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Modern Foraminiferal Bio-facies within a Transgressive Saline Influenced Deltaic Headland, South-Central Louisiana

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Modern Foraminiferal Bio-facies within a Transgressive Saline Influenced Deltaic Headland, South-Central Louisiana

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Table of Contents

List of Figures

List of Tables

Abstract

Incorporating improved preparation techniques, modern taxonomy, and quantitative analysis of environmental variables known to influence marsh foraminifers in other coastal regions refined marsh foraminiferal biofacies of the Mississippi delta region. Elevation, pore water salinity, total carbon, and mean grain size were compared with foraminiferal distributions in a transgressive marsh system of the lower Lafourche headland of the south-central delta plain.

Cluster analysis aided definition of two biofacies, one from the marsh interior and one from the marsh edge. The marsh edge biofacies was further subdivided into levee crest and bayou margin biofacies.

Correlation analysis suggested that seven of the 21 most common foraminifers correlated significantly with physical variables. Juvenile *Trochammina inflata* correlated with salinity; *Ammotium crassus* and *Ammonia parkinsoniana* correlated with elevation; *Polysaccammina ipohalina* and *Miliammina fusca* correlated with grain size; and *Miliammina fusca* correlated with organic carbon. The trends are consistent with relationships observed in many other coastal regions.

Introduction

Foraminiferal biofacies of the Mississippi River delta plain and environs have been documented for a wide array of fluvial and marine environments, characterized primarily by water depth and intertidal exposure, such as the intertidal marsh and mudflat (e.g., Warren, 1956 and 1957; Lankford, 1959; Phleger, 1955, 1960a and 1960b; Plitnik, 1985); interdistributary bay and estuary (Lowman, 1949; Andersen, 1950; Phleger, 1955; Waldron, 1963; Gallacher, 1964; Otvos, 1978); salt wedge of active distributary channels (Phleger, 1960b), delta-front sands and barrier islands (Phleger, 1960b; Kornfeld, 1931; Eger, 1985; Collins, 1988); prodelta (Phleger, 1960b; Lankford, 1959; Eger, 1985); and turbulent inner shelf, middle shelf, and outer shelf (Parker, 1954; Poag, 1981). The majority of these works qualitatively connected estimates of environmental parameters to foraminiferal assemblages and biofacies. Physical variables included salinity of water overlying sites, water depth, estimations of mean sea level, estimated duration of tidal exposure and visual descriptions of lithology, including grain size and organic matter (Lowman, 1949; Treadwell, 1955; Eger, 1985), all measured by means appropriate at the time.

Recent investigations of intertidal settings from various worldwide locations have found that foraminiferal assemblages vary in species composition as a quantitative function of environmental parameters (e.g., Scott and Medioli, 1978; Murray and Alve, 1999; de Rijk and Troelstra, 1998; Murray, 2001; Robinson and McBride, 2003; Culver and Horton, 2005). These studies used a more rigorous quantitative approach to foraminiferal collection methods and measurement of environmental parameters than do studies done prior to ~1970 in the Mississippi delta region. Modern studies of worldwide

marsh locales are compared and contrasted to pre-1970 studies of the Mississippi delta region in the following section on background. The comparison shows a compelling need in the Mississippi delta region for updated taxonomy; updated field and laboratory methods; more rigorous, quantitative analysis of environmental parameters; use of multivariate methods for a quantitative definition of assemblages; and use of statistical methods to determine relationships between faunal and physical variables. The variables investigated in this study consist of surveyed elevation, pore water salinity, total carbon, and mean grain size. A bivariate statistical method is applied to demonstrate the correlation of these parameters with the distribution of foraminiferal species, and multivariate cluster analysis is applied to aid a quantitative definition of biofacies.

The coastal Louisiana location selected for this study is a transgressive, saline marsh within the lower Lafourche headland (Fig. 1). Foraminiferal samples from the marsh surface were taken along transects that extended across highest high-water levee, marsh interior, marsh edge, intertidal mud flat, and tidal creek subenvironments of the transgressive marsh.

This surficial data provide important constraints on the distribution of foraminiferal populations and, consequently, the opportunity to develop a surficial model of foraminiferal biofacies within the intertidal transgressive marsh of the Louisiana coastal zone. Biofacies models can provide comparative tools that can be used to evaluate foraminiferal occupation and propagation and possibly measure the health of coastal marshes or restoration success. Additionally, the biofacies and the variables controlling their distribution may contribute toward establishing depositional environments of buried strata and an indication of trends in Holocene sea level and salinity.

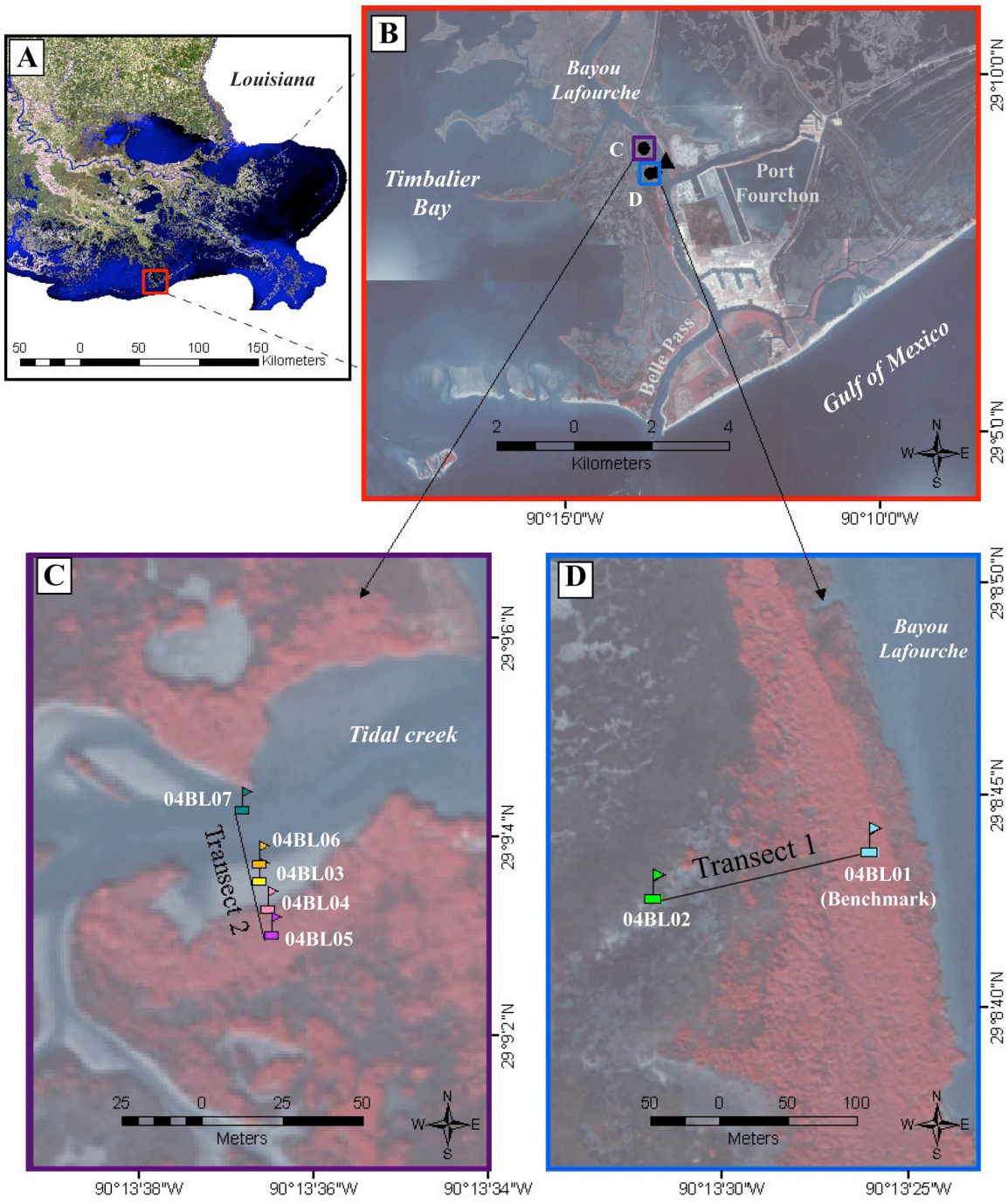


Figure 1. Maps showing the study area along the south-central Louisiana coastal plain (A and B). Inset map C and D are close ups of the study area identifying transects 1 and 2, across which seven sample sites were selected for the study. The sites cover a suite of marsh subenvironments in the lower Lafourche headland from highest high-water levee, to marsh interior, marsh edge, intertidal mud flat, and tidal creek. Bayou Lafourche sites will be shown throughout this document in these representative colors: 04BL01 is light blue, 04BL02 is green, 04BL03 is yellow, 04BL04 is pink, 04BL05 is purple, 04BL06 is orange, 04BL07 is bright blue-green or teal.

Background

Geologic Framework: Deltas of South-Central Louisiana

Accepted models describe Holocene growth of the Mississippi River delta as a multi-stage process reflecting fluvial and marine depositional processes that have been operative for at least the last 7,000 years (Fig. 2; Frazier 1967). Much of the delta plain has been built as active distributaries deposited sediment and constructed deltaic headlands that advanced the deltaic coastline seaward. During progradation, depositional environments proximal to the advancing deltaic headland are often dominated by fast sediment rates and freshwater input. As the abandonment of deltaic depocenters proceeds, they become sediment starved and increasingly more influenced by marine waters and processes. Distributary switching is a natural process that is characterized by distributaries developing shorter, more hydraulically efficient route through time. This first-order process contributes to the stratigraphic complexity and overall geomorphology of the modern Mississippi River delta plain.

The potential range of microfossil assemblages within a continuum of marine environments at the Lafourche headland was the basis for choosing this abandoned deltaic headland as the study location. The intent of this study was to capture a suite of depositional environmental provinces in transgressive conditions that may influence foraminiferal assemblages.

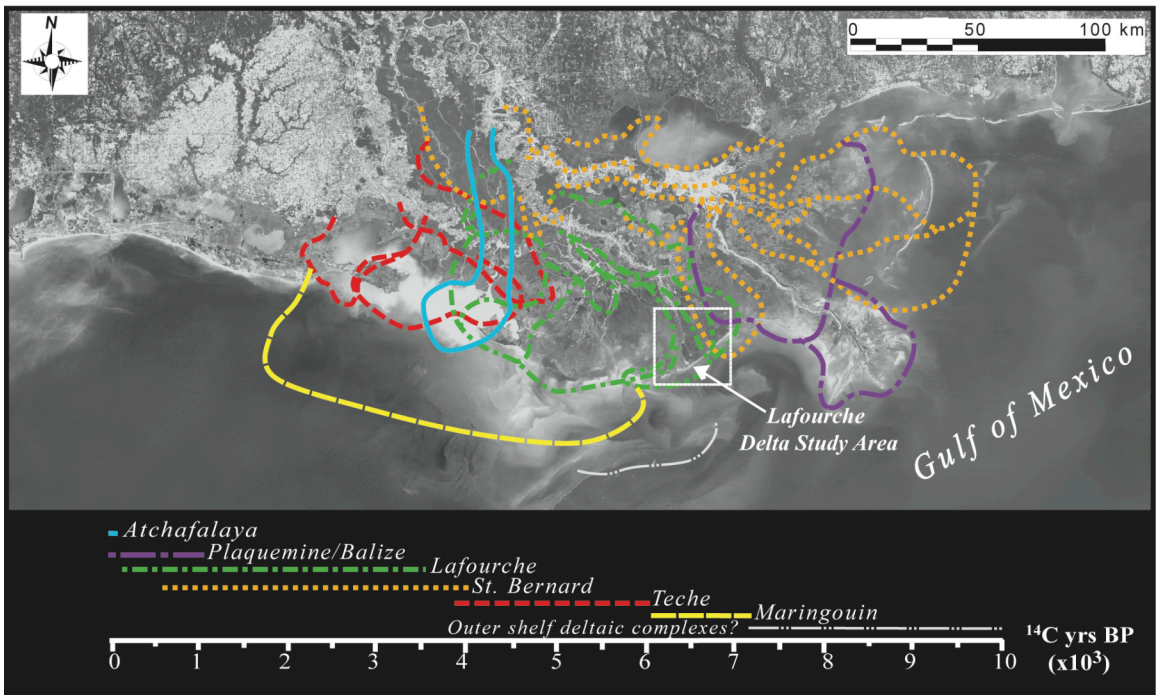


Figure 2. Aerial photograph showing the distribution and chronology of delta lobes on the Holocene Mississippi River delta plain (Frazier, 1967). The study area of this project is outlined by a white box. The figure is modified from Kulp et al., (2005), who combined Frazier (1967) and Tornqvist et al. (1996) chronologies for the delta plain development.

Lafourche Delta Complex: Bayou Lafourche a Transgressive Marsh Environment

The transgressive Lafourche deltaic headland of the south-central Louisiana coastal plain overlies sediments deposited within an incised valley that was excavated by the Mississippi River during the late Wisconsinan sea-level low stand approximately 18,000 yr BP (e.g., Fisk, 1944; Coleman, 1988; Roberts, 1997; Kulp et al., 2002) (Figs. 1 and 2). Deposition of the Lafourche delta complex by its source distributary, Bayou Lafourche, began sometime between 3,300 and 1,500 yr BP (Frazier, 1967; Tornqvist et al., 1996) and continued until approximately 300 yr BP. This depocenter developed within an interdistributary area between the Teche-Maringouin and St. Bernard delta complexes, both of which appear to have formed earlier. On the basis of stratigraphic thickness and its geographic extent (before abandonment) Bayou Lafourche appears to

have been a major distributary of the Mississippi River. In 1904, Bayou Lafourche was closed off from the main river by a dam, additionally altering this once prograding deltaic depocenter into a saline and highly transgressive environment where substantial erosion, subsidence, compaction and northward translation of the coastline has taken place (List et al., 1994). Between 1887 and 1978, the headland had the highest rate of coastal erosion in Louisiana at an average rate of 18.6 m/yr (Penland et al., 1989). This abandonment and transgression has resulted in a change from freshwater dominated environments to more marine dominated environments in the lower Lafourche headland area. The Bayou Lafourche deltaic headland contains both regressive and transgressive features, however, the transgressive features are currently the most dominant at the study site. Within this transgressive setting, eustasy and subsidence combined with sediment reduction has resulted in marine inundation, causing the retreat of the freshwater environments and replacement by salt-water marsh in a landward direction. The salt marsh in the study area consists of *Spartina alterniflora*, *Distichlis spicata* and *Juncus roemerianus* (flood tolerant species) in the lower-elevation marsh (Charbreck and Linscombe, 1988). Black mangroves (*Avicennia germinans*) are present in the higher marsh elevations of the Bayou Lafourche study site instead of the typical *Spartina patens*. Shoreline erosion continues on the Bayou Lafourche headland.

Previous Work on Foraminifera of Coastal Marshes

Methods

In the Mississippi delta region, intertidal marsh assemblages and biofacies were established in studies that pre-date the 1970's (Warren, 1956, 1957; Lankford, 1959;

Phleger, 1955, 1960a, b), and very few recent studies have been done in the area. Therefore, more than thirty years of improved research techniques are needed in this area. Taxonomic improvements used in this study include better understood morphology of juvenile forms, a more refined and stabilized taxonomy of adult forms, and addition of newly described taxa (i.e., *Polysaccammina ipohalina*) to the list of species found in the marshes of the Mississippi delta.

In addition to refined taxonomy, improved sampling practices take into consideration the fact that benthic foraminifers live throughout the upper 10 cm of sediments (Ozarko et al., 1997). This is in contrast to older studies, which used samples taken from the upper one centimeter of the sediment and hence missed species that live deeper than 1 centimeter from the marsh surface. Fossil recovery has been enhanced by use of wet methods throughout sample handling, including use of a settling type splitter modified from a design of Scott and Hermelin (1993). In contrast, older studies typically dried samples at some point in their preparation and/or microscopic examination. Other improvements have included greater fossil recovery by sieving to a smaller size fraction than previous studies. Sieving in previous works used a >63-μm fraction, which recovers medium to large size adult foraminiferal specimens (de Rijk, 1995; Ozarko et al., 1997; de Rijk and Troelstra, 1999; Murray and Alve, 1999; Culver and Horton, 2005). In the Mississippi Delta, several recent studies have incorporated the smaller sieve size of 45-μm, which has increased the recovery of small adult taxa, juveniles and arcellaceans (Scott and Medioli, 1978; Scott et al., 1991). In the Mississippi delta and Pearl River regions, Scott et al. (1991) and Brunner (2003) have applied at least some of these updated methods.

Improved methods of data analysis include use of multivariate Q-mode cluster analysis (Ozarko et al., 1997; de Rijk, 1995; de Rijk and Troelstra, 1999; Horton et. al., 1999; Brunner, 2003; and Culver and Horton, 2005) to quantitatively define assemblages. Additionally, correlation analysis is applied to determine if there is significant covariance between physical variables and common species.

Environmental Variables that Affect Biofacies of Various Marsh Settings

In the following sections, modern worldwide studies are compared and contrasted to Mississippi delta region studies. Discussed within the following sections are each of the environmental variables considered in this study: pore water salinity, surveyed elevation, sediment texture, and organic matter content. These variables have been compared to foraminiferal assemblages by previous intertidal marsh investigations.

Salinity

Recent investigations of intertidal marsh settings discuss pore water salinity as a primary control on faunal zones and foraminiferal assemblages (de Rijk and Troelstra, 1999; Culver and Horton, 2005). Salinity, measured from the pore waters in the sediment where the foraminifers live, gives a more accurate value of salinity that foraminifera are experiencing and improves the correlation of taxa to the salinity variable. In contrast, historical studies primarily used salinity measured in free waters overlying sample sites to correlate with marsh foraminiferal assemblages, biofacies and distributions, including the southern Louisiana and the Mississippi delta region (Warren, 1956 and 1957; Lankford, 1959; Phleger, 1955, 1960a, b; Plitnik, 1985; Scott et al., 1991). Previous methods in which overlying waters were measured may misrepresent salinity conditions that the

foraminifera experience in the sediment. Pore water salinity can be significantly altered relative to overlying waters by processes such as ground water input, rainwater seepage, evaporation and low-temperature diagenesis.

