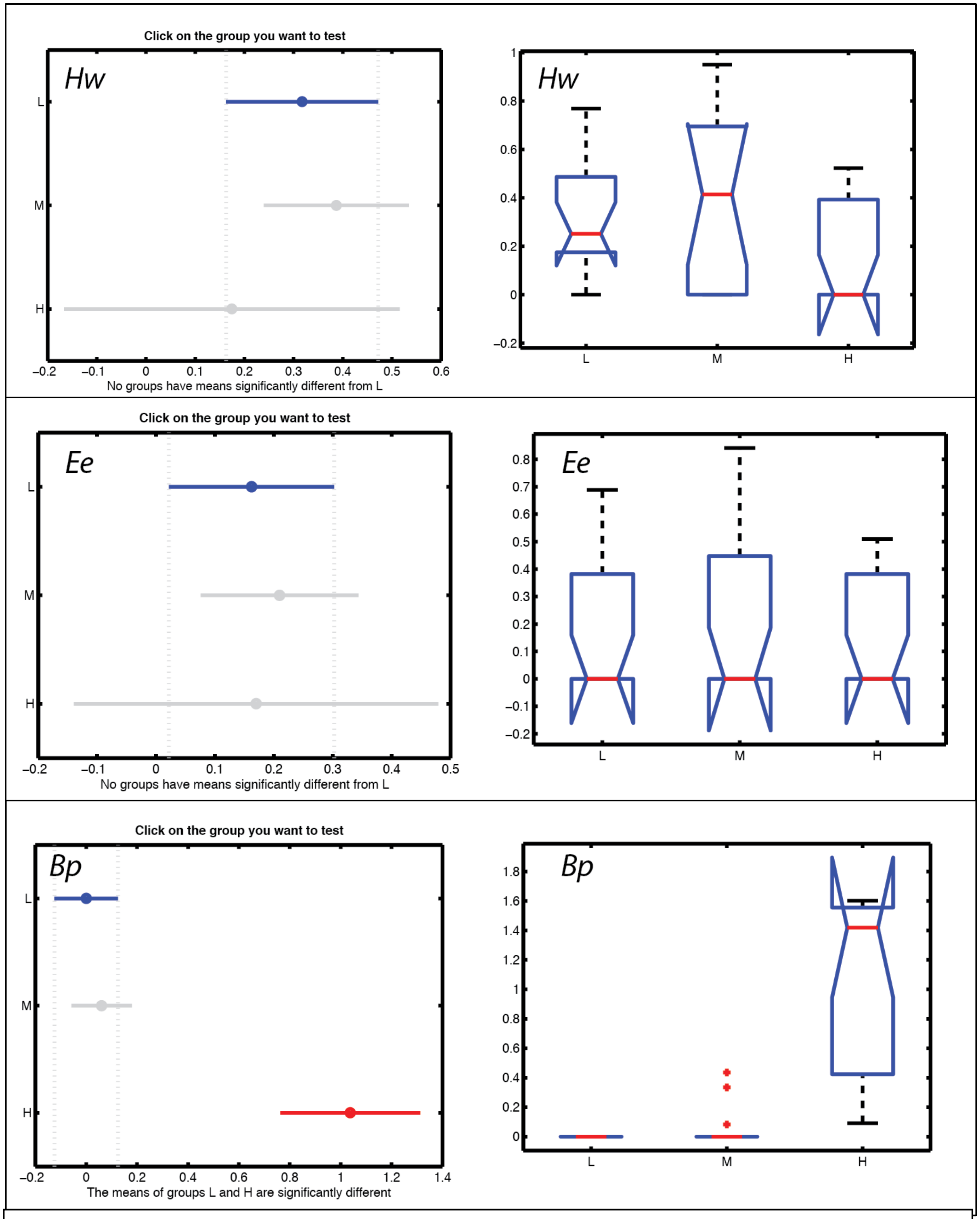
Tide Based ANOVA's



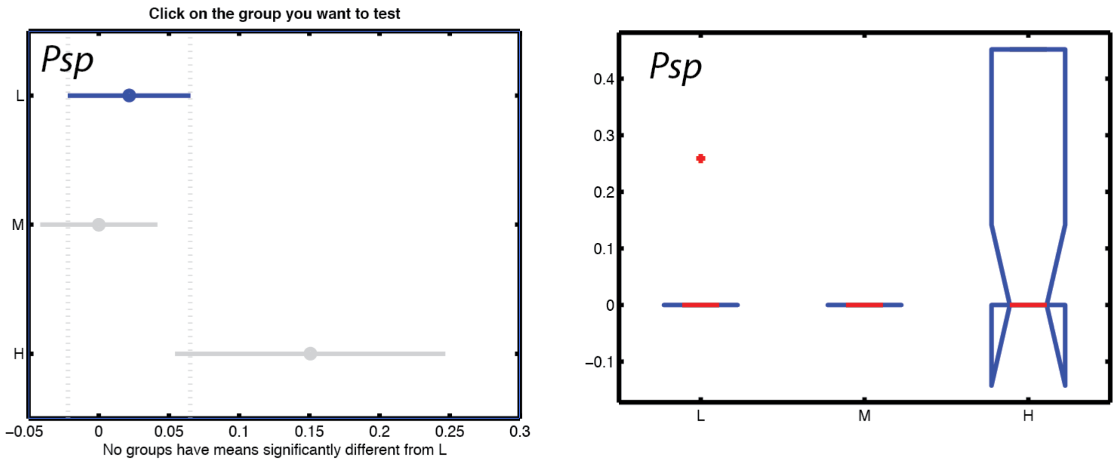
Results from tide-based ANOVA's. The left column displays the overlap between mean abundances within different tidal groupings ('L' Low Marsh; 'M' Middle Marsh; 'H' High Marsh). The right column displays the mean abundances of the species.



Results from tide-based ANOVA's. The left column displays the overlap between mean abundances within different tidal groupings ('L' Low Marsh; 'M' Middle Marsh; 'H' High Marsh). The right column displays the mean abundances of the species.



Results from tide-based ANOVA's. The left column displays the overlap between mean abundances within different tidal groupings ('L' Low Marsh; 'M' Middle Marsh; 'H' High Marsh). The right column displays the mean abundances of the species.