Elevation and water depth

In historical investigations prior to 1978, elevation of sample sites was not surveyed in a rigorous fashion in the Mississippi delta region (Andersen, 1950; Warren, 1956 and 1957; Lankford, 1959; Phleger, 1955, 1960a, b; Plitnik, 1985; Gallacher, 1964; Kornfeld, 1931; Beckman, 1985; and Scott et al., 1991). Instead, elevation was inferred by vegetation zone, estimated duration of tidal inundation or some other approximation of mean sea level. Improvements in measuring elevation have been made by using transects and surveying equipment including accurate Global Positioning System information. Among the first to implement these quantitative methods was Scott and Medioli (1978) in the southern California and Nova Scotia regions. Scott and Medioli (1978) selected closely spaced sites and surveyed transects to obtain accurate vertical and horizontal data and control of the elevation variable. Since, such rigor has become standard in marsh work. The benefits of rigorous measurement of elevation in biofacies work is its application to paleo-sealevel estimates downcore. An outstanding example of such an application is Horton et al. (1999), who used accurate elevation surveys and multivariate analyses to separate high and middle marsh biozones consisting of different abundances of foraminiferal species. They used these to develop transfer functions to estimate a standardized water level index to reconstruct variations in Holocene sea level. Culver and Horton (2005) is another example applying modern biofacies and elevation measurements as a means of reconstructing paleo-sealevel.

Sediment texture

The next environmental variable examined in this study is lithology or sediment characterization. Most foraminiferal investigations from historic to recent, especially in the Mississippi delta region, did not measure sediment grain size (Kornfeld, 1931; Warren, 1956 and 1957; Gallacher, 1964; Lankford, 1959; Phleger, 1955, 1960a and 1960b; Beckman, 1985; Scott et al., 1991). Some investigations noted sediment texture by visual inspection, which can distinguish mud from sand, providing a relatively course qualitative scale of textural characterization (Eger, 1985; Culver and Horton, 2005).

Organic Matter

Many recent studies of foraminifers from subtidal environments from the shelf to the deep sea report a strong correlation between foraminiferal species and organic matter (i.e., Gooday, 1988; Loubere, 1997). It is reasonable to ask if intertidal foraminifers may also be significantly affected by the amount of carbon available to them in their environment. The majority of pre-1970's investigations of the Mississippi delta in the intertidal marsh setting suggested a qualitative relationship between foraminifera and organic matter by the large number of specimens found within samples that had high concentrations of peat (Warren, 1956 and 1957; Waldron, 1963; Gallacher, 1964; Lankford, 1959; Phleger, 1955, 1960a and 1960b). However, in recent investigations there still remains little literature correlating quantitatively analysis of organic matter to foraminiferal assemblages in the intertidal marsh of the Mississippi delta region. A few researchers observed peats and organic matter as having an effect on foraminiferal assemblages in the Mississippi delta region, by suggesting that low organic matter content would contribute to low food supply and affect pH (Scott et al., 1991). Lankford

(1959) suggested that sediment pH was connected with organic carbon and used unpublished data of total organic carbon (TOC) values to suggest a relationship with foraminifera and other environmental factors. Recently, Beckman (1985) suggested foraminiferal assemblages had qualitative associations with organic matter (peats) in surface sediments and in sediment cores from marshes. A number of studies attempt to connect organic matter in a qualitative way to marsh foraminiferal species and assemblages. An example of one study that quantitatively measured several environmental parameters including organic matter by total organic carbon (TOC) within intertidal marsh settings of Denmark was Murray and Alve (1999). However, Murray and Alve (1999) did not mention any significant correlations between foraminifera and TOC but it was suggested that *M. fusca* might have an association with organic-rich muds.

Field Methods

Sampling Procedures

Site Selection and Elevation Surveys

The coastal Louisiana location selected for this study is a transgressive, saline marsh within the lower Lafourche headland (Fig. 1). Samples were collected from seven different subenvironments located along two separate transects. At each of the seven sampling sites, marsh sediment samples were collected for laboratory analysis of foraminifera, sediment texture, carbon content and pore-water salinity. Additionally, sediment and air temperatures were determined at each site while in the field.

The first transect extended from the levee of Bayou Lafourche into the marsh interior away from the brackish influence of the bayou. The second transect extended from a tidal creek toward the marsh interior approximately 0.5 km northwest of the first transect (Fig. 1). This second transect provided samples from the tidal creek, an intertidal mud flat, the marsh edge along the tidal creek, and a natural tidal creek levee. Samples sites along each transect were selected on the basis of elevation, with the intent of sampling from environments that ranged between highest high water to lowest low water and subtidal (Fig. 1). Sampling was completed within one day during a particularly low tide in July of 2004.

An elevation survey of the sample locations was conducted using a global positioning system [GPS; ASHTECH 701975 (Rev A)] and a total station, which was used to establish a sight line from each sample site to a National Geodetic Survey (NGS) benchmark (AU2969; at sample site 04BL01) along Bayou Lafourche. GPS positional

data at the benchmark were collected during a four-hour occupation of an ASHTECH 701975 (Rev A) antenna positioned over the NGS benchmark AU2969 (Fig. 3). The benchmark elevation was determined by OPUS solutions of the collected GPS position data, indicating a benchmark elevation (BM) of 0.62 m ± 0.04 m relative to the NAVD88 datum. This benchmark elevation is a constant in a two-part equation that provides elevation values for each of the sample sites. The dependent and independent variables in the equations are the rod height and the line-sight readings of height and distance, respectively, from each sample site to the benchmark. These variables are measured by using the total station instrument (TSI). The TSI is set up in a location where each sample site is in view, so the TSI will not have to be moved. The semi-permanent position of the TSI makes measurements consistent by setting up the sight-reading apparatus on a tripod and leveling the instrument as a whole, then measuring the instrument height. The utility of this approach is that the TSI can remain stationary and its height remains constant. The next portion of the equipment used is a rod that has tick marks that indicate the rod length at each site. On the top of the rod, a prism is connected and used to collect by line-sight the rest of the variables in the equation: the height, distance, and vertical tangent at each site (Fig. 3). The equation used to find the TSI elevation is

BM + Rod Length – Vertical – TSI Height = TSI Elevation. (1)

The actual elevation for each sample site can be calculated by substituting the calculated TSI elevation term into the following equation:

TSI Elevation + TSI Height +Vertical – Rod Length = Site Elevation. (2)

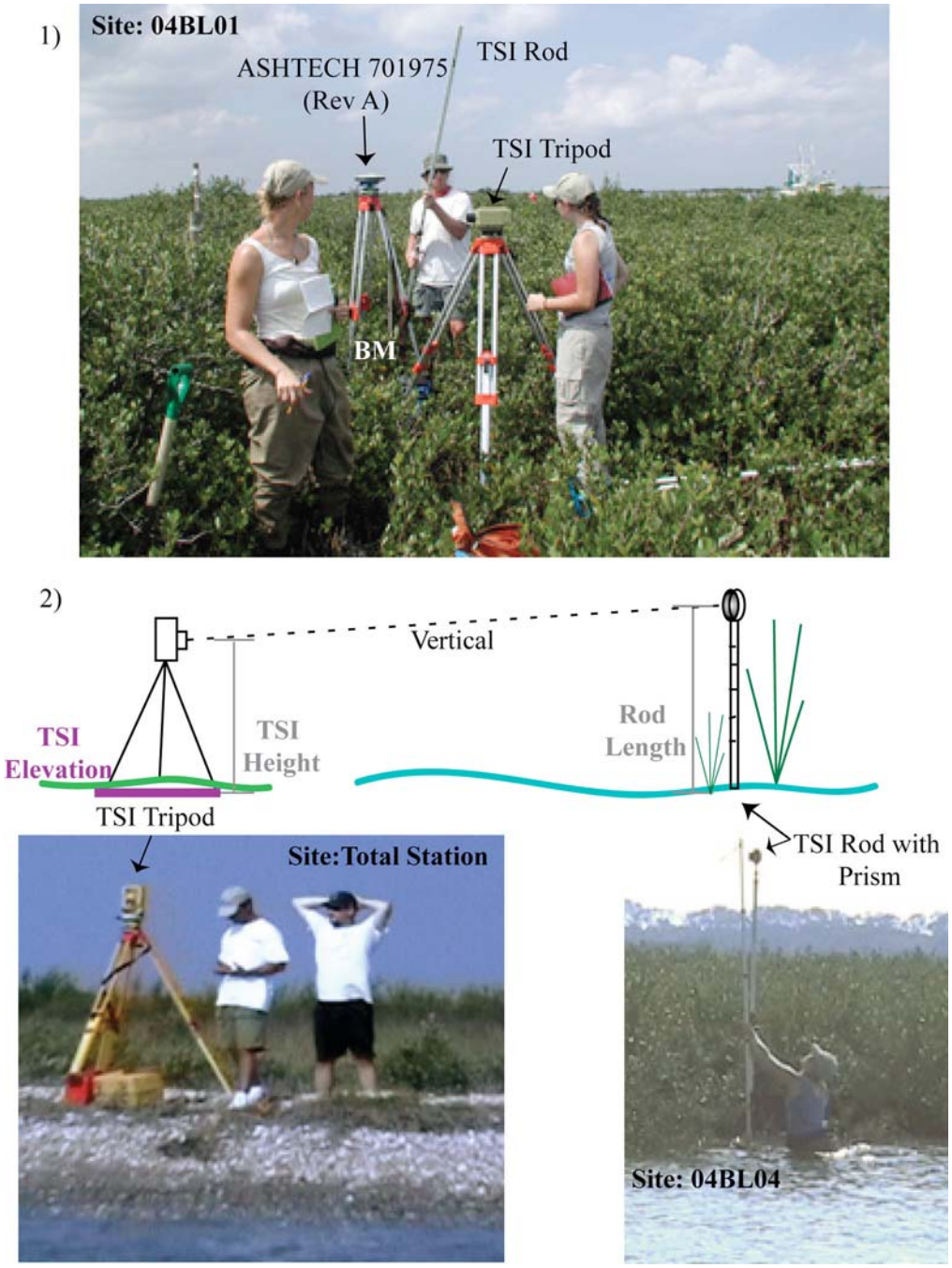


Figure 3. This figure displays the collection of the variables for the above equations as they were measured in the field. 1) Refers to the GNS Benchmark AU2969 location at site 04BL01 and the position of the GPS surveying antenna ASHTECH 701975 (Rev. A). Also shown is a TSI instrument. 2) A composite drawing of the variables in reference to the TSI instrument. Also shown is how the TSI instrument was used to survey in each site, including the BM site, so that equation 1 could be applied to get the TSI elevation and elevations of the rest of the sites. Below the drawing are pictures from the field demonstrating the collection of the variables for equations 1 and 2 above. Note Site 04BL04 was measured during a rising tide.

total station, and the calibration specifications has a measured site elevation (m.s.e.) accuracy

(2 mm + (distance (km) * (2 e -6)) = m.s.e. (± mm) at each site (Hagg and Trammell Inc., personal communication, 2006). (3)

Next each sites elevations were based upon the benchmark location (0.62 m ± 0.04 m) that was calculated by OPUS relative to Geoid03 NAVD88 datum:

(m.s.e. (± mm) + BM error (40 mm) + the BM m.s.e. (± 2.81 mm)) = overall total station measurement accuracy (m) (Phil McCarty, personal communication, 2006). (4)

Elevations for two subtidal sites were not recorded. These two sites were in the tidal creek: one on the tidal creek edge (04BL06) and the other in the center (04BL07) of the tidal creek. Depths were estimated at 1 m for site 04BL06 on the edge of the tidal creek and 2 m for site 04BL07 in the center of the tidal creek (Fig. 1). Tidal inundation for Port Fourchon, LA had a highest tide of +0.615 m and the lowest tide of -0.190 m for the month of July 2004. The relative tidal ranged between +0.429 m at mean higher-high water (MHHW), + 0.213 m during mean sea level (MSL) and - 0.024 m at the mean lower-low water (MLLW) during the summer of July 2004 based on the MLLW datum (NOAA, 2004). Survey equipment malfunctions prevented collection of elevation data on the day of sample collection. Consequently, each sample location was marked with a pole and line of sight surveys from the benchmark to the sample locations were completed approximately one month later, which had a very similar tidal regime.

Marsh Sampling Procedure

A key component of this work is that updated methods were used. In field sampling, samples from the marsh surface to a depth of 10 cm were taken in order to include deep-living foraminiferal species (Ozarko et al., 1997) that would otherwise be missing from a standard 0-1-cm sample. Another important component was that care was taken to measure physical variables with the accuracy and precision of modern instrumentation compared to those from pre-1970's studies of foraminifera from the delta region.

At each sample site, two replicate holes A and B were dug to approximately 0.3 m depth to let pore waters infiltrate and collect at the base of the hole. Pore waters within the holes were field-tested for salinity with a hand-held refractometer. Additionally, turbid pore waters were collected from each hole with a 10 ml Luer Loc syringe, then capped and stored in a Ziploc bag until the end of the day when each sample was filtered using a Whatman 0.45 μm syringe filter to remove unwanted suspended matter. These samples were filtered within 12 hours of collection to reduce ion exchange between pore water and clays. These pore water samples were returned to the laboratory for additional salinity analysis. Samples containing approximately 60 cm^3 of sediment were collected at each hole to obtain a representative foraminiferal population, textural character of the sediment, and total carbon. These sediment samples were collected in 60 cm^3 minicorers (made from cutoff, 60-ml syringes) that sampled from the surface of the marsh to a depth of 10 cm, a procedure that includes deep-living foraminiferal species (Ozarko et al., 1997). The type of vegetation and an estimate of vegetative cover at each site were noted and representative vegetation was collected for later identification.

Laboratory Methods

A key component of this work is that improved methods for processing foraminifera were used. Updated laboratory methods included (1) keeping the foraminifera moist to minimize post-collection destruction of agglutinated forms, (2) the application of modern well-established taxonomy, (3) the use of a small size fraction (> 45 μm) to collect a larger proportion of the foraminifer specimens including small adults and juveniles.

In the laboratory, all surface sediment samples (including both replicates A and B from each site) were split from the initial 60 cm^3 into aliquots of grain size, organic carbon, diatoms, dry weight content and foraminifera. Each study site had two replicate sediment samples (A and B; each 60 cm^3), and each was separately homogenized in a plastic container and subsampled using a 10-ml (=10 cm^3) syringe with a cutoff, beveled tip. The samples were homogenized by kneading the sample in a bowl, while wearing gloves. Then each subsample was removed from the homogenized bulk sample and processed in the following fashion. Firstly, 20 cm^3 were extracted to determine the wet and dry weights of the sample. The wet and dry weights, however, were not used in this study. Secondly, 20 cm^3 were used for foraminiferal identification. This sample aliquot was stored in 70% isopropyl alcohol and kept moist. Samples were refrigerated to further prevent deterioration by bacteria. (Please note that only replicate A was used in the faunal census: replicate B was not used in the faunal census.) Thirdly, 3 cm^3 was removed for total carbon content (TCC), measured by carbon-hydrogen-nitrogen-sulfur (CHNS) analysis. This aliquot was dried in an oven at 70 C° then stored in a desiccator until

further analysis. Fourthly, 5 cm^3 were collected for diatom analysis (not analyzed in this study) then put into a plastic bottle with ~10 ml of 10% formalin, covered with parafilm, capped, and stored in the refrigerator. Finally, 2 cm^3 were extracted for grain-size analysis using a Coulter LS 200 particle-size analyzer (Table 1). The remaining sediment was held in reserve in case additional analyses were needed.

Break down of initial sample split:	
Split for:	*Amount:*
Dry Weight Content	20 cm^3
Foraminifera	20 cm^3
Diatoms (not analyzed)	5 cm^3
Organic Carbon	3 cm^3
Grain size	2 cm^3
Sediment held in reserve	10 cm^3
Total Sample size	60 cm^3

Table 1. Table showing the break down of initial splits for each 60 cm^3 sample. The grain size aliquots were the last process in subsampling allowing for the reserve samples containing 10 cm^3 ± 2 cm^3.

Foraminiferal Species Analysis

Each of the 20-cm^3 subsamples for foraminifera from each site was washed separately in a stack of sieves with openings of 700 μm and 45 μm. The sieve with largest (700 μm) openings excluded coarse peat debris and the sieve with smallest openings (45 μm) insured recovery of juveniles of taxa, small adults, and arcellaceans. Washed subsamples were stored wet in a solution of tap water and 70% isopropyl alcohol, and kept moist throughout sieving, splitting, picking and identification of foraminifera, as described in Scott and Hermelin (1993), Murray and Alve (1991), and Ozarko et al. (1997).

Foraminiferal samples were split into six equal parts using a settling type splitter modified from a design of Scott and Hermelin (1993). Approximately 150 to a maximum of ~300 foraminifera were counted from a $1/6^{th}$ split of each 20-cm^3 sample. All of the specimens of a split were tabulated. The number of foraminifera that needed to be counted to characterize a sample was estimated from theoretical sampling curves of Patterson and Fishbein (1989). Their curves are calculated in much the same way as those for point counts of sediment grains (i.e., Krumbein and Pettijohn, 1938, p. 472), except that a confidence interval of 95% was applied (rather than 50%). All foraminifera were classified and counted by placing the split sample into a gridded Petri dish with water and observing the sample using a zoom stereo-microscope (Olympus SZX12) with magnification up to 100 X. Examples of most species were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS (Appendix A). Some individuals were picked and stored for additional identification purposes. Individuals were identified and assign to species using the online Catalogue of Foraminifera (Ellis and Messina, 1940-). Assignment to genus and higher taxa follows the classification of Loeblich and Tappan (1987; see Taxonomic Notes in Appendix 1). Most species consisted of adult forms, however, several species had significant numbers of juvenile forms. Juveniles of coiled forms are defined as have a single whorl of chambers or less, whereas juveniles of serial forms are defined arbitrarily as have 5 or fewer chambers (adults typically have 15 or more chambers). Assignment of juveniles to species was based on the unpublished notes of Brunner (personal communication, 2004). Individual counts were tabulated into a census, and species frequencies were calculated (Appendix

A). The relative frequencies of each of the foraminiferal species was calculated by dividing the number of specimens of each species counted at a site by the total number of all foraminifera counted at each site and multiplied by 100. A 95% confidence interval for sampling error was calculated for each species frequency (Patterson and Fishbein, 1989; error bars in Figs. 11-14). The simplified equation from Patterson and Fishbein (1989) used to find the 95% confidence interval for theoretical sampling error is

$$[P / 100 * ((100 – P) / 100)) / N]^{½} * \text{Student's t} * 100, \qquad (3)$$

where the calculated percentage of species for each sample is P, the number of tests counted in each sample is N, and the value of Student's t is 1.96, which is suitable for N (N in the Lafourche samples ranged between 150-300 specimens; see Appendix A). Specimen density in each subsample was calculated as the number of fossils standardized by unit volume, which was taken as 10 ml (this is half of the original sample size) in conformity with a majority of other studies.

Total Carbon Content Analysis

A carbon-hydrogen-nitrogen-sulfur (CHNS) Thermo Finnigan Flash EA 1112 analyzer was used to determine total carbon content (TCC). Carbonate values were not determined due to time constraints and equipment failure. The 3-cm^3 subsamples of sediment were taken from the homogenized field sample of 60 cm^3 to determine carbon content at the sample sites. The TCC of each site is replicated by two samples, one from each sample hole A and B. The samples were initially dried in a gravity convection oven

at 21° - 26° Celsius, then ground by mortar and pestle to a uniform fine powder. The powder was weighed and then split into two equal portions. One half of the replicate sample was weighed and prepared for three repeated measurements of the total carbon analysis. Preparation consisted of placing a small portion, 10 to 20 mg of the original sample, into a pre-weighed universal tin container. The tin was then folded to enclose the sample and put into a sample press to create a small tin puck for analysis by combustion. The sample press condenses the sample and removes excess air, which if not removed could result in abnormally high nitrogen values. Four standards were used to calibrate the instrument: a soil standard, and standards of sulfanilamide, L-cystine, and methionine. Samples and standards were placed consecutively into an automatic sampler disk, which is a part of the CHNS Flash EA 1112 analyzer. The CHNS Flash EA contains two furnaces, absorption filters, and chromatographic columns that separate the reaction products generated through the combustion process. The Flash EA uses helium as a carrier and oxygen as an oxidation agent for the products to be analyzed for CHNS content. The Thermo Finnigan software, called Eager 300, reports analysis results of the CHNS Flash EA. This software provides a table that lists the amount of each element, the weight and number of replicates for all the samples analyzed. The standard control sample values were matched to the amounts of CHNS listed on the control sample labels to see if the instrument was correctly calibrated.

Pore Water Salinity Analysis

A total of 3 ml of pore water from each of the 10 ml pore water samples obtained in the field by syringes and were filtered using a Whatman 0.45 μm syringe filter. These

3-ml samples (from 5 samples sites, each site with two replicate samples, A and B) were then processed in the laboratory to measure magnesium (Mg), specific conductivity, and chlorinity (Cl^-), providing a more accurate measurement of pore water salinity at each site than the refractometer measurements taken in the field. For measurement of pore water salinity using Mg as a proxy, both replicates samples (A and B) were run with two repeated samples for precision. For specific conductivity as a proxy of salinity, replicates A and B from each sample site were run with one repeated measurement of each sample for accuracy. For Cl^- as a proxy of salinity, only one measurement of pore water from hole A of each site was analyzed. Salinity for Mg and specific conductivity are reported as averaged values of A and B and all salinity analyses are reported in practical salinity units (psu).

Magnesium

Pore waters were analyzed for magnesium (Mg) using a light trace element analyzer called a direct-coupled plasma spectrometer (DCP), manufactured by Beckman as a Spectrascan. The DCP was calibrated by three standards of diluted pure Mg in 100-ppm, 10-ppm, and 1-ppm solutions. The high and low calibration was performed using the 100- and 1-ppm solutions, and the 10-ppm standard was run as an unknown to check for accuracy. A wavelength of 517.27 nm was used with 10 seconds of collection time. The standards were prepared to have Na contents comparable to the "unknown" solutions. Thus two sets of standards were used, one with a Na content higher than the highest expected (estimated from refractometer measurements) salinity and one with a Na content lower than the lowest estimated salinity. On the basis of the refractometer reading in the field, most of the Bayou Lafourche sites were initially determined to have

high salinity values relative to those of normal seawater. Because of the high salinity values, a portion of each of the samples, including replicates, was diluted to 1:10 ml to give greater accuracy when analyzed through the DCP. The DCP analysis was conducted at the University of New Orleans (UNO) in the Department of Earth and Environmental Sciences. The purpose of analyzing Mg was to evaluate pore waters for salinity. However, salinity analysis using Mg is a non-traditional method, thus, back-up methods were used to validate the salinity of the pore waters. The amount of Mg in each sample was recorded in parts per million (ppm) and converted to practical salinity units (psu).

Specific Conductivity

Specific conductivity was used to evaluate the salinity of the pore water samples from each field location. The specific conductivity probe measures the electric conductivity of salts in an aqueous solution and reports the values at 25^{o} C, using a seawater algorithm to transform the measured value at any given temperature to that at 25^{o} C. Values were measured in the laboratory within two degrees of 25^{o} C, so minimal error is expected to have resulted from the transformation algorithm. Specific conductivities approach zero mS/cm in distilled water and are more than 50 mS/cm in average seawater (35 psu). A Hydrolab Quanta G probe was used to measure the specific conductivity of diluted samples. The measured values were multiplied by the dilution factors to get the value for the undiluted samples. Dilution was necessary because of the limited sample volume available for the measurements. The probe was calibrated and checked for accuracy using standard KCl solutions. The specific conductivity probe had nearly perfect reproducibility. The Bayou Lafourche samples were split (for analytical

replicates) and mass-diluted with distilled and deionized water to a range of 1:60 to 1:100, depending on the refractometer readings, which provided an initial estimate of the salinities. In subsequent discussions when salinity is mentioned, it has been measured from specific conductivity.

Chlorinity

The chlorinity of the pore waters was measured by chloride concentrations using a Dionex 1000 liquid ion chromatograph (IC) in the Geochemistry Laboratory at the UNO Earth and Environmental Sciences Department. The IC utilizes an exchange column to separate anions or cations and a conductivity detector to measure a signal that is linearly proportional to their concentrations. The sample is injected into a moving effluent (pumped 1.2 ml/min), which carries the sample through the column and provides ions for filling the column exchange sites. Prior to reaching the detector, the effluent signal is removed by a suppressor in which ions are exchanged for H+ and OH- ions to form H_2O, which does not yield a signal on the detector.

Standard solutions were used to calibrate the IC between 0.0, 0.8, 4.0 and 8.0 mg/kg of Cl^-, and the unknowns were diluted to fall within these ranges. Dilutions of the samples were critical to insure that they fall within the range of the standard solutions, so that they do not interfere with each other or other components, and to reach dilute concentrations of mg/kg. The Bayou Lafourche samples were mass diluted by a factor of 500.

Salinity calculations

Calculations for salinity in practical salinity units (psu) used a specific conductivity algorithm (Chapman, 2006). This algorithm estimates the salinity of a diluted sample, which is then multiplied by the mass-dilution factor of the sample. For chlorinity, the IC measured Cl^- concentrations that were converted to g/kg for use in the chlorinity algorithm. Agreement between salinities computed by the two algorithms was within 5 % for the Bayou Lafourche samples. The IC accuracies are estimated to be within 2 % for both the measured Cl^- concentrations and the measured specific conductivities. Additional unknown errors occur in the use of the algorithms to convert to salinity. However, the excellent agreement of the sample salinities computed by both methods, suggests the errors were small.

Grain Size

Sediment Preparation and Analysis

The sediment aliquot required preparation before analysis could begin. Organic matter was digested from the samples prior to textural measurements. Approximately 5 cm^3 of sediment sample was put into a centrifuge vial and filled with 3 to 5 cm^3 of hydrogen peroxide, capped and put into a wrist shaker machine for 1.5 hours (modified from Poppe et al., 2001). The hydrogen peroxide was used to chemically digest plant material and other fine-grained organic matter in the sample. The reaction of the hydrogen peroxide with the organic matter caused an effervescence that caused the solid organic matter to be pushed into the cap, where it created a mat of undigested organic

matter that was later removed. Mineral sediment with high densities quickly collected at the bottom of the vial, whereas the lighter sediment fraction was allowed to settle for a period of 24 hr. Organic material suspended in the liquid was then poured off. Sediment remaining after decanting was transferred to snap-lid cups and filled with distilled water. The sediment samples were allowed to settle for 24 to 36 hrs or until the water column looked clear. Next, the supernatant was decanted to 40 ml. This remaining volume of distilled water and sediment was subsequently analyzed for textural character using a Coulter LS 200 particle-size analyzer, manufactured by Beckman Coulter.

The Coulter LS 200 consists of a reservoir that contains water and detection sensors that prevent overflow, thus, maintaining an acceptable amount of water in the reservoir. This reservoir is where the sample is added, and then the water-and-sediment sample mixture is cycled through the instrument. The flow passes between two glass lenses with an opening of only a few centimeters in width. Analysis begins here, where a laser is focused through these glass lenses onto the sediment-laden fluid, and particle sizes are detected in millimeters as the laser diffraction caused by the particles is recorded opposite the laser. Analysis with the Coulter LS 200 only requires a small amount of sample, usually between 5 and 10 ml or less, depending on the textural character of the sample. There were fourteen sediment sample cups, these are the A and B replicates from each of the seven sample sites. Each replicate had the following process repeated three times for precision. The sediment samples in each cup were shaken, and then sampled with a clean plastic pipette that was pre-washed with distilled water and 70 % isopropyl alcohol. With the plastic pipette, approximately 5 ml was withdrawn (each time) from the well-mixed sediment sample cup. The pipette sample was carefully added

to the sample analysis reservoir of the *Coulter LS 200* until the systems operating software indicated that an appropriate amount of sediment had been introduced. The sediment-water mix was then pumped through the laser detection window so that obscurity created by the mix is no greater than 12 %. After the sample completes its run through the system, the reservoir is automatically flushed and rinsed prior to addition of the next sample. Size-data output files generated by the analyzer were then processed with a Microsoft Excel macro program (Kulp et al., 2005). This macro utilizes the instrument information and data files to determine the percent sand, silt and clay, as well as mean grain size and sorting of the sediment in the sample. Unpublished UNO Coastal Laboratory reports document the similarity of grain size results obtained by standard mechanical sieve analysis and the LS200 approach.

Statistical Methods

Bio-, chemo- and lithofacies data were assessed using a statistical procedure that quantifies the variance of the physical and biological variables. Bivariate correlation analysis using a Pearson correlation coefficient (r) with a 2-tailed test of significance was calculated to determine which environmental parameters covary with foraminiferal densities. Pearson's r measures the degree of linear association between pairs of variables and varies from -1 to +1, where 0 indicates no relationship and 1 is perfect correspondence (Norusis, 2006 and Garson, 1998). The variables in the analysis included the 21 most common foraminiferal taxa (those present in at least four of the seven sample sites) recalculated to species density (total number of specimens of each species in 10 cm^3 of sediment). These were compared to elevation (m), salinity (psu), total carbon

(percent), and mean grain size (phi) at each sample site (Appendix B) using the Statistical Package for the Social Sciences (SPSS, version 11.5). Two-tailed tests of significance were calculated at alphas of 0.05 and 0.01.

It is important to note that although a species may correlate well to a known variable, it does not prove that the variable controls the foraminifer distribution and it does not preclude the possibility of other controlling factors. Correlations could conceivably exist with an untested variable and with variables not yet known to influence distributions. Numerous studies to date have, however, suggested that the variables tested in this study are likely the major factors influencing foraminiferal marsh assemblages and biofacies (e.g., Warren, 1956 and 1957; Lankford, 1959; Phleger, 1955, 1960a and 1960b; Scott and Medioli, 1978; Eger, 1985; Plitnik, 1985 Collins, 1988; Scott et al., 1991; Rijk and Troelstra, 1998; Murray, 2001; Robinson and McBride, 2003; Brunner, 2003; Culver and Horton, 2005).

A multivariate method, Q-mode cluster analysis, was used to defined biofacies using the Statistical Package for the Social Sciences (SPSS, version 11.5). The Q-mode analysis ranked and grouped together samples with similar species composition based on the relative frequencies of the 15 most common species. This cluster analysis calculated a simple Euclidean distance coefficient between every possible pair of samples, and amalgamated the samples into a dendrogram using averaged linkage between groups. The resulting clusters quantitatively separate samples into assemblages based on their species composition.

Results

Five variables were examined at each of the seven sample sites in this study: elevation, salinity, total carbon, sediment texture and foraminifera species frequencies to determine biofacies and statistical correlations. The results of sampling and the laboratory analysis are presented here in four sections: first, the physical variables are presented; second, foraminiferal densities and species frequencies among sites; third, biofacies based on multivariate cluster analysis using a simple Euclidian distance coefficient; and fourth, results of the bivariate correlation of foraminiferal species and environmental parameters, using Pearson's correlation coefficient.

Physical Variables

Elevation

Elevations were not repeated for precision, however, previous field experience with the total station suggests that the vertical accuracy of such measurements is ± 2 mm added to horizontal error is ± 0.8 – 1.3 mm (depending on distance) the total vertical and horizontal error from the TSI to the site and back ranged from ± 4.6 – 5.5 mm. This total vertical and horizontal accuracy of TSI survey was added to the benchmark elevation error (±0.04 m), making the total elevation accuracy ± 0.05 m (Table 2; Phil McCarty, personal communication, 2006). The intertidal sites ranged in elevation from 0.59 m to -0.02 m (1.94 ft to -0.06 ft; Table 2) relative to the NAVD88 datum. Elevations for subtidal sites 04BL06 and 04BL07 are estimated at -1 m and -2 m for graphical purposes (see methods section). Transect 1 begins at site 04BL01 (elevation = 0.59 m) on the levee

crest in the black mangroves, then trends west to the interior marsh site 04BL02 (0.45 m; Table 2, Figs. 4, 5). Along this transect, numerous topographic lows exist in the interior marsh and appear to have a dendritic drainage system of thalwegs (Fig. 4B) that are typically inundated during high tide, resulting in wet soils. During low tide, however, these areas can become drained and exposed. Elevation ranges from 0.59 m at 04BL01 to 0.45 m at site 04BL02 along Transect 1.

Elevations in the second transect (Table 2, Fig. 5) range between 0.54 m at 04BL05 on the natural creek levee to 0.12 m at the marsh edge and -0.02 m at site 04BL03 on the outer mudflat. The tidal creek sites are estimated to lie at depths of –1 m and –2 m.

Site Identification	Elevation (ft)	Elevation (meters)
Total Station	4.18 ± 0.15	1.27 ± 0.05
Transect 1		
04_BL_01	1.94 ± 0.15	0.59 ± 0.05
04_BL_02	1.47 ± 0.15	0.45 ± 0.05
Transect 2		
04_BL_05	1.77 ± 0.15	0.54 ± 0.05
04_BL_04	0.38 ± 0.15	0.12 ± 0.05
04_BL_03	-0.06 ± 0.15	-0.02 ± 0.05
04_BL_06	Tidal Creek (-3.28 ft)	Tidal Creek (-1 m)
04_BL_07	Tidal Creek (-6.56 ft)	Tidal Creek (-2 m)

Table 2. Elevation data arranged by location. Note that elevations for tidal creek sites 04BL06 and 04BL07 were estimated and not measured, but are known to be below lowest low tide. The errors are estimated as one standard deviation from past performance of the survey system (see methods section).