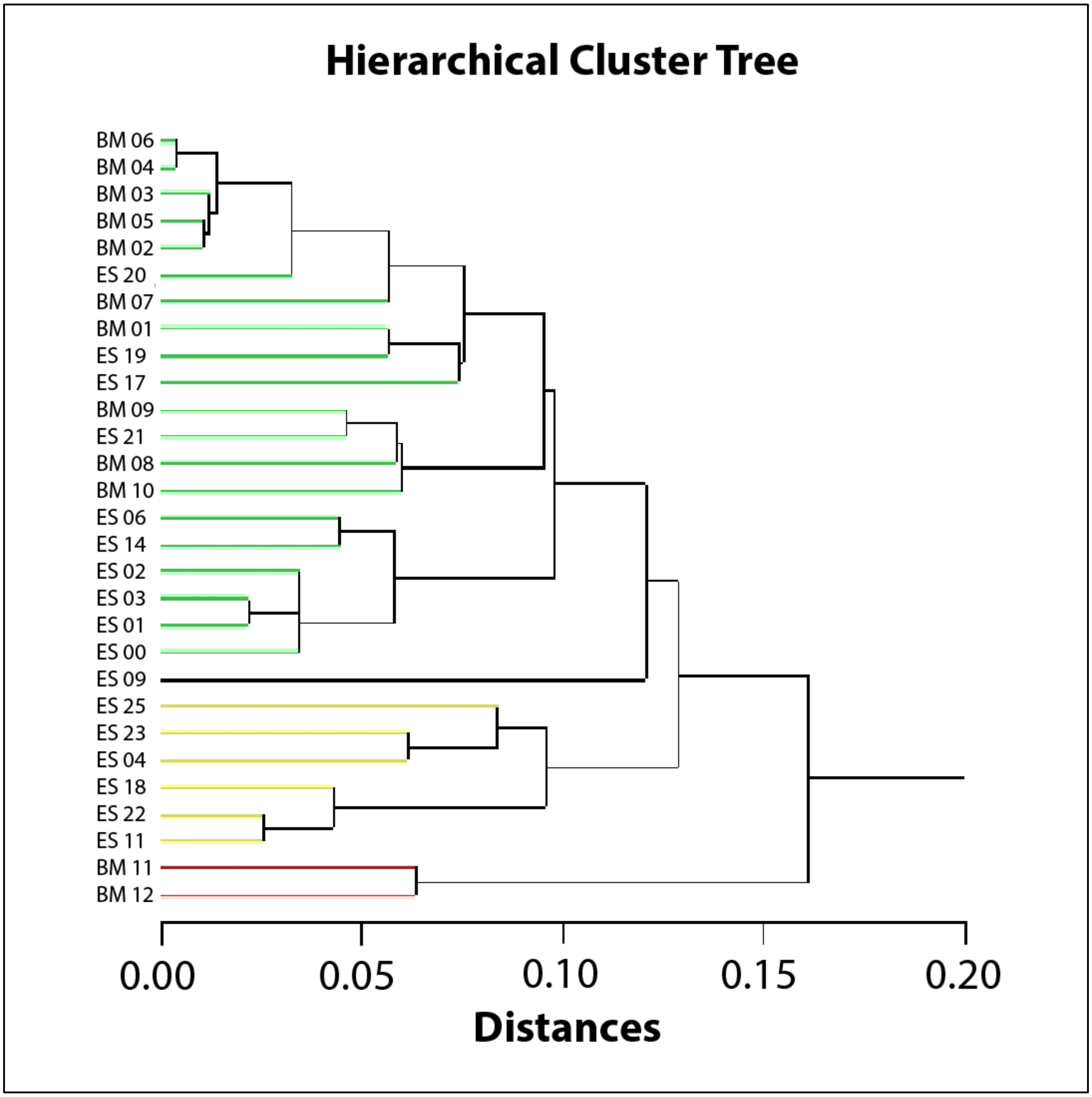


Results from tide-based ANOVA's. The left column displays the overlap between mean abundances within different tidal groupings ('L' Low Marsh; 'M' Middle Marsh; 'H' High Marsh). The right column displays the mean abundances of the species.