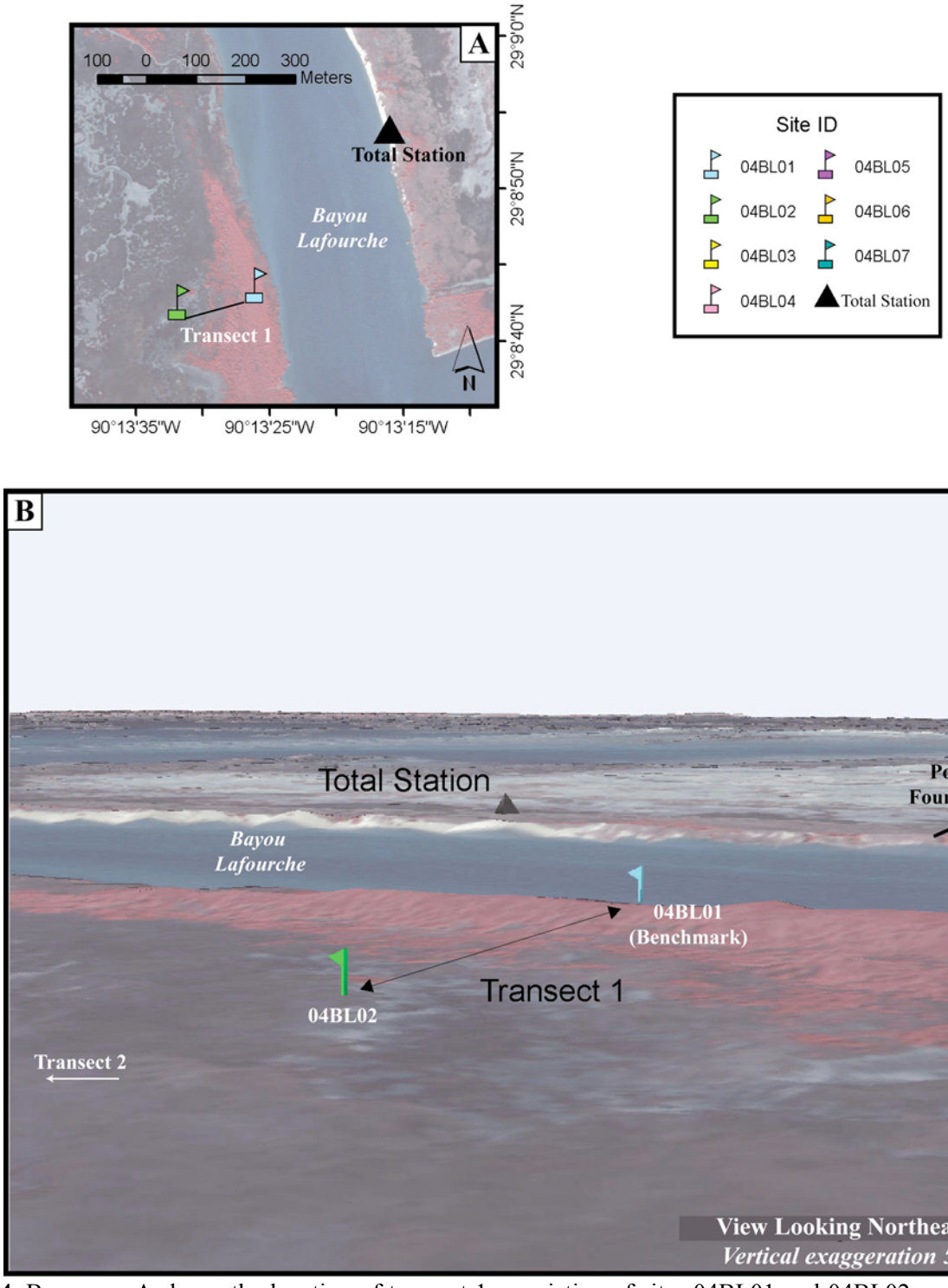


Figure 4. Base map A shows the location of transect 1, consisting of sites 04BL01 and 04BL02. Below, map B is an adjusted elevation model constructed from GIS and LIDAR data. The deep reds show trees or mangroves on higher elevations, whereas the greens are grasses and browns are bare mud at lower elevation. The blues represent water and indicate elevation below mean sea level. Exact elevations for each site are provided in Table 2. Map B has a vertical exaggeration of 5x.

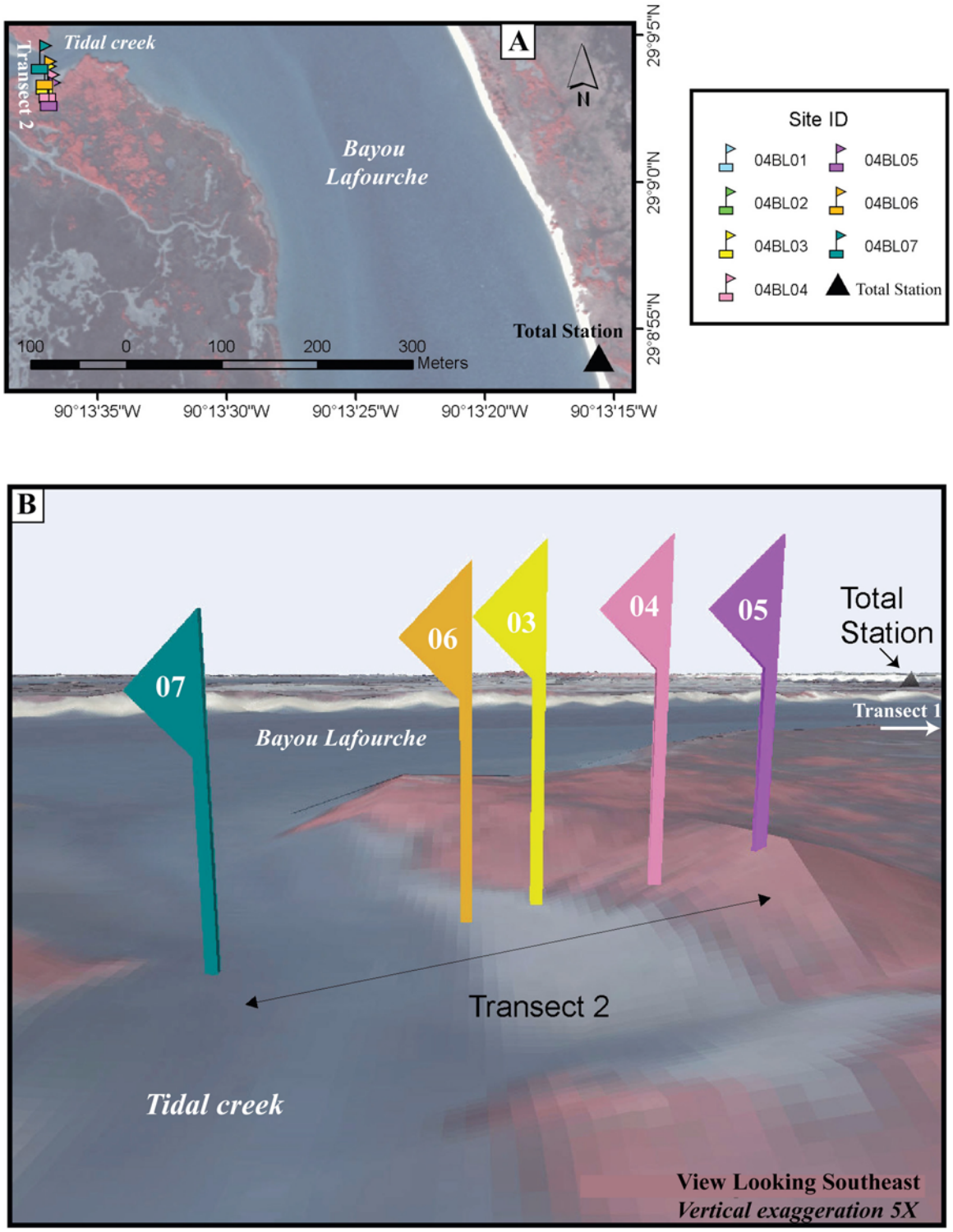


Figure 5. Base map A showing the location of transect 2, consisting of intertidal sites 04BL03, 04BL04, 04BL05 and tidal creek sites 04BL06 and 04BL07. Below, map B is an adjusted elevation model constructed from GIS and LIDAR data. The deep reds show trees or mangroves on higher elevations, whereas the greens are grasses and browns are bare mud at lower elevation. The blues represent water and indicate elevation below mean sea level. Exact elevations for each site are provided in Table 2. Map B has a vertical exaggeration of 5x.

Pore Water Salinity

Pore water salinity varied substantially between sites (Table 3 and Fig. 6). The highest value of 54 ± 1 psu was measured in the black mangroves of the Bayou Lafourche (04BL01) and the next highest value of 37 ± 1 psu was at the tidal creek levee site (04BL05). While the black mangroves at both these levee locations may add some salt to the soils by osmoregulation, tidal stage and evaprotranspiration have a larger effect on increasing soil salinity (Clarke and Hannon, 1969). Mangroves have a limit to the soil salinity that they tolerate. When soil salinity increases above the tolerance, death of the plant occurs (Cintron et al., 1978). Lower values of 24 ± 2 psu and 22.7 ± 0.4 psu was found in soils covered mainly by *Spartina alterniflora* grasses of the interior marsh (04BL02) and in the barren mudflat (04BL03), respectively. Salinity at the marsh edge site (04BL04) was slightly higher (30 ± 2 psu) than at the marsh interior (04BL02; 24 ± 2 psu) and mudflat (04BL03; 22.7 ± 0.4 psu) sites, but lower than the 54 ± 1 psu and 37 ± 1 of the mangroves sites, 04BL01 and 04BL05, respectively. Pore water salinity was not collected or recorded for the tidal creek sites (04BL06, 04BL07) because these sites were constantly covered with refreshed bayou water and little altered by evapotranspiration. Salinity values reported in Table 3 were constrained by laboratory analysis of pore water samples. The magnesium values calculated to salinity were consistently lower compared to the specific conductivity and chlorinity values and may be due to an ionic exchange with the clays in the soil (Fig. 6).

Salinity for Bayou Lafourche Sample Sites (psu)				
Sample Name	Specific Conductivity	Chlorinity	Mg Salinity	Refractometer Salinity
04BL01	54 ± 1	54.2	32 ± 7	60 ± 1
04BL02	24 ± 2	22.9	10 ± 2	29 ± 1
04BL03	22.7 ± 0.4	22.6	6 ± 1	28 ± 1
04BL04	30 ± 2	28.3	13 ± 2	34 ± 1
04BL05	37 ± 1	38.2	15 ± 1	42 ± 2

Table 3. Table showing the pore water salinities for each sample site. Values were determined by laboratory methods described in the methods section, except for the refractometer readings, which occurred in the field. Tidal creek sites 04BL06 and 04BL07 are not listed because no pore waters were collected in these locales. All values are in practical salinity units (psu). The pore water salinities from the laboratory analysis are displayed graphically in Figure 5.

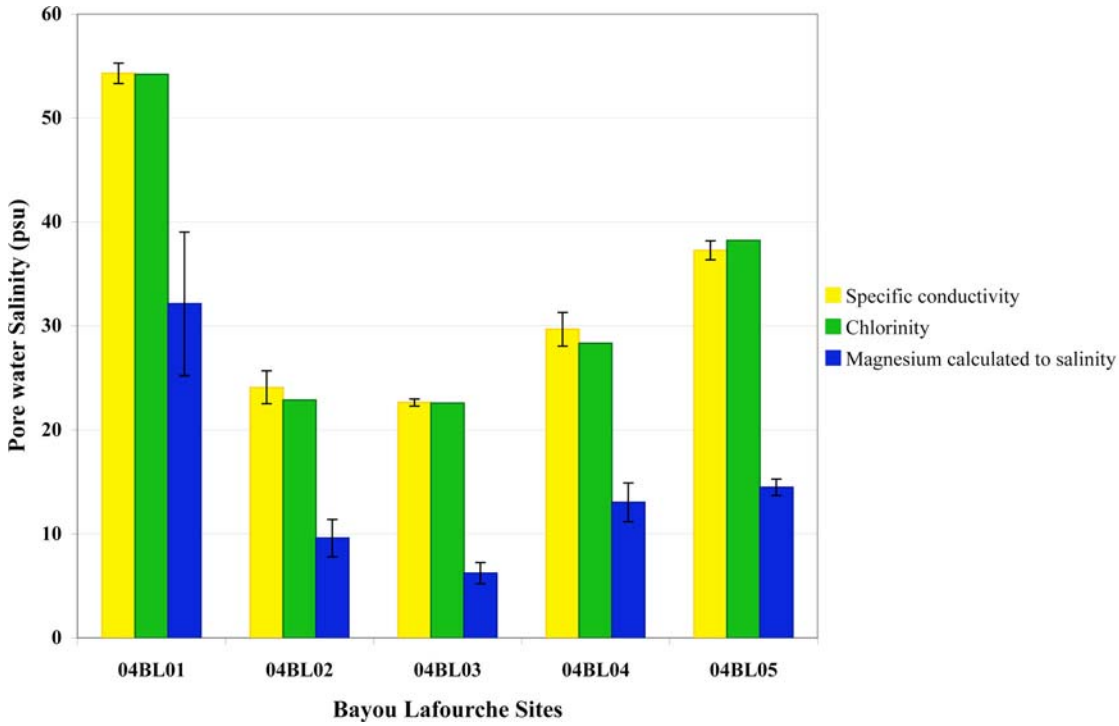


Figure 6. Pore water salinity values by method and sample location. Tidal creek sites 04BL06 and 04BL07 are not listed because no pore water samples were collected in these locales. Pore waters were measured by refractometer in the field and subsequently collected, filtered and analyzed in the laboratory for magnesium (Mg), specific conductivity and chlorinity (Cl^-) to more accurately determine the salinity values.

Total Carbon

Overall, the total carbon was relatively low, just 5 % or less, throughout the study area, with the exception of the interior site (04BL02). The interior site had the greatest amount of total carbon compared to any other site, averaging 23 ± 7 % (Fig. 7). *Spartina alterniflora* was the major marsh grass that surrounded this site (04BL02), but other varieties of marsh grasses were also present. The next highest total carbon values were present at the benchmark site (04BL01) with values approaching 5.1 ± 0.6 % total carbon. The higher values at the Bayou Lafourche levee site may be the result of leaf litter from the black mangroves. The mudflat (04BL03) had a total carbon average of 2.7 ± 0.6 %, which was higher than most of the subtidal sites. It had the most carbonate-test-building foraminifera compared to all the other sites. The addition of the carbonate tests of foraminifera may have contributed slightly to the total carbon average. However, due to time constraints and equipment failure the carbonate values alone were not measured. The minimal differences between total carbon values at the levee, intertidal and subtidal sites could be attributed to other environmental conditions that were not measured during this study such as seasonal variations, flood, drought, runoff, growth and death rates of the local vegetation, and the residence time and role of organic carbon in the total carbon cycle.

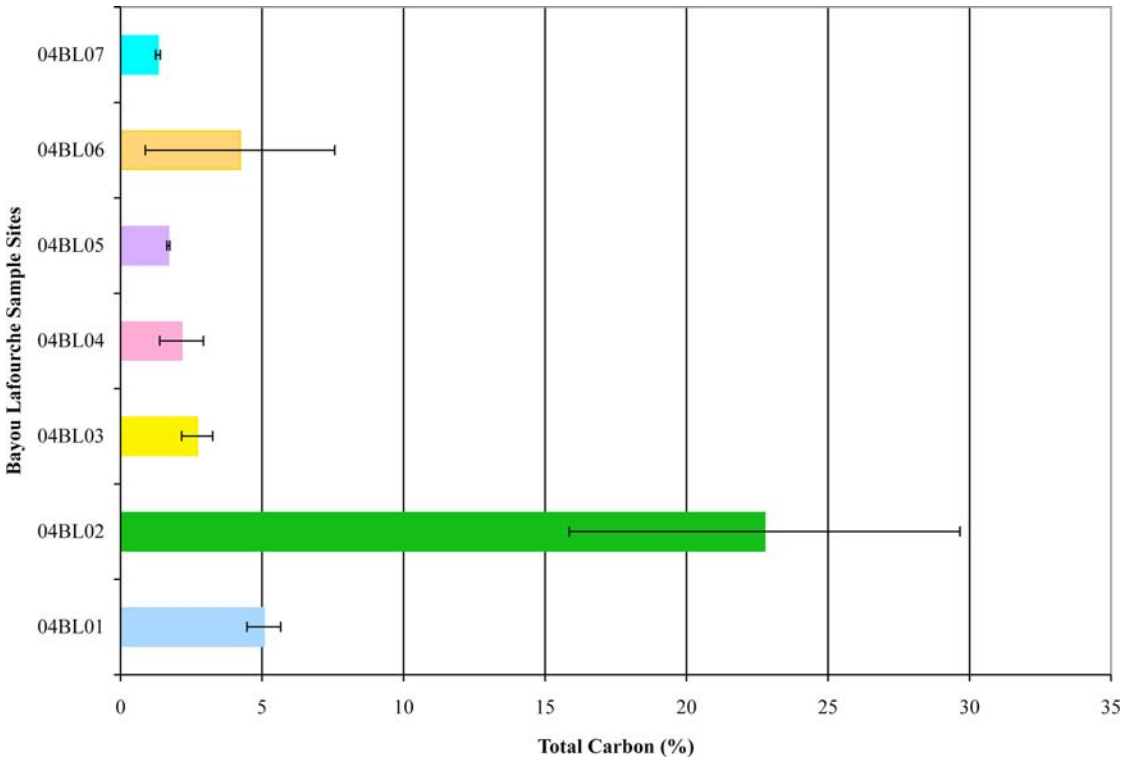


Figure 7. Percentage of total carbon by sample site. It is obvious that site 04BL02 has the highest percentage of total carbon. Note that Bayou Lafourche sites will be graphed and displayed throughout this document in these representative colors: 04BL01 is light blue, 04BL02 is green, 04BL03 is yellow, 04BL04 is pink, 04BL05 is purple, 04BL06 is orange, 04BL07 is cyan.

Grain Size

Across the seven sites, the sediment texture was relatively uniform and primarily consisted of silt with slight additions of sand and clay components (Fig. 8). The two transects were approximately 0.5 km apart and sites within transects were no more than 150 m apart, thus a large variation in grain size was not expected. However, a decrease of ~2 phi in mean grain size was documented from the tidal creek levee (5.1 ± 0.4 phi) to the tidal creek and from both levee crests to the marsh interior, which had the finest sediment of all (7.162 ± 0.004 phi). Analyses (Fig. 8) show that all sites had different ratios of sand, silt and clay components, but in all cases silt was the most common size. Therefore, textures in Bayou Lafourche can be characterized as either sandy silt or clayey silt (Fig. 8), with mean sizes between 5 and 7 phi (Fig. 9). A sandy component (~ 40 % sand) and silt mean grain size was documented for the tidal creek levee bank (04BL05; 5.1 ± 0.4 phi) and the marsh edge site (04BL04; 5.4 ± 0.1 phi; Fig. 9). A more uniform silt grain size was recognized for the mud flat site (04BL03; 5.9 ± 0.2 phi) with ~20% clay and sand components. The Bayou Lafourche levee bank (04BL01; 6.1 ± 0.2 phi) was mainly silt with less than 15 % each of clay and sand, and the middle tidal creek sample sites (04BL07; 6.5 ± 0.4 phi) had even less sand (Fig. 9). The tidal creek edge (04BL06, 6.8 ± 0.6 phi) and interior marsh (04BL02; 7.2 ± 0.0 phi; Fig. 9) exhibit increased clay content (~ 30 – 40 % clay).

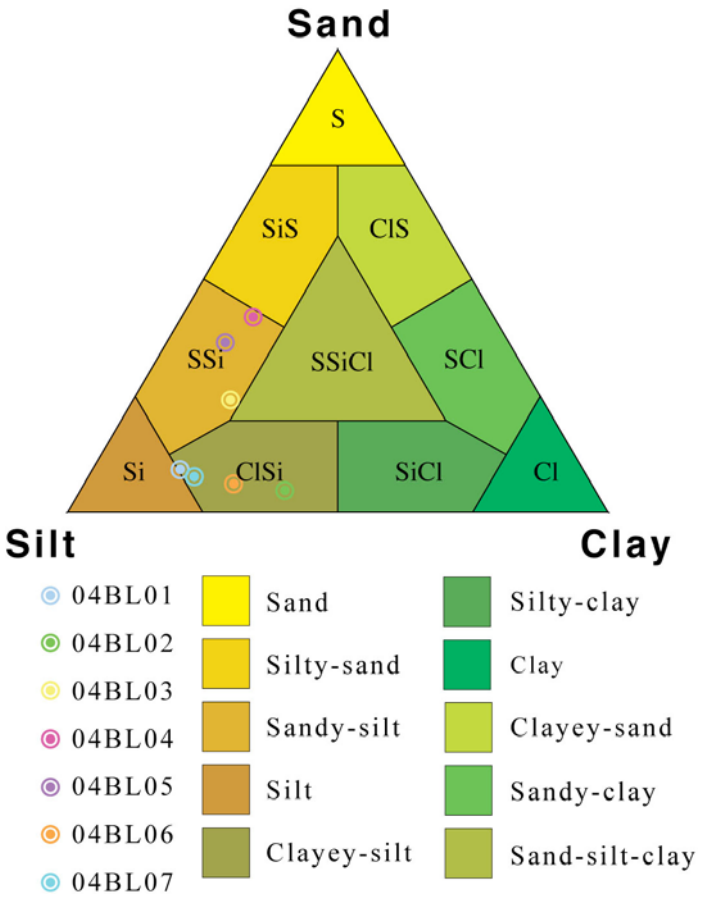


Figure 8. The ternary diagram modified from Flocks et al. (2006) suggests a way to classify the sediment types observed at each sample site based on the proportions of silt, clay and sand. The individual sites are plotted on the ternary diagram. The histograms of the sand, silt and clay components in percent, mean grain size and standard deviation can be found in Figure 9.

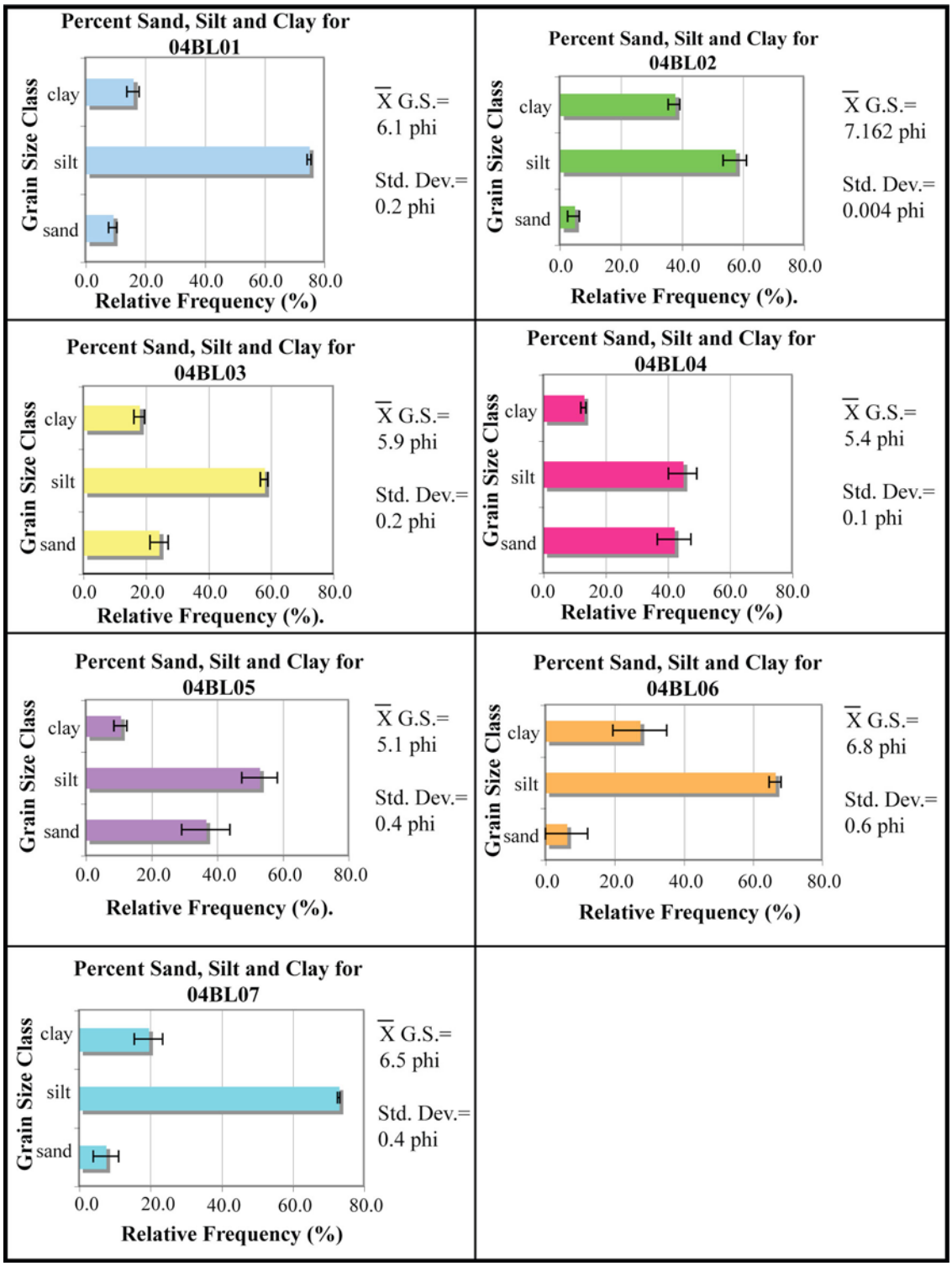


Figure 9. Histograms of sand, silt and clay. Each sediment site was replicated by two samples that were analyzed by an LS200 laser particle analyzer. Average grain size (XG.S.) and standard deviation (Std.Dev.) by phi are also reported.

Foraminiferal Assemblages

Foraminiferal Specimen Density

Total specimen density ranged between a maximum of 5,900 tests/10 ml in the mudflat site (04BL03) and a minimum of 500 tests/10 ml in the tidal creek location (04BL07) just a short distance away (Table 4). The specimen density in the marsh interior, levee sites, and marsh edge ranged between 2,500 and 4,300 tests/10 ml (Table 4).

Sample Site	Site Location	Specimen density in 10 ml
04BL01	Bayou Lafourche Levee	2,900
04BL02	Marsh Interior	2,500
04BL03	Mudflat	5,900
04BL04	Marsh Edge	4,300
04BL05	Tidal Creek Levee	3,400
04BL06	Tidal Creek Edge	500
04BL07	Middle Tidal Creek	500

Table 4. Table showing the total number of foraminifera in 10 ml of sediment at each sample site.

Examination of the specimen density by species suggests several, notable trends in species composition for each sample location. Some species were common at every location, and other species were found at only a few of the sites. Eighteen taxa were the most common across all of the sample sites. In order of abundance, the eighteen taxa are *Arenoparrella mexicana*, *Haplophragmoides wilberti*, *Miliammina fusca*, *Ammonia*

parkinsoniana, *Trochammina inflata*, coarsely agglutinated planispiral forms, juvenile forms of a textularid species, *Siphotrochammina lobata*, *Ammotium crassus*, juvenile *Trochammina inflata*, adult forms of a textularid species, *Trochammina macrescens*, *Elphidium matagordanum*, *Ammoastuta salsa*, juvenile *Haplophragmoides wilberti*, *Ammonia parkinsoniana* with only an organic test lining, *Trochamminita irregularis* and *Trochamminita salsa.* These eighteen taxa varied in specimen density and frequency between the sample sites, however, one of the eighteen was either dominant or common at any one of the sample sites. Of the top eighteen taxa, most species were present as adults. However, some species had an abundance of juvenile forms, which were counted separately (Fig. 10). Species with significant numbers of juveniles include *Haplophragmoides wilberti*, *Trochamminita salsa*, *Trochammina inflata*, *T. macrescens* and *Siphotrochammina lobata.* An unabridged listing of all foraminiferal species counted appears in the taxonomic notes in Appendix A.

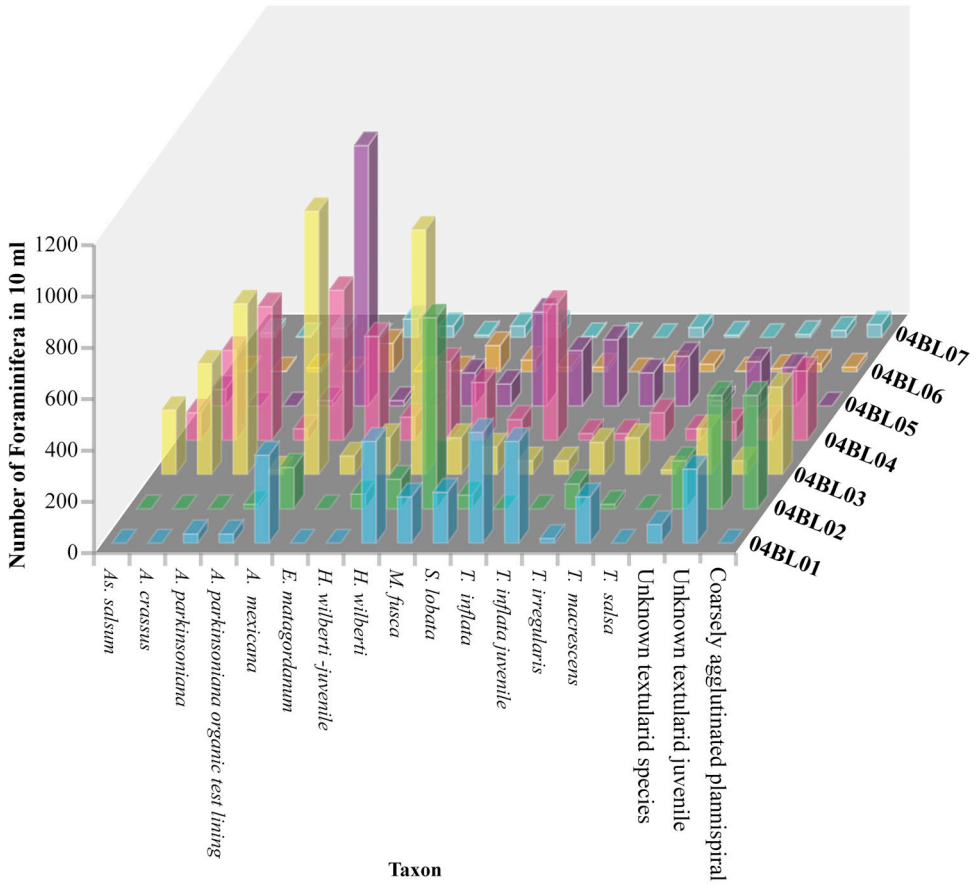


Figure 10. The graph above shows fossils density (tests/10 ml) at each site. The distribution of foraminiferal taxa among the sites is shown. The graph is arranged so that each site is stacked in a line from site 04BL01 (front) to 04BL07 (back). The representative value of each taxon is in line with each abbreviated foraminiferal species and counting group name. The values appear in Appendix A.

Relative Frequency of Foraminifera

The relative frequency of species varied with location (Table 5; Figs. 11-14). Distribution of these species by relative frequency is described below for each site by transect. There are eighteen taxa that are common in frequency, thirteen of these were the most common in frequency throughout the sample sites and are noted in Table 5.

Sample Sites	Most Common Species (Relative Frequency)
04BL01	*Trochammina inflata* (juveniles and adults), *Haplophragmoides wilberti*, *Arenoparrella mexicana*, *Siphotrochammina lobata* and juveniles of an unknown textularid species.
04BL02	*Miliammina fusca*, coarsely agglutinated planispiral, juveniles of an unknown textularid species, *Arenoparrella mexicana*, unknown textularid species and *Trochammina irregularis*.
04BL03	*Arenoparrella mexicana* and *Haplophragmoides wilberti*, *Ammonia parkinsoniana*, and *Ammotium crassus*.
04BL04	*Arenoparrella mexicana*, *Trochammina inflata*, *Ammonia parkinsoniana*, *Elphidium matagordanum*, *Haplophragmoides wilberti*, *Ammotium crassus*, *Miliammina fusca* and coarsely agglutinated planispiral forms.
04BL05	*Arenoparrella mexicana*, *Siphotrochammina lobata*, and *Trochammina inflata* (juveniles and adults).
04BL06	*Arenoparrella mexicana* and *Haplophragmoides wilberti*, *Miliammina fusca* and juveniles of an unknown textularid species.
04BL07	*Arenoparrella mexicana*, *Miliammina fusca*, coarsely agglutinated planispiral, *Haplophragmoides wilberti*, *Elphidium matagordanum*, *Trochamminita irregularis* and *Ammonia parkinsoniana*.

Table 5. A table summary indicating the most common marsh foraminiferal species, based on relative frequency at each sample site.

Transect One

At site 04BL01, *Trochammina inflata,* as both adult and juvenile, dominates the assemblage, and the others that were common at this location were adult forms of *Haplophragmoides wilberti*, *Arenoparrella mexicana*, *Siphotrochammina lobata* and juveniles of an unknown textularid species (Figs. 11, 15; Table 5). Site 04BL01 lies at highest high water on the levee of Bayou Lafourche (0.59 ± 0.05 m) and is surrounded by black mangroves. This site had the highest pore water salinity (54 ± 1 psu) of all the sites and was composed primarily of silt to clayey-silt sediment (mean grain size 6.1 ± 0.2 phi; Figs. 8, 9).

The marsh interior site 04BL02 is approximately 45 m west of the levee site (Fig. 4) and 14 cm lower in elevation. The interior site has one species, *Miliammina fusca*, that is most common and which is more frequent at this site than at any other. Other common foraminifera at this site are coarsely agglutinated planispiral forms, possibly related to *Ammotium* cf. *A. crassus*, and juveniles (with a maximum of five chambers) of an unknown textularid (Figs. 11 and 15). At site 04BL02, the pore water salinity ranged from 24 ± 2 psu and the texture consisted of the finest grained soil of any site (average grain size 7.162 ± 0.004 phi). Additionally, this interior site contained the highest total carbon value of 23% ± 7 for all of the sites. This site in the marsh interior was densely populated by marsh grasses, such as *Spartina alterniflora*, and lay at a lower elevation (0.44 ± 0.05 m) than that of the Bayou Lafourche levee. Because of the relatively lower elevation, tidal waters are able to inundate the site and infiltrate the pore waters more frequently than at the levee, perhaps reducing the effects of evapotranspiration.

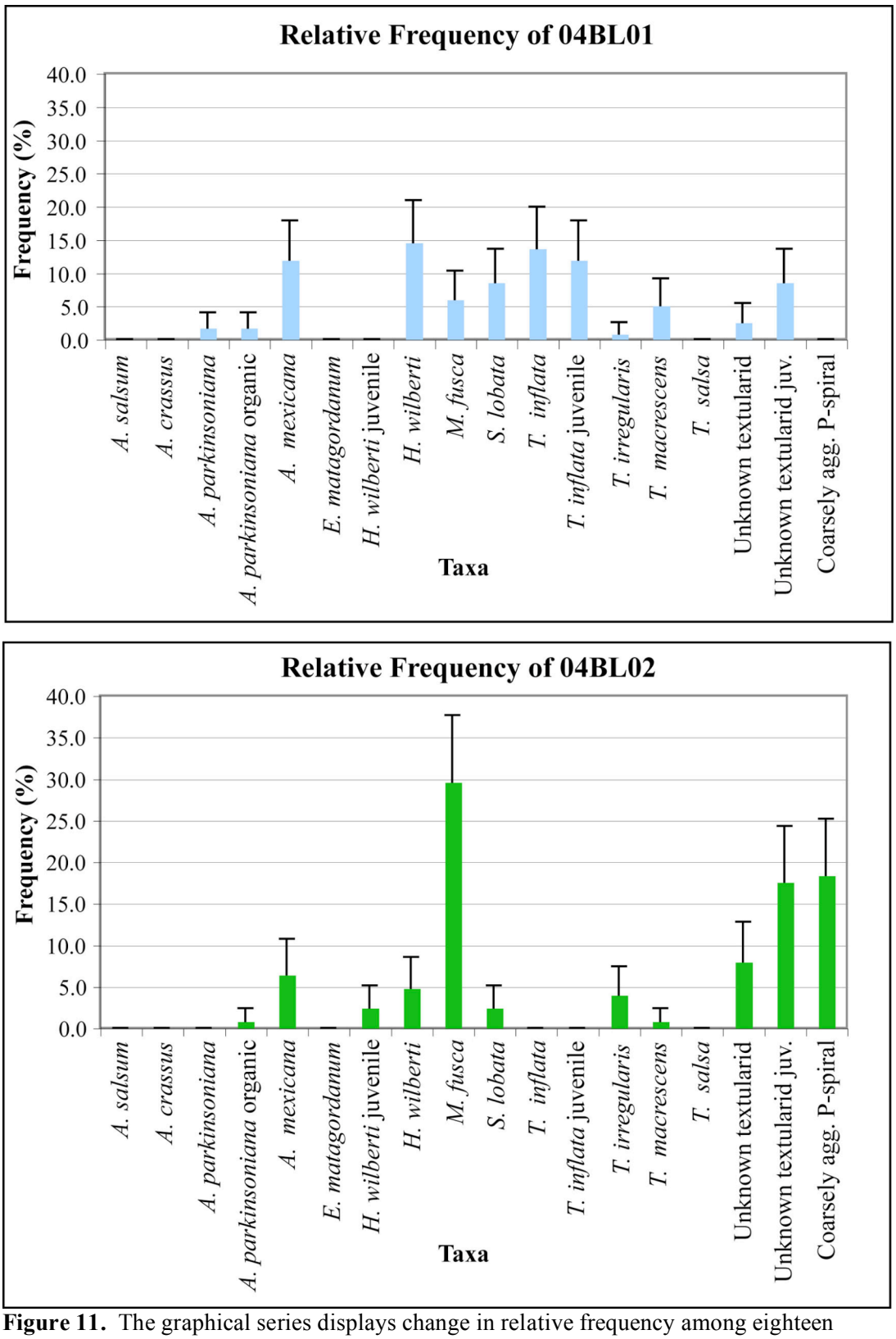


Figure 11. The graphical series displays change in relative frequency among eighteen species. The most abundant species at site 04BL01 are *H. wilberti*, *T. inflata* adults and juveniles, and *A. mexicana*. The dominant species at site 04BL02 is *M. fusca*. Error bars are 95 % confidence level of theoretical sampling error (Patterson and Fishbein, 1989).