Cluster Analysis

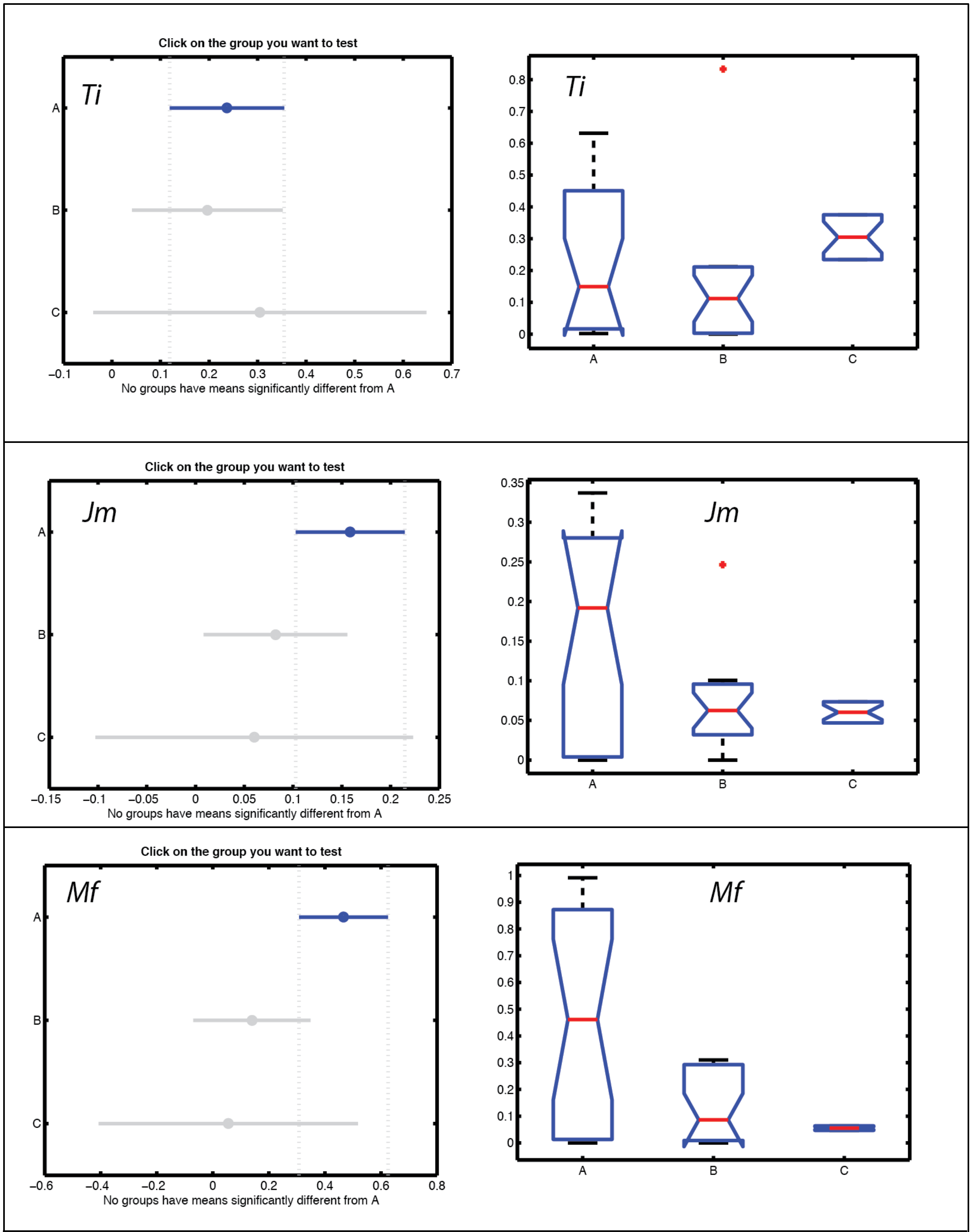
Clusters Joining		at Distance	No. of Members	Case ID Reference	Sample ID Reference
Case 2	Case 1	0.004	2	15	CS_BM_06
Case 5	Case 4	0.011	2	1	CS_BM_04
Case 5	Case 3	0.012	3	3	CS_BM_03
Case 2	Case 5	0.014	5	7	CS_BM_05
Case 19	Case 18	0.022	2	2	CS_BM_02
Case 27	Case 26	0.026	2	16	CS_ES_20
Case 2	Case 6	0.033	6	12	CS_BM_07
Case 19	Case 17	0.034	3	6	CS_BM_01
Case 19	Case 20	0.035	4	8	CS_ES_019
Case 27	Case 25	0.043	3	4	CS_ES_017
Case 16	Case 15	0.044	2	18	CS_BM_09
Case 12	Case 11	0.046	2	14	CS_ES_021
Case 2	Case 7	0.056	7	11	CS_BM_08
Case 9	Case 8	0.057	2	20	CS_BM_010
Case 16	Case 19	0.058	6	15	CS_ES_06
Case 12	Case 13	0.058	3	19	CS_ES_014
Case 12	Case 14	0.06	4	5	CS_ES_002
Case 24	Case 23	0.062	2	13	CS_ES_003
Case 29	Case 28	0.063	2	17	CS_ES_001
Case 9	Case 10	0.074	3	9	CS_ES_0000
Case 2	Case 9	0.075	10	27	CS_ES_0009
Case 24	Case 22	0.083	3	22	CS_ES_025
Case 2	Case 12	0.095	14	25	CS_ES_00023
Case 24	Case 27	0.096	6	26	CS_ES_0004
Case 2	Case 16	0.098	20	23	CS_ES_00018
Case 2	Case 21	0.12	21	21	CS_ES_00022
Case 2	Case 24	0.128	27	24	CS_ES_00011
Case 2	Case 29	0.161	29	28	CS_BM_012
				29	CS_BM_011

Table of inputs for the Hierarchical Cluster based dendogram. The left two columns display samples that are joined by cluster analysis. The 3rd column displays the Euclidean distances between the samples from columns 1 and 2. The 4th column displays the number of samples in each grouping. The 5th and 6th columns are a reference for which sample corresponds to which Case ID.

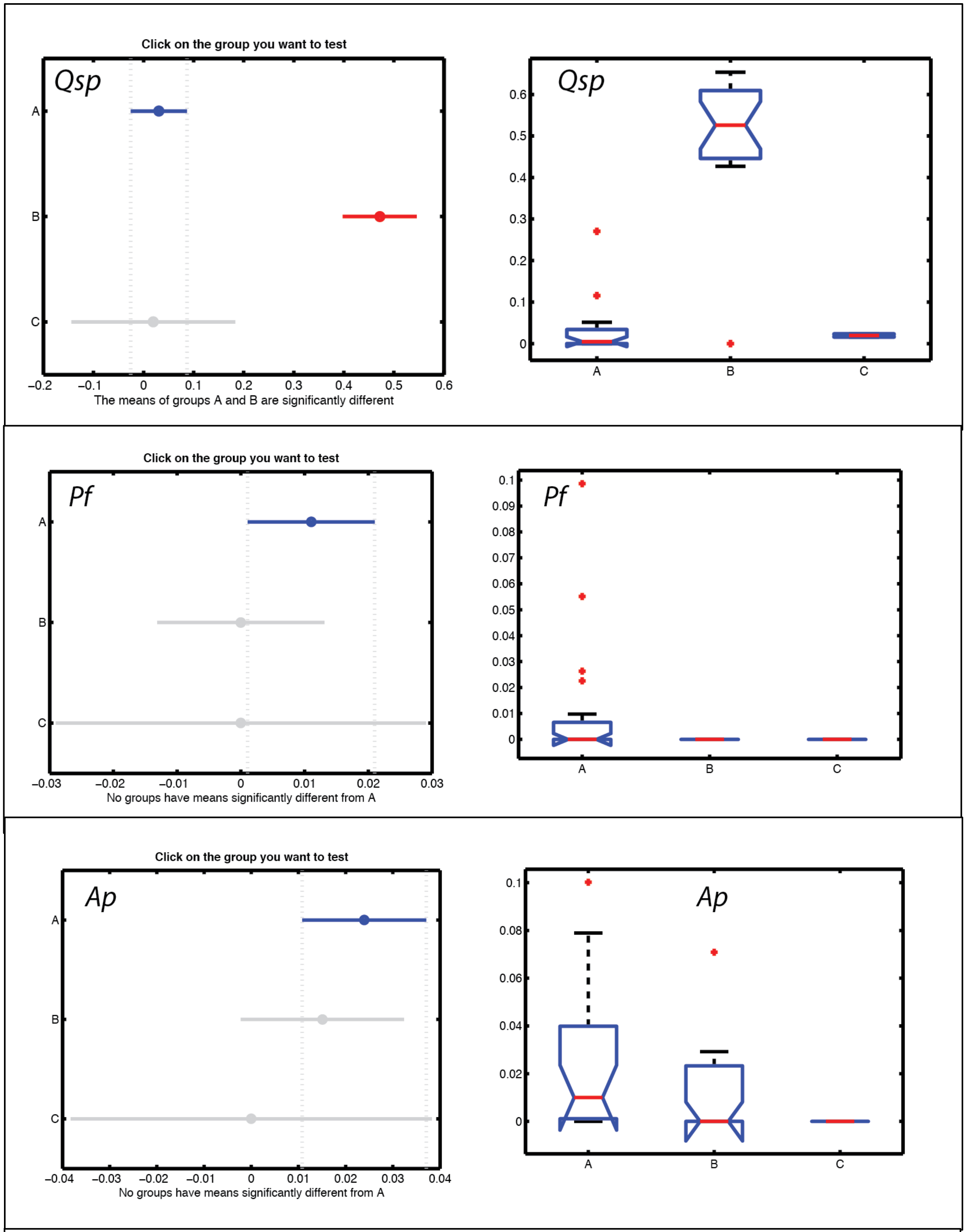


Resultant dendogram separating Carpinteria Slough samples into distinct groups. Green lines represent Zone 1, Yellow lines represent Zone 2, Red lines represent Zone 3