Transect Two

The three intertidal sites on transect 2 are discussed in order of decreasing elevation and are closely located to each other. Although the sample sites are closely spaced, differences between the subenvironments are significant enough to influence the species distribution.

Site 04BL05 was surrounded by black mangroves at an elevation of 0.54 ± 0.05 m and is located on the natural levee of the tidal creek (Fig. 5). The most frequent foraminiferal species include *Arenoparrella mexicana*, *Siphotrochammina lobata* and juvenile and adult forms of *Trochammina inflata* (Figs. 13, 15). *Arenoparrella mexicana* of sample 04BL05 had the greatest relative frequency of all sample (Fig. 13). The assemblage seen at this site is most similar to that of site 04BL01 of transect 1 on the Bayou Lafourche levee. Site 04BL05 had the second highest elevation of all the sites and the second lowest total carbon at 1.7 ± 0.1 %. At site 04BL05 salinity ranged from 37.2 ± 0.9 psu, was ~17 psu lower than the levee crest site (04BL01) of transect 1 and ~10 psu higher than the marsh interior site (04BL02) of transect 1 (Fig. 15). Additionally, the sediment was the coarsest (mean grain size of 5.1 ± 0.4 phi) of any other site.

Site 04BL04 is located at the marsh edge, where vegetation gives way to the mudflat adjacent to the tidal creek. Six taxa at site 04BL04 had relative frequencies over 10 %. The most frequent species were the agglutinated *Arenoparrella mexicana* and *Trochammina inflata* along with the carbonate-test-building *Elphidium matagordanum* and *Ammonia parkinsoniana*, none of which is significantly different from the others based on the theoretical sampling error (Patterson and Fishbein, 1989). Lesser in frequency are *Ammotium crassus* and *Haplophragmoides wilberti*, with minor but

significant frequencies of *Miliammina fusca* and coarsely agglutinated planispiral forms (Figs. 12, 15). Compared to site 04BL05, site 04BL04 had lower salinity (30 ± 2 psu), but a similar mean grain size (5.4 ± 0.1 phi). At an elevation of 0.11 ± 0.05 m, this site was at a substantially lower elevation (~ 0.30 m lower) than the marsh interior site (04BL02; Fig. 15). Because of the lower elevation, this site was much more frequently flooded during the exchange of tidal waters in the lower Lafourche headland. Additionally, its location along the intertidal banks of the tidal creek has potential for periodic erosion by storm surge.

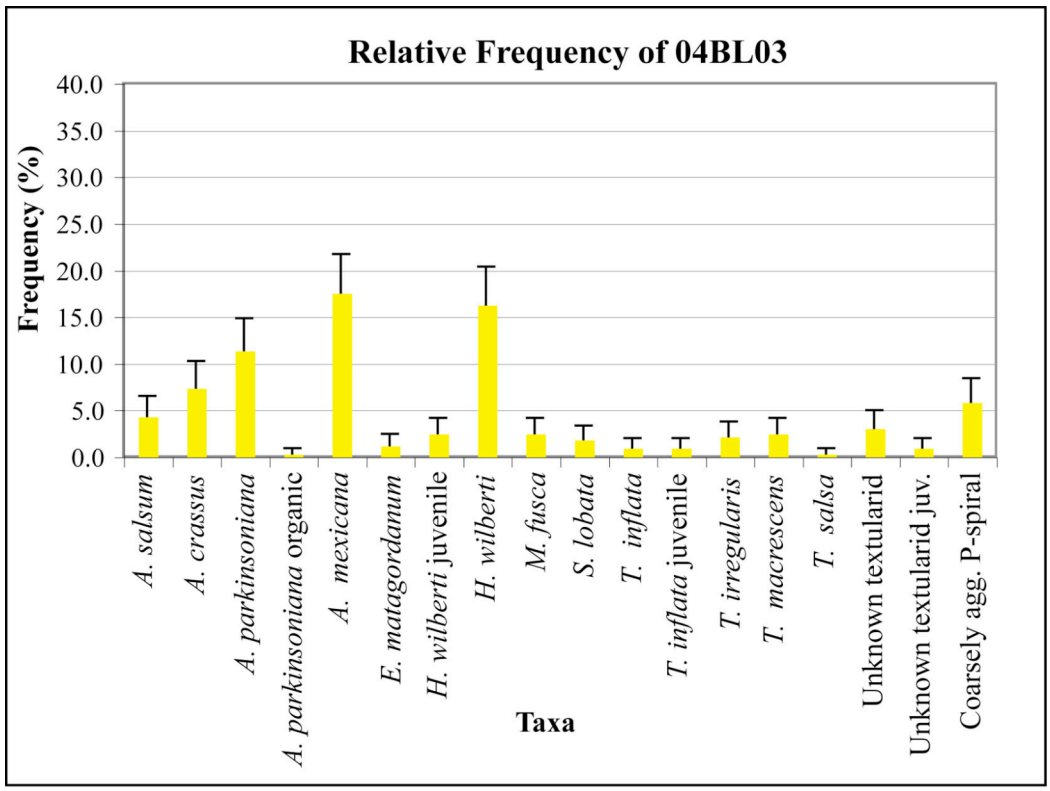
Site 04BL03, from the outer mudflat, is in close proximity to site 04BL06, the subtidal site on the tidal creek edge and close by is site 04BL07, which is located in about the middle of the tidal creek (Fig. 5). Microfossil species at mudflat site 04BL03 mainly consisted of adults of the agglutinated species *Arenoparrella mexicana* and *Haplophragmoides wilberti* (Figs. 12, 15). The next most frequent foraminifera were the carbonate species *Ammonia parkinsoniana* and two coarsely agglutinated taxa, *Ammotium crassus* and coarsely agglutinated planispiral forms (Figs. 12, 15). At the mudflat site (04BL03; Fig. 15), the salinity was lower and the texture was more silt-rich (average grains size = 5.9 ± 0.2 phi) compared to those at sites 04BL04 and 04BL02 (22.7 ± 0.4 psu). This site had a slightly higher total carbon content of 2.7 ± 0.6 % than the marsh edge site (04BL04; Fig. 15). A lower elevation at this location (-0.01 ± 0.05 m) allows for short periods of aerial exposure during the lowest low tide of many spring tides, whereas the site remains inundation during normal tidal cycles (Fig. 5). The mudflat (04BL03) also had fewer juvenile species when compared to sites 04BL01 and 04BL02, which are both higher in elevation and have a comparatively higher ratio of

clayey silt (Fig. 15). However, the frequency of common foraminiferal taxa at this site was most similar to that of its neighboring marsh edge site (04BL04).

The last two northernmost sites on transect 2 were completely subtidal and inundated continuously with tidal creek waters except possibly during the most extreme weather-driven falls in sea level. Although closely spaced, the environmental variability between the tidal creek edge, site 04BL06, and the center of the tidal creek, site 04BL07, appears to be significant enough to influence the species distribution (Fig. 5). Site 04BL06 is in close proximity to site 04BL03, and both share co-dominant species, *Arenoparrella mexicana* and *Haplophragmoides wilberti. H. wilberti* had the highest frequency at 04BL06 compared to all other sample sites. Other common agglutinated foraminiferal species at this site were *Miliammina fusca* and the juveniles of an unknown textularid (Figs. 13, 15). These common species are similar to those seen in the interior marsh (04BL02) of transect 1. At site 04BL06, there was no significant difference in total carbon content (4.2 ± 3.3 %) compared to that of the neighboring sites, although the slight average increase in total carbon content observed from the mudflat (04BL03) to this site could be due to an increase in carbonate test-bearing foraminifera observed at these sites. At the tidal creek edge site (04BL06), a slight decrease in mean grain size to clayey-silt (6.8 ± 0.6 phi) was noted compared to the tidal flat site (04BL03; 5.9 ± 0.2 phi; Fig. 15). Elevation for sites 04BL06 and 04BL07 were not measured, but are known to be below lowest low tide. Site 04BL06 is representative of an environment that, for the majority of the year, with the possible exception of weather-driven setdown of sea level, is completely inundated during the tidal cycle (Fig. 5).

Site 04BL07, located in the center of the tidal creek, had a notable increase of carbonate foraminiferal species, mainly *Elphidium matagordanum* and *Ammonia parkinsoniana* (Figs. 14, 15). The species at site 05BL07 were equitably distributed such that the 5 most common species, (*Arenoparrella mexicana, Miliammina fusca*, *Elphidium matagordanum*, *Haplophragmoides wilberti*, *Trochamminita irregularis*, and the coarsely agglutinated planispiral form that is similar to that of site 04BL02) were not significantly different in frequency. The common species seen at this site were similar to those of the marsh edge (04BL04), mudflat (04BL03) and its neighbor tidal creek edge (04BL06) sites. *Trochamminita irregularis* was more frequent at this site than any other (Figs. 14, 15), although this species is not known to live in subtidal environments. In the center of the tidal creek, site 04BL07 had the lowest elevation as well as the lowest total carbon (1.2 ± 0.1 %) of all the sites. The mean grain size at this site was silt (6.5 ± 0.4 phi; Fig. 15), compared to the previously mentioned tidal creek site that had a more clayey-rich sediment texture.

Additionally, this location (04BL07) contained more arcellaceans, the fresh-water "cousin" of foraminifera, than any other site. The arcellaceans were not counted, but their presence suggests that the tidal creek may have periods when there is a lower salinity than what was documented or transport has taken place from a lower salinity locale. This variability between fresh and marine-dominated conditions may reflect periods of increased or decreased freshwater run off or seasonality that influences tidal inundation. Another possibility could be that incising of subsided brackish to fresh transgressive marsh is occurring and that the bottom sediments are being reworked.



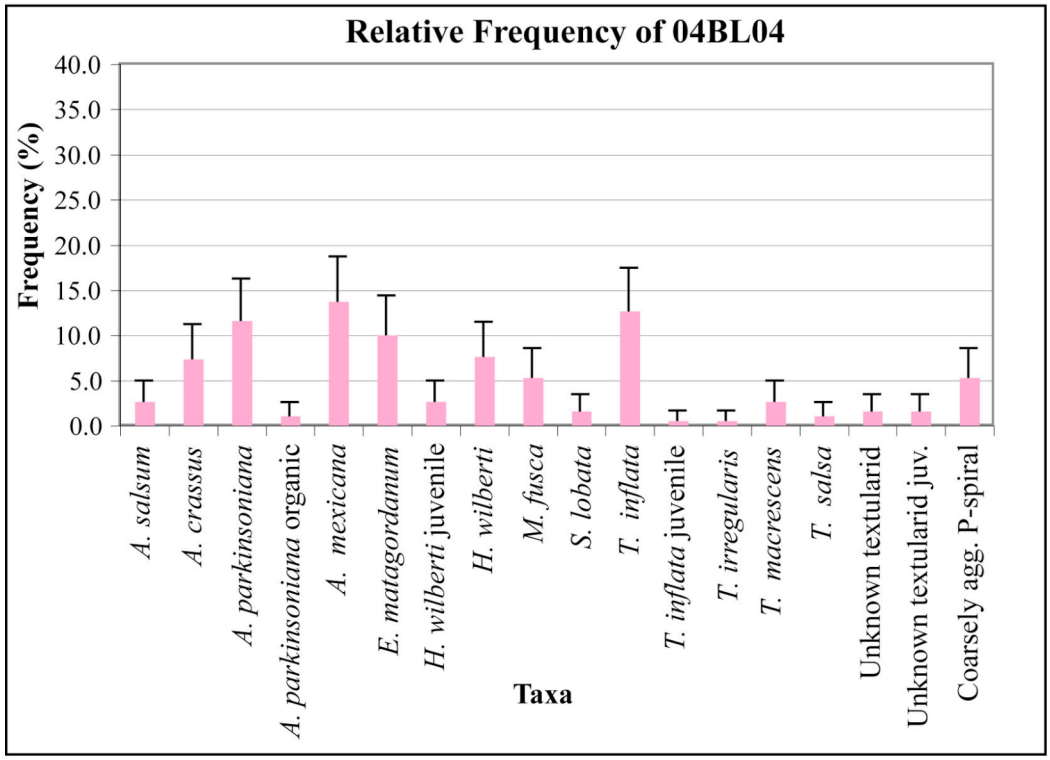


Figure 12. The graphical series displays change in relative frequency among eighteen species. The most frequent species at site 04BL03 are *A. mexicana* and *H. wilberti.* The most frequent species at site 04BL04 are *A. mexicana*, *T. inflata*, *A. parkinsoniana* and *E. matagordanum*. Error bars are 95 % confidence level of theoretical sampling error (Patterson and Fishbein, 1989).

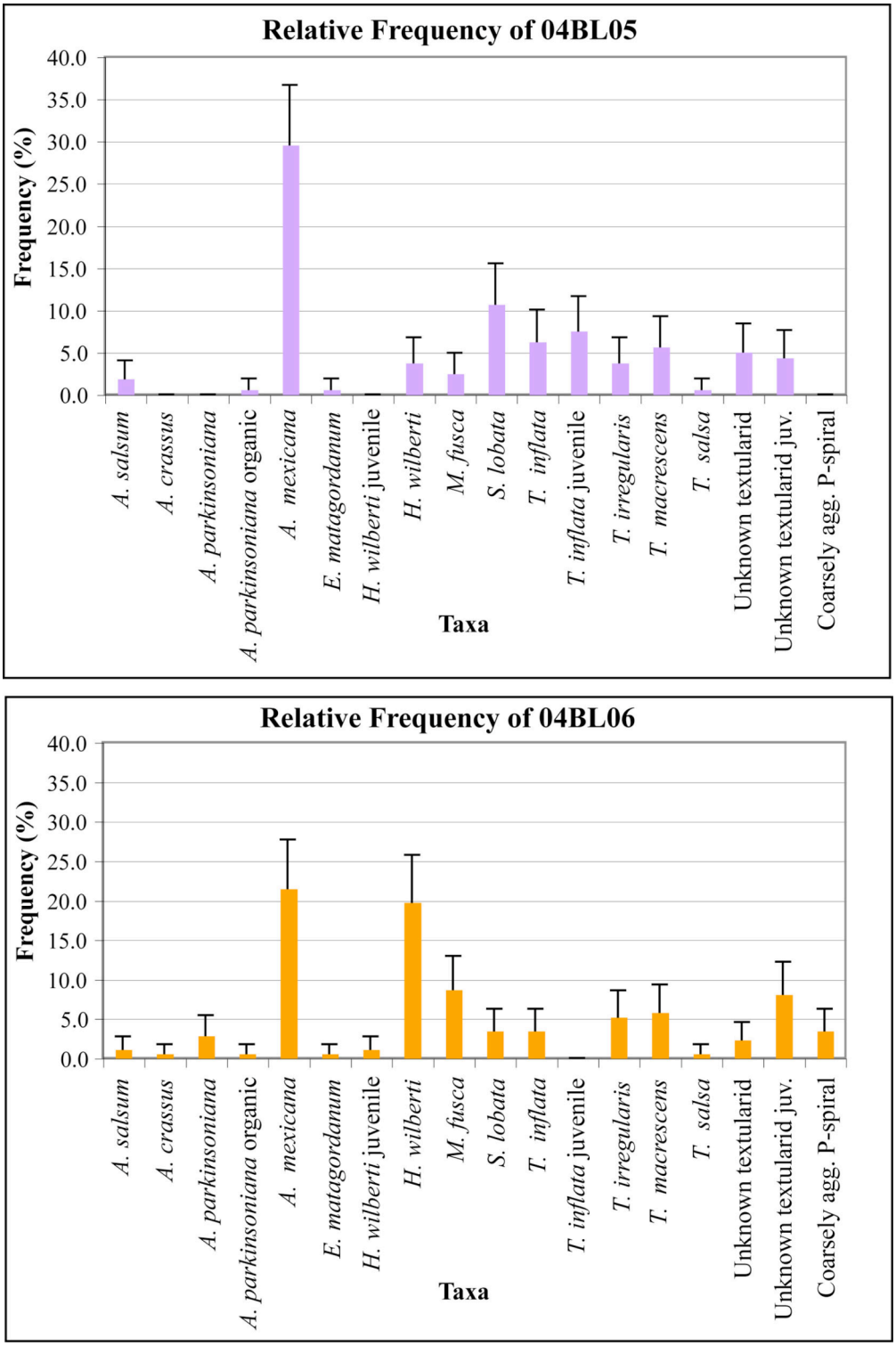


Figure 13. The graphical series displays change in relative frequency among eighteen species. The most abundant species at site 04BL05 is *A. mexicana.* The most abundant species at site 04BL06 are *A. mexicana* and *H. wilberti*. Error bars are 95 % confidence level of theoretical sampling error (Patterson and Fishbein, 1989).