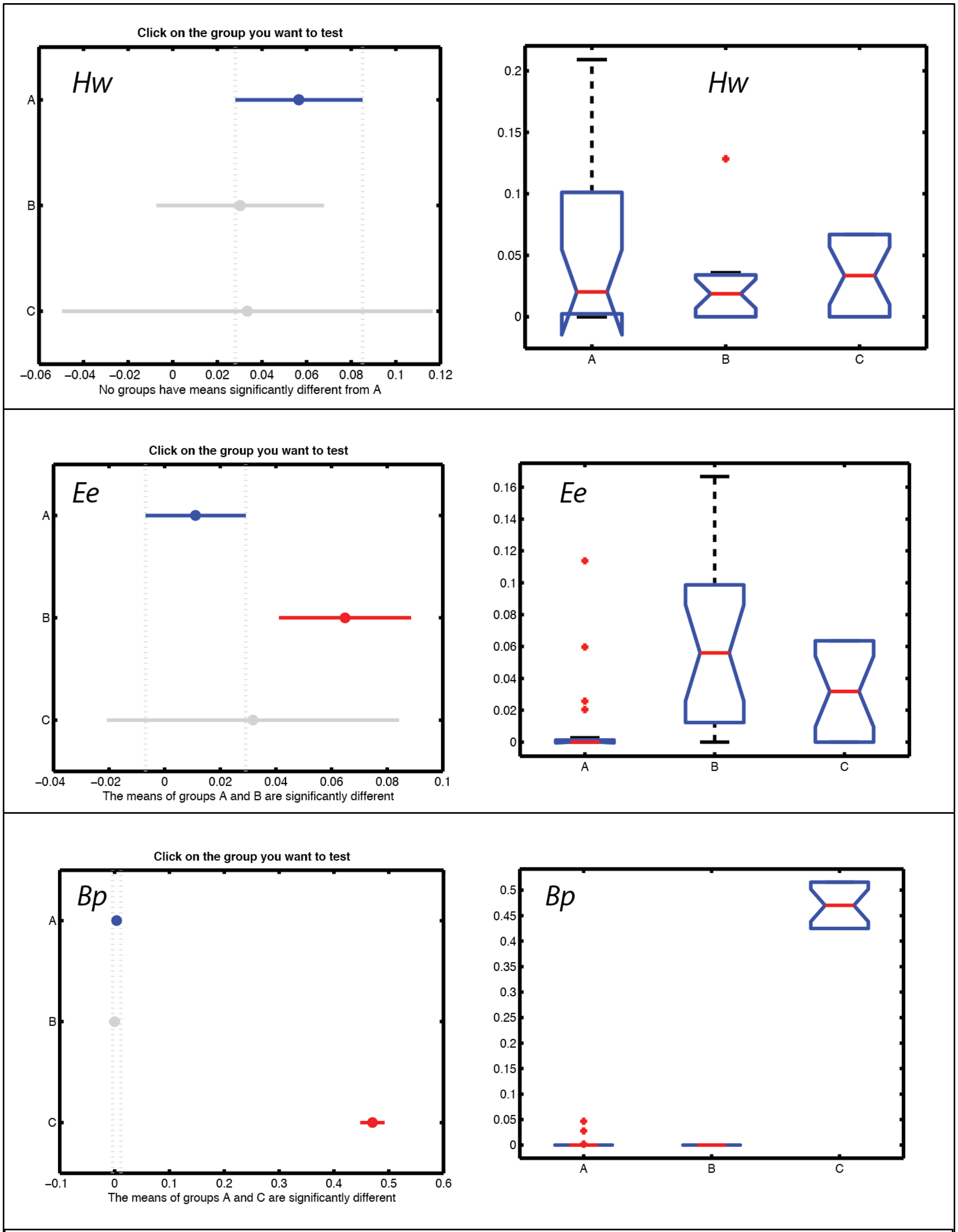
Cluster Based Anovas



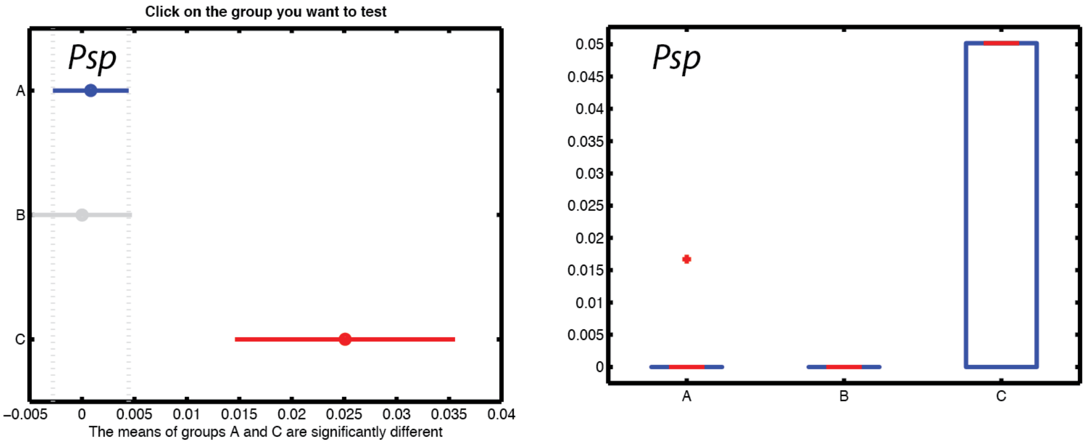
Results from cluster-based ANOVA's. The left column displays the overlap between mean abundances within different cluster zones ('A' Zone 1; 'B' Zone 2; 'C' Zone 3). The right column displays the mean abundances of the species.



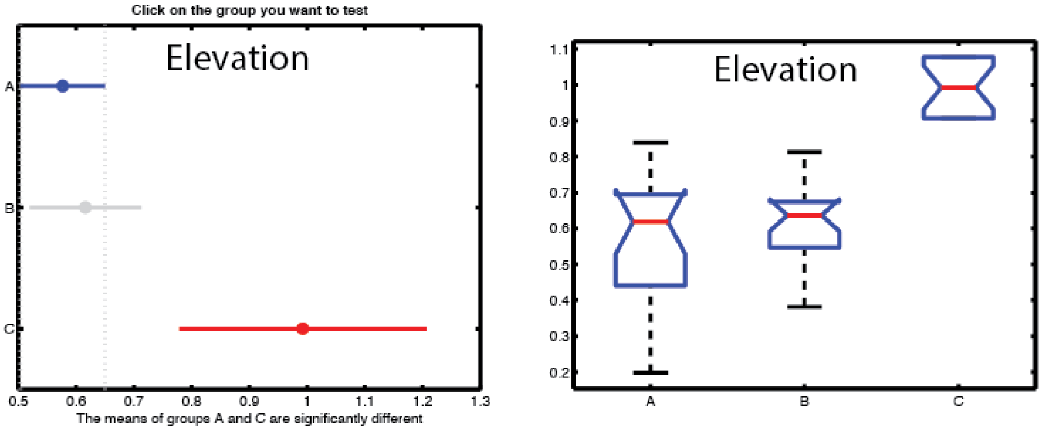
Results from cluster-based ANOVA's. The left column displays the overlap between mean abundances within different cluster zones ('A' Zone 1; 'B' Zone 2; 'C' Zone 3). The right column displays the mean abundances of the species.



Results from cluster-based ANOVA's. The left column displays the overlap between mean abundances within different cluster zones ('A' Zone 1; 'B' Zone 2; 'C' Zone 3). The right column displays the mean abundances of the species.



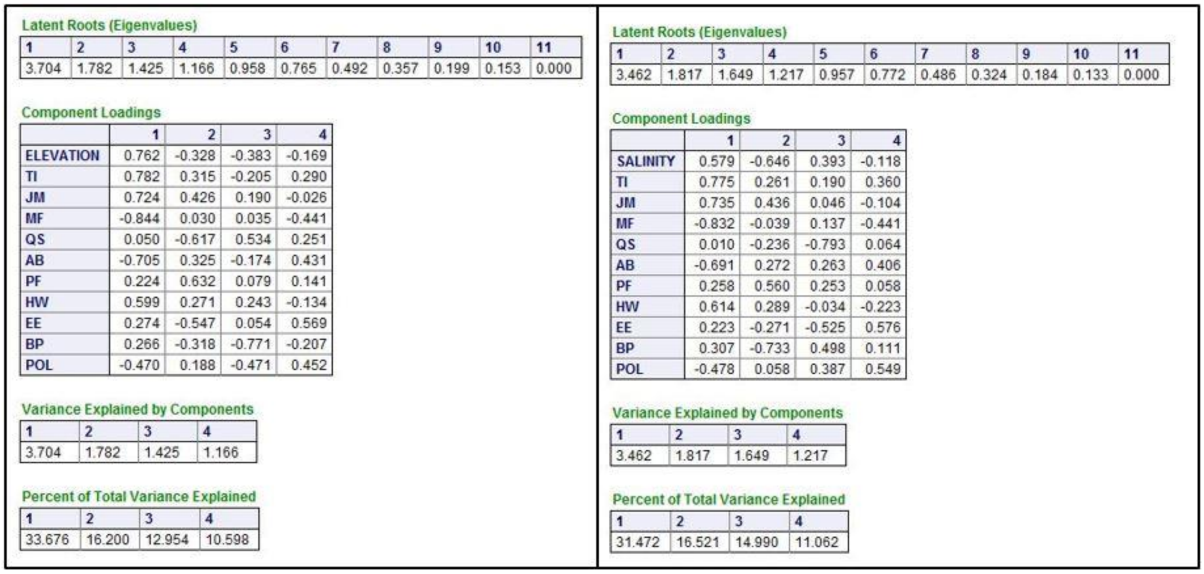
Results from cluster-based ANOVA's. The left column displays the overlap between mean abundances within different cluster zones ('A' Zone 1; 'B' Zone 2; 'C' Zone 3). The right column displays the mean abundances of the species.



Results from cluster-based ANOVA on elevation. The left column displays the overlap between mean elevations within different cluster zones ('A' Zone 1; 'B' Zone 2; 'C' Zone 3). The right column displays the mean elevations and standard deviations for each cluster zone..