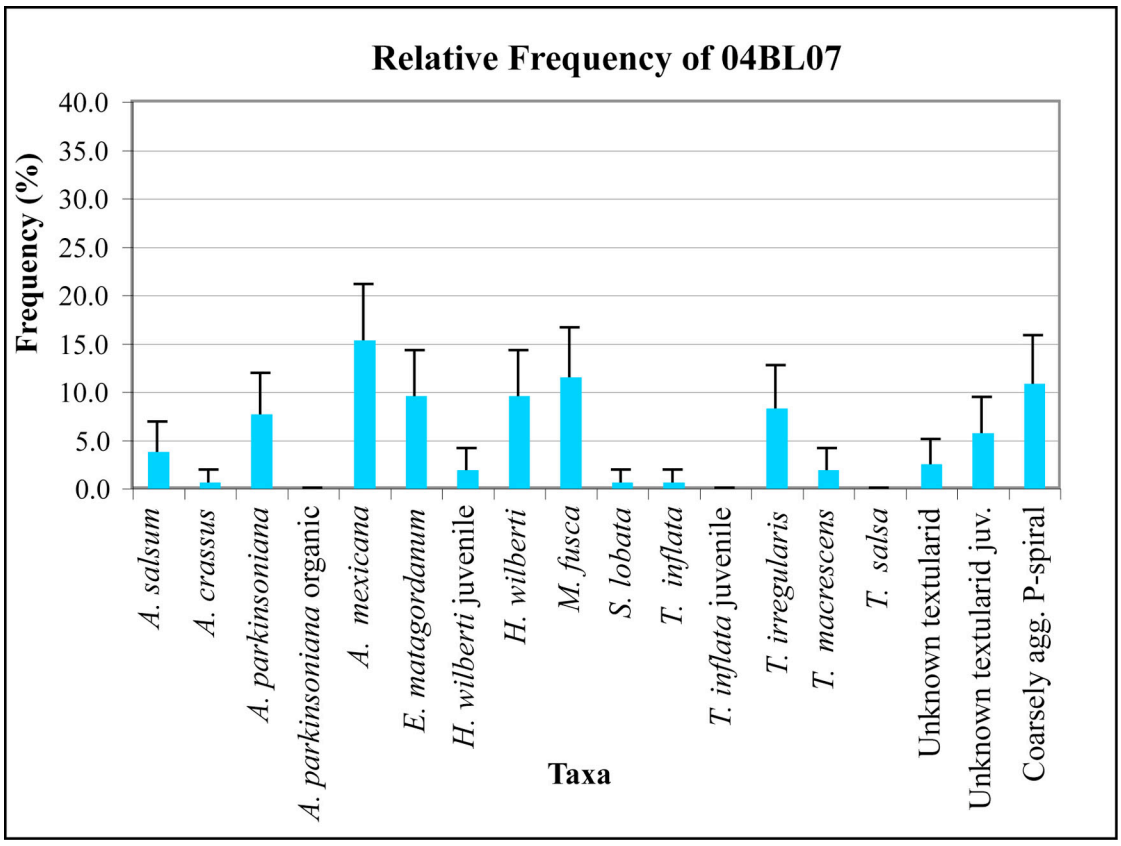
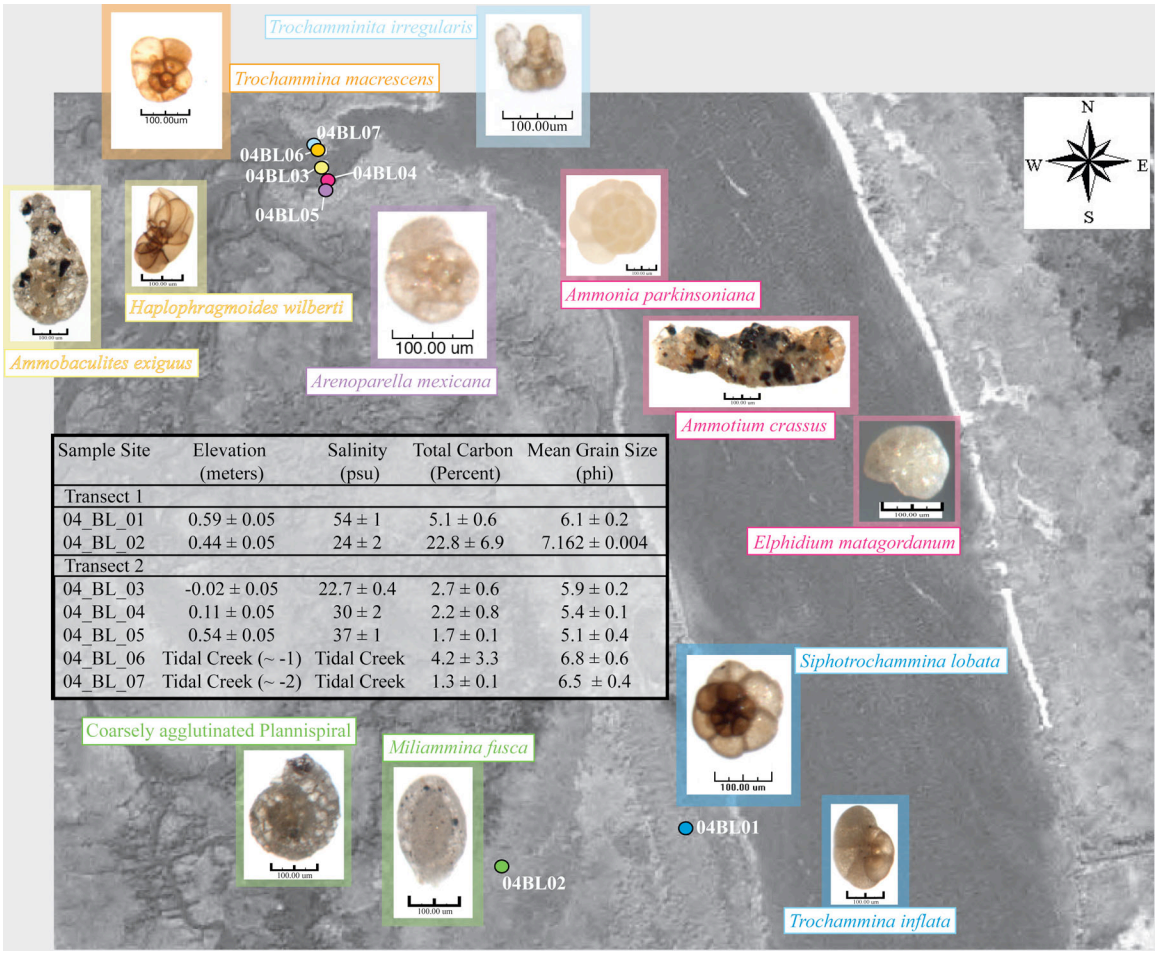


Figure 14. The graphical series displays change in relative frequency among eighteen species. The most abundant species at site 04BL07 are *A. mexicana*, *M. fusca*, and coarsely agglutinated planispiral forms. Error bars are 95 % confidence level of theoretical sampling error (Patterson and Fishbein, 1989).



Sample Site	Elevation (meters)	Salinity (psu)	Total Carbon (Percent)	Mean Grain Size (phi)
Transect 1				
04_BL_01	0.59 ± 0.05	54 ± 1	5.1 ± 0.6	6.1 ± 0.2
04_BL_02	0.44 ± 0.05	24 ± 2	22.8 ± 6.9	7.162 ± 0.004
Transect 2				
04_BL_03	-0.02 ± 0.05	22.7 ± 0.4	2.7 ± 0.6	5.9 ± 0.2
04_BL_04	0.11 ± 0.05	30 ± 2	2.2 ± 0.8	5.4 ± 0.1
04_BL_05	0.54 ± 0.05	37 ± 1	1.7 ± 0.1	5.1 ± 0.4
04_BL_06	Tidal Creek (~ -1)	Tidal Creek	4.2 ± 3.3	6.8 ± 0.6
04_BL_07	Tidal Creek (~ -2)	Tidal Creek	1.3 ± 0.1	6.5 ± 0.4

Figure 15. This figure displays the site locations and the dominant or most frequently occurring foraminiferal species for each site. It also displays the environmental variables in the table: elevations, salinity, total carbon and mean grain size for each site. **Note:** This background map is not for navigational purposes and is only used here to display the foraminifera and environmental variables relative to the site locations.

Multivariate Cluster Analysis

Cluster analysis was used to group together samples with similar species composition and to assist in recognition of foraminiferal assemblages that may be related to marsh subenvironments. The dendrogram (Fig. 16) shows a strong difference between sample 04BL02 and all other samples at a value of 25 of the re-scaled Euclidean distance coefficient. Cluster 1 (in light blue) includes the majority of the study sites: the mudflat (04BL03), tidal creek edge (04BL06), middle of the tidal creek (04BL07), marsh edge (04BL04), the Bayou Lafourche levee (04BL01) and the natural tidal creek levee (04BL05). Two subclusters occur within Cluster 1 below a rescaled Euclidean distance coefficient of ~13, determined to be a significant difference based on inspection of the assemblages. The first subcluster (Cluster 1A) groups together sites 04BL03, 04BL06, 04BL07 and 04BL04 based on similarity in foraminiferal assemblages, and these sites are all very close in location on the mudflat and adjacent tidal creek channel. The second subcluster (Cluster 1B) includes sites 04BL01 and 04BL05, which are both from levee crest locales. Cluster 2 (in red) consists of a single sample from the interior marsh site (04BL02). Clearly, the clusters, which are defined based solely on the relative frequency of foraminifers, have separated the samples into groupings consistent with subenvironments in the marsh and may be considered biofacies.

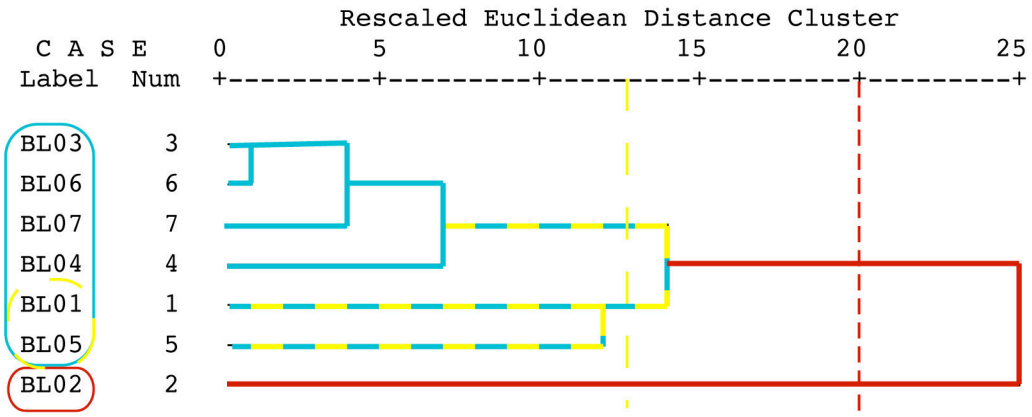


Figure 16. This dendrogram show the Bayou Lafourche study sites on the left and the average linkage between groups by the simple Euclidean distance coefficient between every possible pair of samples. This shows a relationship between the sample pairs is that the closer the samples are to each other the more similar they are. The opposite is true, that the further in distance the samples are from each other the more dissimilar they become and can be split into groups. There are two main clusters, the lt. blue and the red cluster separated by the (red dash line) 20 distance coefficient. There is a subcluster of the lt. blue cluster. This is denoted by the (yellow dash line) at the ~ 13 distance coefficient. This subcluster is outlined in lt. blue and yellow dashed lines.

Each cluster contains a distinctive assemblage of species, which will be regarded as biofacies because of their connection with marsh subenvironments. These biofacies are named by their relationship to the subenvironments and defined by the species content of the clusters and subclusters analyses. Each biofacies may have some overlapping species between groups, however, the relative frequencies are different and are documented below by the most dominant, then the most frequent followed by minor species that characterize each cluster. Figure 17 displays a summary of each biofacies described below.

Cluster 1 is dominated by *Arenoparrella mexicana* and *Haplophragmoides wilberti*, with frequent amounts of adult *Trochammina inflata*, *Miliammina fusca*, *Ammonia parkinsoniana*, and *Siphotrochammina lobata* and minor amounts of juvenile *Trochammina inflata*, *Trochammina macrescens*, and *Trochamminita irregularis.* This assemblage is named the Marsh Biofacies.

Subcluster 1A is dominated by *Arenoparrella mexicana*, and *Haplophragmoides wilberti* with frequent amounts of *Ammonia parkinsoniana*, *Elphidium matagordanum*, *Ammotium crassus, Miliammina fusca* and *Trochammina inflata* and minor amounts of *Trochamminita irregularis* and *T. macrescens.* This assemblage is named the Marsh Edge Biofacies (Fig.17).

Subcluster 1B is dominated by *Arenoparrella mexicana*, with frequent amounts of adult and juvenile *Trochammina inflata* and *Siphotrochammina lobata* and minor amounts of *Trochammina macrescens.* This assemblage is named the Marsh Levee Biofacies (Fig.17).

Cluster 2 is dominated by *Miliammina fusca* with frequent amounts of *Arenoparrella mexicana* and minor amounts of *Haplophragmoides wilberti* and *Trochamminita irregularis.* This assemblage is named the Interior Marsh Biofacies (Fig.17).

In general, the calculated percent frequency of the dominant, common, and minor foraminiferal species present at each location varied within each of the seven sample sites. The cluster analysis has quantitatively defined assemblages, which are interpreted as biofacies based on their distribution and will be used in the following discussion. In the next section, statistical comparisons are introduced as a means of gauging the degree of correlation between the aforementioned foraminiferal frequencies and measured environmental variables of the transgressive marsh within the lower Lafourche headland.

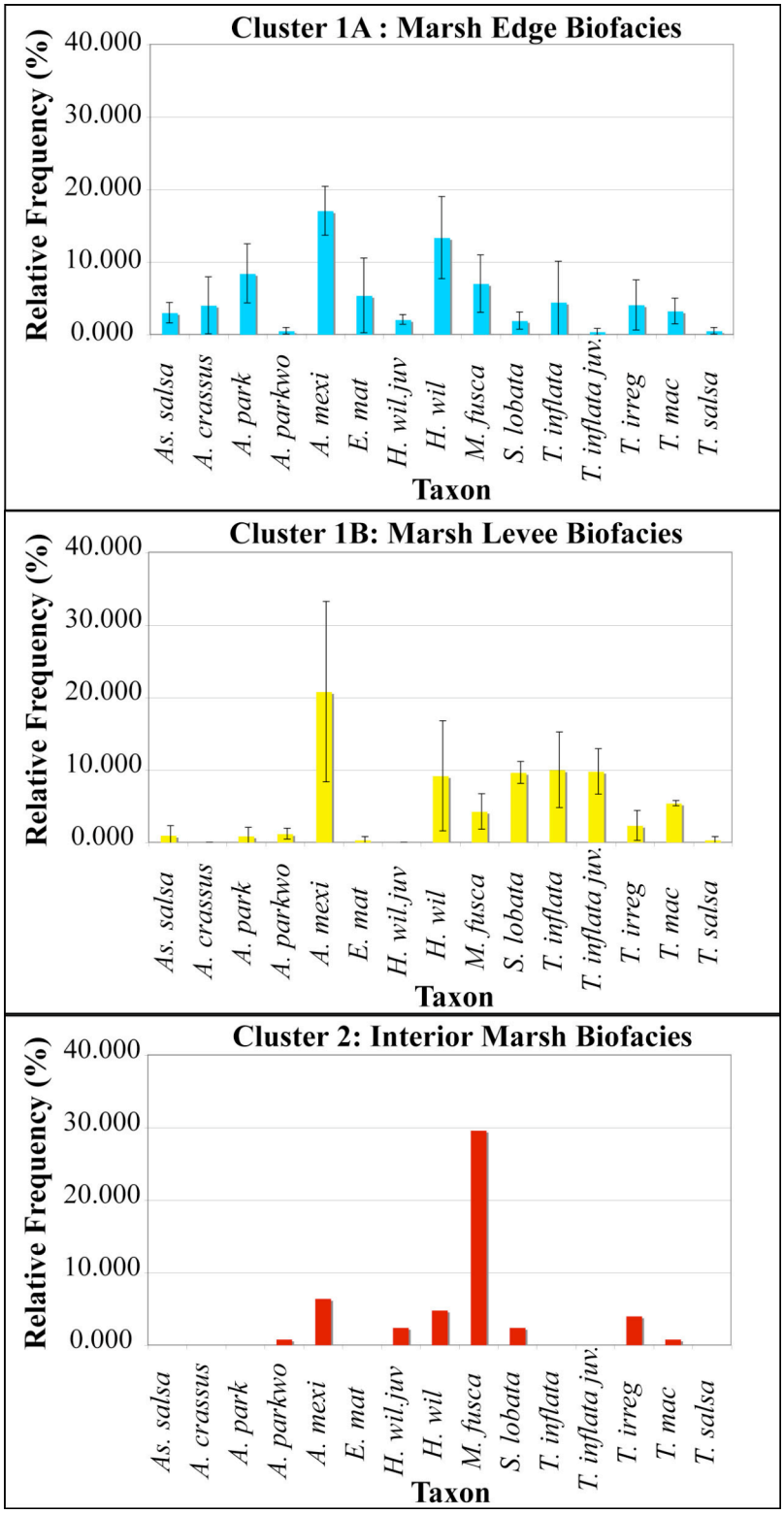


Figure 17. Average species compositions of two subclusters and one cluster of samples based on Q-mode cluster analysis. The error bars, except for Cluster 2, which only represents sample 04BL02, show the standard deviation for each species. The color of each histogram is representative of the cluster color in the dendrogram as well as the biofacies based on cluster analyses (Fig.16).