PCA

Panel 1



Latent Roots (Eigenvalues)

1	2	3	4	5	6	7	8	9	10	11
3.704	1.782	1.425	1.166	0.958	0.765	0.492	0.357	0.199	0.153	0.000

Component Loadings

	1	2	3	4
ELEVATION	0.762	-0.328	-0.383	-0.169
TI	0.782	0.315	-0.205	0.290
JM	0.724	0.426	0.190	-0.026
MF	-0.844	0.030	0.035	-0.441
QS	0.050	-0.617	0.534	0.251
AB	-0.705	0.325	-0.174	0.431
PF	0.224	0.632	0.079	0.141
HW	0.599	0.271	0.243	-0.134
EE	0.274	-0.547	0.054	0.569
BP	0.266	-0.318	-0.771	-0.207
POL	-0.470	0.188	-0.471	0.452

Variance Explained by Components

1	2	3	4
3.704	1.782	1.425	1.166

Percent of Total Variance Explained

1	2	3	4
33.676	16.200	12.954	10.598

Latent Roots (Eigenvalues)

1	2	3	4	5	6	7	8	9	10	11
3.462	1.817	1.649	1.217	0.957	0.772	0.486	0.324	0.184	0.133	0.000

Component Loadings

	1	2	3	4
SALINITY	0.579	-0.646	0.393	-0.118
TI	0.775	0.261	0.190	0.360
JM	0.735	0.436	0.046	-0.104
MF	-0.832	-0.039	0.137	-0.441
QS	0.010	-0.236	-0.793	0.064
AB	-0.691	0.272	0.263	0.406
PF	0.258	0.560	0.253	0.058
HW	0.614	0.289	-0.034	-0.223
EE	0.223	-0.271	-0.525	0.576
BP	0.307	-0.733	0.498	0.111
POL	-0.478	0.058	0.387	0.549

Variance Explained by Components

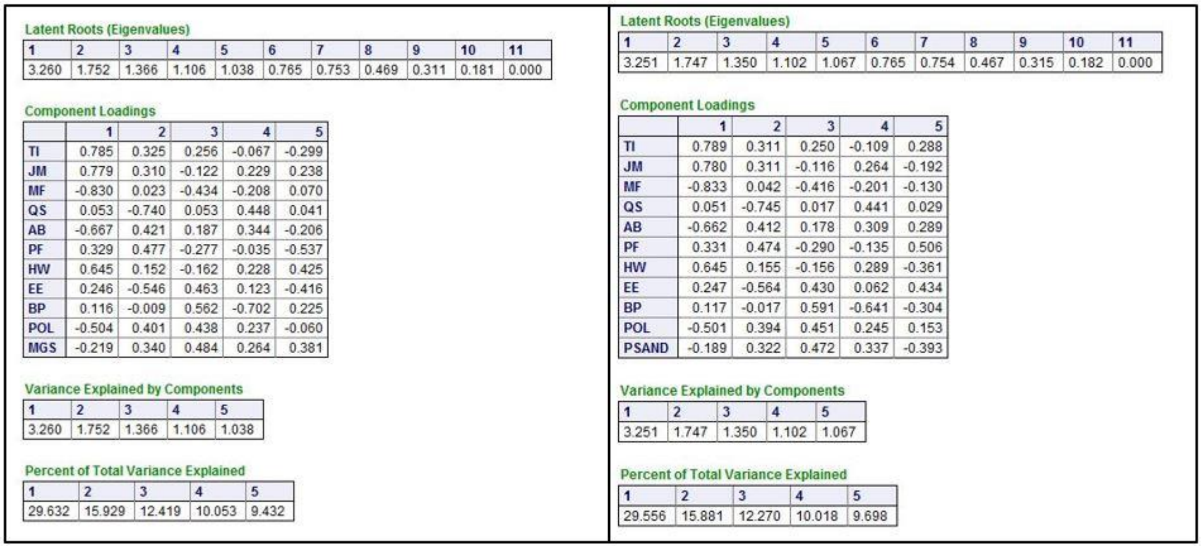
1	2	3	4
3.462	1.817	1.649	1.217

Percent of Total Variance Explained

1	2	3	4
31.472	16.521	14.990	11.062

PCA Outputs from SYSTAT: Left Panel – Elevation and all taxonomic data; Right Panel – Salinity and all taxonomic data

Panel 2



Latent Roots (Eigenvalues)

1	2	3	4	5	6	7	8	9	10	11
3.260	1.752	1.366	1.106	1.038	0.765	0.753	0.469	0.311	0.181	0.000

Component Loadings

	1	2	3	4	5
TI	0.785	0.325	0.256	-0.067	-0.299
JM	0.779	0.310	-0.122	0.229	0.238
MF	-0.830	0.023	-0.434	-0.208	0.070
QS	0.053	-0.740	0.053	0.448	0.041
AB	-0.667	0.421	0.187	0.344	-0.206
PF	0.329	0.477	-0.277	-0.035	-0.537
HW	0.645	0.152	-0.162	0.228	0.425
EE	0.246	-0.546	0.463	0.123	-0.416
BP	0.116	-0.009	0.562	-0.702	0.225
POL	-0.504	0.401	0.438	0.237	-0.060
MGS	-0.219	0.340	0.484	0.264	0.381

Variance Explained by Components

1	2	3	4	5
3.260	1.752	1.366	1.106	1.038

Percent of Total Variance Explained

1	2	3	4	5
29.632	15.929	12.419	10.053	9.432

Latent Roots (Eigenvalues)

1	2	3	4	5	6	7	8	9	10	11
3.251	1.747	1.350	1.102	1.067	0.765	0.754	0.467	0.315	0.182	0.000

Component Loadings

	1	2	3	4	5
TI	0.789	0.311	0.250	-0.109	0.288
JM	0.780	0.311	-0.116	0.264	-0.192
MF	-0.833	0.042	-0.416	-0.201	-0.130
QS	0.051	-0.745	0.017	0.441	0.029
AB	-0.662	0.412	0.178	0.309	0.289
PF	0.331	0.474	-0.290	-0.135	0.506
HW	0.645	0.155	-0.156	0.289	-0.361
EE	0.247	-0.564	0.430	0.062	0.434
BP	0.117	-0.017	0.591	-0.641	-0.304
POL	-0.501	0.394	0.451	0.245	0.153
PSAND	-0.189	0.322	0.472	0.337	-0.393

Variance Explained by Components

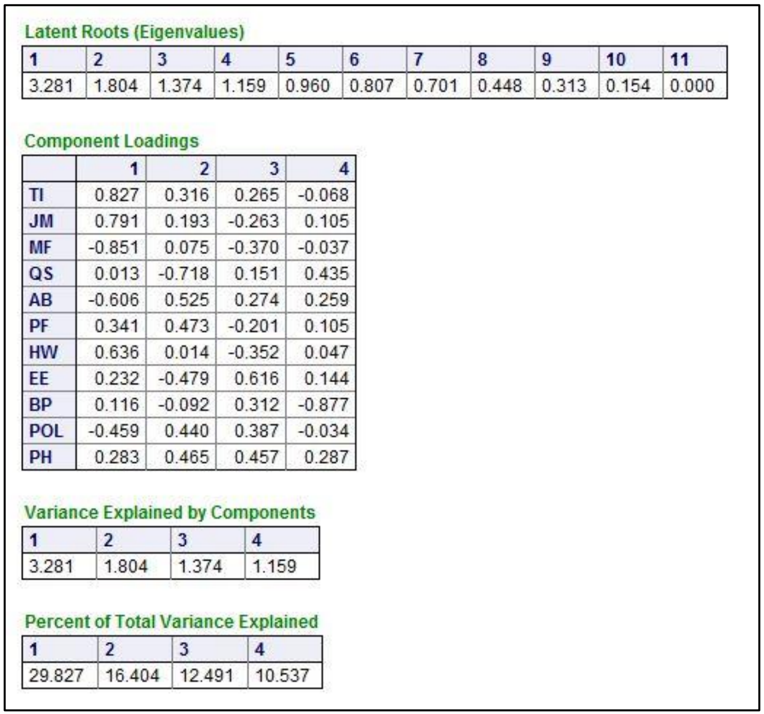
1	2	3	4	5
3.251	1.747	1.350	1.102	1.067

Percent of Total Variance Explained

1	2	3	4	5
29.556	15.881	12.270	10.018	9.698

PCA Outputs from SYSTAT: Left Panel – Median Grain size and all taxonomic data; Right Panel – % Sand and all taxonomic data

Panel 3



Latent Roots (Eigenvalues)

1	2	3	4	5	6	7	8	9	10	11
3.281	1.804	1.374	1.159	0.960	0.807	0.701	0.448	0.313	0.154	0.000

Component Loadings

	1	2	3	4
TI	0.827	0.316	0.265	-0.068
JM	0.791	0.193	-0.263	0.105
MF	-0.851	0.075	-0.370	-0.037
QS	0.013	-0.718	0.151	0.435
AB	-0.606	0.525	0.274	0.259
PF	0.341	0.473	-0.201	0.105
HW	0.636	0.014	-0.352	0.047
EE	0.232	-0.479	0.616	0.144
BP	0.116	-0.092	0.312	-0.877
POL	-0.459	0.440	0.387	-0.034
PH	0.283	0.465	0.457	0.287

Variance Explained by Components

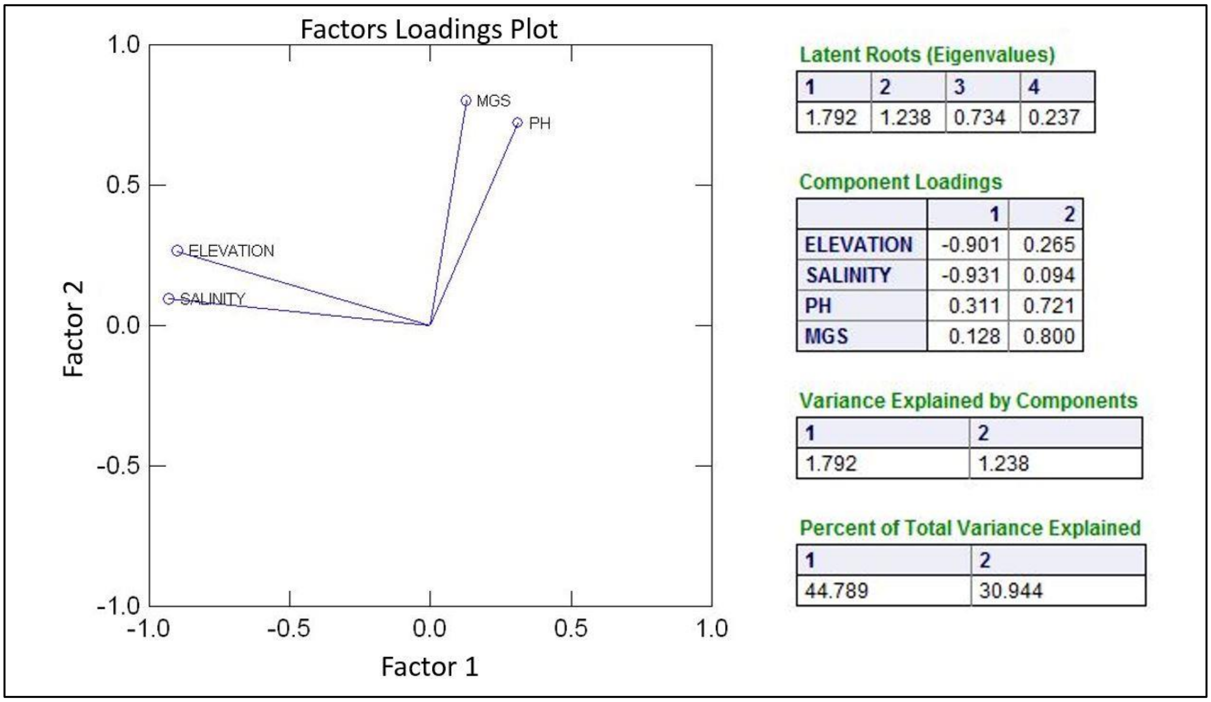
1	2	3	4
3.281	1.804	1.374	1.159

Percent of Total Variance Explained

1	2	3	4
29.827	16.404	12.491	10.537

PCA Outputs from SYSTAT: pH and all taxonomic data

Panel 4



Latent Roots (Eigenvalues)

1	2	3	4
1.792	1.238	0.734	0.237

Component Loadings

	1	2
ELEVATION	-0.901	0.265
SALINITY	-0.931	0.094
PH	0.311	0.721
MGS	0.128	0.800

Variance Explained by Components

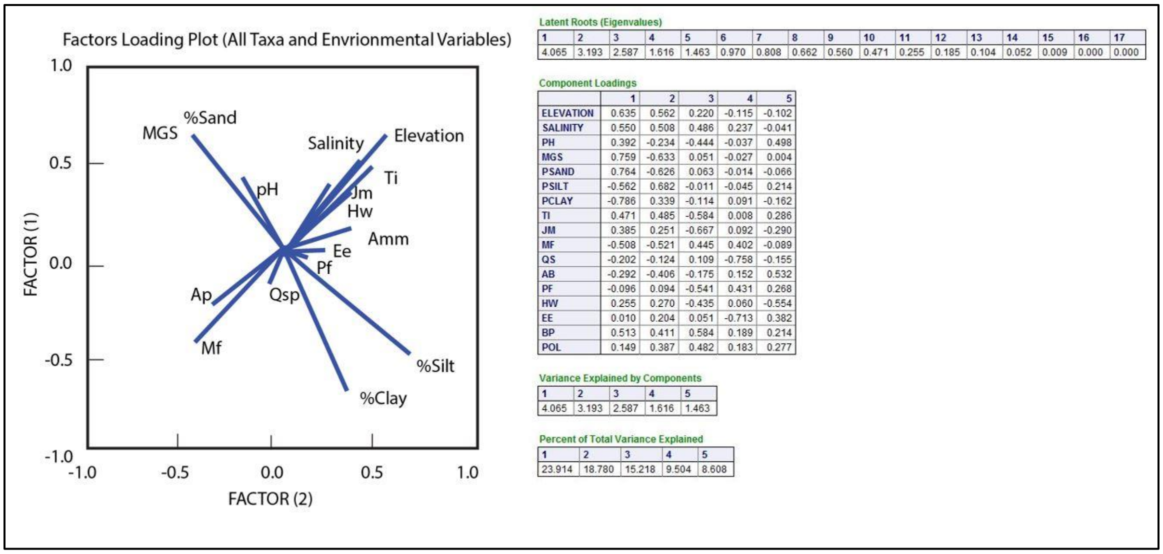
1	2
1.792	1.238

Percent of Total Variance Explained

1	2
44.789	30.944

PCA Outputs from SYSTAT: On Left—Factor Loadings plot for PCA run on environmental variables of Elevation, Salinity, pH, and Median Grain size (MGS). On right – output explaining the PCA run on Elevation, Salinity, pH, and Median Grain size.

Panel 5



Latent Roots (Eigenvalues)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
4.065	3.193	2.587	1.616	1.463	0.970	0.808	0.662	0.560	0.471	0.255	0.185	0.104	0.052	0.009	0.000	0.000

Component Loadings

	1	2	3	4	5
ELEVATION	0.635	0.562	0.220	-0.115	-0.102
SALINITY	0.550	0.508	0.486	0.237	-0.041
PH	0.392	-0.234	-0.444	-0.037	0.498
MGS	0.759	-0.633	0.051	-0.027	0.004
PSAND	0.764	-0.626	0.063	-0.014	-0.066
PSILT	-0.562	0.682	-0.011	-0.045	0.214
PCLAY	-0.786	0.339	-0.114	0.091	-0.162
TI	0.471	0.485	-0.584	0.008	0.286
JM	0.385	0.251	-0.667	0.092	-0.290
MF	-0.508	-0.521	0.445	0.402	-0.089
QS	-0.202	-0.124	0.109	-0.758	-0.155
AB	-0.292	-0.406	-0.175	0.152	0.532
PF	-0.096	0.094	-0.541	0.431	0.268
HW	0.255	0.270	-0.435	0.060	-0.554
EE	0.010	0.204	0.051	-0.713	0.382
BP	0.513	0.411	0.584	0.189	0.214
POL	0.149	0.387	0.482	0.183	0.277

Variance Explained by Components

1	2	3	4	5
4.065	3.193	2.587	1.616	1.463

Percent of Total Variance Explained

1	2	3	4	5
23.914	18.780	15.218	9.504	8.608

PCA 2 Outputs from SYSTAT: A factor loadings plot (left panel) showing the correlation between environmental variables and the taxanomic data with the PC1 and PC2 making up the y and x axes respectively. Environmental Variables are: Elevation; Salinity; pH; (% Clay) percent clay; (% Sand) percent sand; (% Silt) percent silt; (MGS) median grain size. Explanation of the Eigen values and component loadings (right panel).

Regression (OLS and Polynomial)

Polynomial Results

Elevation vs Species Abundances (Polynomial Regression 'p' values)				
	^1	^2	^3	^4
Ti	0.029	0.791	0.559	0.786
Jm	0.045	0.099	0.183	0.245
Mf	0.046	0.473	0.769	0.6
Qsp	0.915	0.175	0.904	0.342
Ap	0.017	0.974	0.934	0.672
Pf	0.3	0.653	0.453	0.897
Hw	0.078	0.847	0.321	0.923
Ee	0.314	0.589	0.838	0.487
Bp	0.742	0.022	0.001	0.578
Pi	0.098	0.117	0.165	0.127

'P-values' (probability that a variable predicts species values at a 95% confidence level) plotted for polynomial regressions (up to 4th order polynomials) analyzing the fit observed between elevation and individual species. Highlighted values indicate the polynomial order of best fit for each species.

OLS Results

	Ti	Jm	Mf	Qs	Ab	Pf	Hw	Ee	Bp	Pol
ELEVATION	0.034	0.345	0.034	0.574	0.039	0.703	0.167	0.214	0.542	0.3
SALINITY	0.616	0.515	0.79	0.26	0.488	0.984	0.751	0.239	0	0.008
PH	0.003	0.342	0.061	0.416	0.333	0.452	0.747	0.866	0.792	0.643
MGS	0.314	0.409	0.952	0.857	0.423	0.979	0.744	0.909	0.003	0.283
PSAND	.	.	.	.	.	.	.	0.852	.	0.296
PSILT	0.619	0.465	0.837	0.976	0.389	0.971	0.892	0.597	0.001	0.942
PCLAY	0.322	0.378	0.957	0.782	0.478	0.769	0.367	.	0.027	.
Factor(1)	0.04	0.171	0.01	0.899	0	0.529	0.186	0.504	0	0.152
Factor(2)	0.034	0.384	0.067	0.445	0.44	0.822	0.793	0.984	0.145	0.58

'P-values' (probability that a variable predicts species values at a 95% confidence level) plotted for each foraminiferal species against each environmental variable. Factor(1) and Factor(2) refer to the first two principle components produced from the initial PCA. Highlighted values indicate statistically significant results.