Statistical Quantification of Factors Controlling Foraminifera

In the previous sections, geographic variability for a range of parameters was documented. These parameters included elevation, salinity, total carbon content and mean grain size. Statistical analysis is required in order to determine if the any of these factors correspond to the spatial distribution of foraminiferal species (specimen density). Specifically, the correlation analysis can test for relationships between the foraminiferal taxa and each of the measured physical parameters. Seven of the 21 most common foraminiferal taxa had a strong correlation (significant at the $\alpha \leq 0.05$ level) with one or more of the variables. In addition, another 3 taxa had a marginal correlation (significant at the $\alpha \leq 0.1$ level) with one or more of the variables. Four of the taxa had a negative correlation and six had a positive correlation with one or more of the environmental parameters (Table 6a, b). Four taxa showed potential correlation but were just slightly outside of the marginal correlation level, thus, 11 of the 21 taxa analyzed showed no significant linear correlation with any of the variables.

Correlations

The following will highlight each environmental variable and the foraminiferal species with which it correlates (Table 6 continued to 6a, 6b). The correlating taxa within each variable will be arranged first to describe any positive correlations then any negative correlations. However, it is important to note that each species can have more that one correlation.

Elevation correlations

There are two taxa that correlate significantly and two that are marginally correlated with elevation. The two foraminiferal taxa with the most significant negative correlations are *Ammotium crassus* (r=-0.966; $\alpha = 0.008$; Table 6) and *Ammonia parkinsoniana* (r=-0.940; $\alpha = 0.018$; Table 6). The two marginal negative correlations for elevation are *Ammoastuta salsa* (r=-0.863; $\alpha = 0.060$; Table 6) and juvenile *Haplophragmoides wilberti* (r=-0.794; $\alpha = 0.108$; Table 6a).

Salinity correlations

Three taxa correlate with salinity. Only juvenile *Trochammina inflata* (r = 0.957; $\alpha = 0.011$; Table 6b) correlates significantly to salinity. The other two taxa have marginal correlations. The positive marginal correlation is to the organic test linings of *Ammonia parkinsoniana* (r=-0.828; $\alpha = 0.083$; Table 6b), and the negative marginal correlation is with juvenile *Haplophragmoides wilberti* (r=-0.848; $\alpha = 0.070$; Table 6a).

Mean grain size correlations

Three taxa correlate significantly with mean grain size. All three are significant positive correlations for mean grain size and are as follows: *Polysaccammina ipohalina* (r=0.866; $\alpha = 0.012$; Table 6a), juveniles of an unknown textularid (r=0.826; $\alpha = 0.022$; Table 6b), and *Miliammina fusca* (r=0.790; $\alpha = 0.035$; Table 6a).

Total carbon correlations

Three taxa correlate significantly with total carbon. The positive correlations to total carbon are with *Miliammina fusca* ($r=0.925$; $\alpha = 0.003$; Table 6a), the juveniles of an unknown textularid ($r=0.835$; $\alpha = 0.019$; Table 6b), and adult forms of the unknown textularid ($r=0.791$; $\alpha = 0.034$; Table 6b).

Variables		*As. salsa*	*A. crassus*	*A. parkinsoniana*	*A. parkinsoniana (organic test)*	*A. mexicana*	*Elphidium* spp.	*E. matagordanum*
Elevation (m)	Pearson Correlation	❖-0.863	❁ -0.966	❁-0.940	0.553	0.067	0.274	-0.538
	Sig. (2-tailed)	0.060	0.008	0.018	0.334	0.915	0.656	0.350
	N	5	5	5	5	5	5	5
Salinity: (Specific Conductivity) (psu)	Pearson Correlation	-0.534	-0.526	-0.433	❖ 0.828	0.110	0.745	-0.228
	Sig. (2-tailed)	0.354	0.363	0.466	0.083	0.860	0.149	0.713
	N	5	5	5	5	5	5	5
Total Carbon; (Ctotal Avg.) (%)	Pearson Correlation	-0.612	-0.324	-0.488	0.179	-0.642	-0.291	-0.403
	Sig. (2-tailed)	0.144	0.478	0.267	0.702	0.120	0.527	0.369
	N	7	7	7	7	7	7	7
Mean Grain Size (phi)	Pearson Correlation	-0.381	-0.451	-0.325	-0.137	-0.570	0.172	-0.252
	Sig. (2-tailed)	0.398	0.310	0.477	0.769	0.182	0.712	0.585
	N	7	7	7	7	7	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

Table 6. Matrix of correlation coefficients for species versus physical parameters. The type of correlation, positive or negative, is dependent on the Pearson's positive or negative value. The key below the table denotes two designations: a very significant correlation is defined herein as $\alpha \leq 0.05$ and marginally significant is $\alpha \leq 0.1$. Each species correlate to more than one variable. The full correlation matrix of all variables is in Appendix B.

Variables		*H. wilberti* juvenile	*H. wilberti*	*M. fusca*	*P. ipohalina*	*S. lobata*	*T. comprimata*	*T. inflata*
Elevation (m)	Pearson Correlation	❖ -0.794	-0.390	0.267	0.443	0.787	0.565	0.244
	Sig. (2- tailed)	0.108	0.516	0.664	0.455	0.115	0.321	0.692
	N	5	5	5	5	5	5	5
Salinity: (Specific Conductivity) (psu)	Pearson Correlation	❖ -0.848	0.206	-0.328	0.313	0.754	0.370	0.747
	Sig. (2- tailed)	0.070	0.740	0.590	0.608	0.141	0.540	0.147
	N	5	5	5	5	5	5	5
Total Carbon; (Ctotal Avg.) (%)	Pearson Correlation	0.269	-0.323	❁ 0.925	0.373	-0.150	-0.075	-0.341
	Sig. (2- tailed)	0.560	0.480	0.003	0.410	0.749	0.873	0.455
	N	7	7	7	7	7	7	7
Mean Grain Size (phi)	Pearson Correlation	0.246	-0.266	❁ 0.790	❁ 0.866	-0.433	-0.381	-0.553
	Sig. (2- tailed)	0.595	0.564	0.035	0.012	0.332	0.400	0.198
	N	7	7	7	7	7	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

Table 6a (continued). Matrix of correlation coefficients for species versus physical parameters. The type of correlation, positive or negative, is dependent on the Pearson's positive or negative value. The key below the table denotes two designations: a very significant correlation is defined herein as $\alpha \leq 0.05$ and marginally significant is $\alpha \leq 0.1$. Each species correlate to more than one variable. The full correlation matrix of all variables is in Appendix B.

Variables		*T. inflata* juvenile	*T. irregularis*	*T. macrescens*	*T. salsa*	Unknown textularid juvenile	Unknown textularid	Coarsely agglutinated planispiral
Elevation (m)	Pearson Correlation	0.723	0.323	0.509	- 0.434	0.593	0.417	-0.143
	Sig. (2-tailed)	0.167	0.596	0.381	0.465	0.292	0.485	0.818
	N	5	5	5	5	5	5	5
Salinity: (Specific Conductivity) (psu)	Pearson Correlation	❁ 0.957	-0.387	0.786	-0.225	0.028	0.338	-0.667
	Sig. (2-tailed)	0.011	0.520	0.115	0.717	0.965	0.579	0.218
	N	5	5	5	5	5	5	5
Total Carbon; (Ctotal Avg.) (%)	Pearson Correlation	-0.193	0.000	-0.500	-0.431	❁ 0.835	❁ 0.791	0.570
	Sig. (2-tailed)	0.678	0.999	0.253	0.335	0.019	0.034	0.182
	N	7	7	7	7	7	7	7
Mean Grain Size (phi)	Pearson Correlation	-0.387	0.473	-0.348	-0.638	❁ 0.826	0.436	0.646
	Sig. (2-tailed)	0.391	0.283	0.444	0.123	0.022	0.328	0.117
	N	7	7	7	7	7	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

Table 6b (continued). Matrix of correlation coefficients for species versus physical parameters. The type of correlation, positive or negative, is dependent on the Pearson's positive or negative value. The key below the table denotes two designations: a very significant correlation is defined herein as $\alpha \leq 0.05$ and marginally significant is $\alpha \leq 0.1$. Each species correlate to more than one variable. The full correlation matrix of all variables is in Appendix B.

Discussion

Specimen Densities and Diversity

Total specimen density reported herein ranged between a maximum of 5,900 tests/10 ml in the mudflat site (04BL03) and a minimum of 500 tests/10 ml in the tidal creek location (04BL07) a short distance away (Table 4). In contrast, test densities reported in studies prior to the 1970's were consistently lower in the Mississippi delta. For example, Lankford (1959) reported a value of 162 tests/10 ml in the single marsh sample he examined. Phleger (1955) reported an average of ~455 tests/10 ml in the marsh and 925 tests/10 ml in tidal creeks and channels flanked by marsh. Fossil densities reported in this study and other recent studies in the intertidal marsh of this region are consistently higher, perhaps because of the improved sampling and preparation methods. For example, a recent study in south-central Louisiana (Scott et al., 1991) applied sampling and preparation methods similar to those of this study and reported specimen densities of 1–2906 tests/10 ml in their transects 1-3 through saline marshes similar to that of this study.

Comparison of this study with others from around the world (i.e., Europe, United Kingdom, and eastern coast of the U. S.) also suggests that sampling and preparation methods may have an effect on the total density. Horton et al. (1999) sampled 10 different intertidal locales distributed around the coast of the United Kingdom. They sampled to 10 cm in depth, used wet splitting and other wet techniques, and used the >63-μm fraction. Their specimen densities ranged between 0-3,000 specimens/10 ml, which fall within the range reported in this study. On the east coast of the U. S., de Rijk

(1995) used the wet splitting techniques but sampled to depths of only 1 cm. She found densities of 179-2,000 tests/10 ml and in another recent study (de Rijk and Troelstra, 1999) densities of 0-1,800 tests/10 ml. In North Carolina, Culver and Horton (2005) used methods similar to those of this study, and found densities of 0-1,300 individuals/10 ml. While most of these recent studies have improved one or two sampling and preparation methods from older studies, all of these seem to have a similar range, which is about half of the maximum specimen density recorded in this study. Therefore, by using a combination of improved methods, such as keeping the samples hydrated, sampling to 10 cm depth, and sieving to 45 μm, higher specimen densities are recovered. Alternatively, specimen densities of the study area may be naturally higher than those in other marshes of the world due either to enhanced production of foraminifera or sediment starvation.

The diversity reported at Bayou Lafourche is larger than that reported from other older studies in the Mississippi delta region. In this study, the diversity was 39 species. Historically, researchers working in the Mississippi delta have reported 8 to 13 taxa as the total number of species in marsh and intertidal environments (Kornfeld, 1931; Warren, 1957; Lankford, 1959; Phleger, 1955, 1960a, 1960b; and Gallacher, 1964). In contrast, diversity similar to that of this study were reported in more recent studies in the region. For example, Scott et al. (1991) reported 37 species in saline marsh environments of the Mississippi delta, of which 14 species are the same as those of this study. However, Scott et al. (1991) study lacks the deeper dwelling foraminifera, such as *Haplophragmoides wilberti,* which is present between 3-7 cm (Ozarko et al., 1997), because Scott et al. (1991) sampled only the top 1 cm. In this study, samples were taken

to 10 cm depth, increasing the total number of species and improving the diversity observed in intertidal marsh taxa in this region. Culver and Horton (2005) in the North Carolina marshes also sampled to 10 cm depth and had the most similar diversity, which was 29 species, of which 15 are the same as those found in this study.

Comparison of Bayou Lafourche Biofacies to those of other regions

Three distinct biofacies within the study site are distinguished by their assemblages and are comparable to those of other regions. The first of the three biofacies, the Marsh Levee Biofacies, has large relative frequencies of *Arenoparrella mexicana, Trochammina inflata* and *Siphotrochammina lobata* with minor amounts of *T. macrescens*. It is further characterized by high salinity, high elevation and a sandy-silt mean grain size. In contrast, the second biofacies, the Marsh Edge Biofacies, is characterized by high frequencies of *A. mexicana, Haplophragmoides wilberti*, *Miliammina fusca* and *T. inflata,* common amounts of *Ammonia parkinsoniana*, *Elphidium matagordanum* and *Ammotium crassus* and minor amounts of *T. macrescens*, *Trochamminita irregularis* and *Ammoastuta salsa.* The biofacies is further characterized by intermediate salinities and intermediate to low elevations. The third biofacies, the Interior Marsh Biofacies, is dominated by *M. fusca* with common amounts of *A. mexicana* and minor amounts of *H. wilberti* and *T. irregularis.* The biofacies is further characterized by intermediate to low elevation and salinity, a clayey-silt mean grain size, and the highest percentage of total carbon.

Biofacies described in this study are compared to intertidal biofacies of previous studies. After establishing whether or not the biofacies are comparable to those of other

areas, the range of individual species across environmental gradients is compared with those of other areas. The Marsh Levee Biofacies of this study is most comparable to the high-salinity to intermediate-salinity, high-marsh setting distinguished by Culver and Horton (2005) in North Carolina. While their biofacies was similar in having common *Arenoparrella mexicana, Trochammina inflata, Siphotrochammina lobata* and frequent amounts of *Haplophragmoides wilberti*, it differed by including common to minor amounts of several species, like *Tiphotrocha comprimata* and *Jadammina macrescens* that were not a part of the Marsh Levee Biofacies of this study. Williams (1994) noted that *Arenoparrella mexicana* with *Trochammina inflata* dominates the high marsh elevations in Port Bay, Texas. *T. inflata* is found as a characteristic species of the high to middle marsh with high to intermediate salinities in eastern and Pacific U. S. coastal marshes and in the Atlantic coastal marshes of the United Kingdom (Scott and Medioli, 1978; de Rijk and Troelstra, 1999; Horton et al., 1999; Murray and Alve, 1999; Culver and Horton, 2005).

Trends of individual species at Bayou Lafourche are similar to species trends at other locales. However, in older studies of the intertidal zone of the Mississippi Delta, *Arenoparrella mexicana* was reported as less common than in this study and not considered a major biofacies species (Lankford, 1959; Warren, 1957 and Phleger, 1955, 1960a, b). In contrast, it is noted as an important species in recent papers of the south-central Louisiana to Texas intertidal marsh areas (Scott et al., 1991 and Williams, 1994).

When comparing the Marsh Edge Biofacies with previous works, the high-salinity, low-marsh biofacies assemblage of Culver and Horton (2005) was most similar having in common *Arenoparrella mexicana* and *Haplophragmoides wilberti* with

frequent amounts of *Miliammina fusca* whereas, several other studies had two or three of the same species but did not include all of the species that make up this biofacies at the Bayou Lafourche study site. Those studies with assemblages consisting of a combination of agglutinated and calcareous foraminifera include Horton et al. (1999), Scott et al. (1991) and Williams (1994). However, none are a close match in all species.

Distributions of individual species of the Marsh Edge Biofacies at Bayou Lafourche are similar to those at other locales of the Mississippi delta and Texas. *Trochammina inflata* and *Haplophragmoides wilberti* were observed as common species in marsh facies, the only exception being that *H. wilberti* was not observed in the Port Bay Texas marshes, probably due to sampling methods (Lankford, 1959; Warren, 1957 and Phleger, 1955, 1960a, b; Scott et al., 1991 and Williams, 1994). In the Outer Banks intertidal marsh setting of North Carolina, there were several similarities to the Marsh Edge Biofacies of this study as noted above. Additional species in common were *Ammobaculites crassus*, *Trochamminita irregularis*, *Miliammina fusca* and carbonate species, all of which were common in the intermediate to low-salinity and low marsh elevations (Culver and Horton, 2005). Herein, *Ammoastuta salsa* was present in common frequencies only in the mudflat and the middle of the tidal creek, a distribution consistent with its marginal negative correlation with elevation. A recent investigation by Williams (1994) noted *As. salsa* in low elevations of Port Bay and the Aransas River estuary, Texas. Lastly, in this study, the marsh edge, mudflat, and middle tidal creek locations of the Marsh Edge Biofacies contained calcareous species, in particular *Ammonia parkinsoniana*. On the east coast of the U.S. Culver and Horton (2005) reported

larger numbers of calcareous species at lower marsh elevations, however, *A. parkinsoniana* was not found.

The Marsh Interior Biofacies is most similar to the lower marsh transect 3 of Scott et al. (1991), with the co-dominating *Miliammina fusca* and *Arenoparrella mexicana.* The Marsh Interior Biofacies also resembles the Nova Scotian and southern Californian Low Marsh A and B facies of Scott and Medioli (1978) with the dominance of *Miliammina fusca*. Although again for both works, there were differences among less common species. Similarly, *M. fusca* was described as a dominant species in an intermediate elevation in the intertidal marsh biofacies of Port Bay, Texas (Williams, 1994). The preference of *M. fusca* for the intermediate to low marsh has been recognized worldwide (e.g., Murray, 1991 and Horton et al., 1999).

Correlations Between Foraminifera and Physical Variables

The consensus among scientists was that foraminiferal assemblages were controlled by a number of variables, but it was unclear which were important. In this study, correlation analysis was used to infer significant trends between species and four environmental parameters. Overall, seven species of 21 exhibited significant ($\alpha \leq 0.05$) correlation with elevation, salinity, mean grain size and total carbon and three had marginal correlations ($0.05 \leq \alpha \leq 0.10$) with elevation and salinity. These will be discussed in the sections below. Additionally, four taxa showed correlation slightly outside the set limit of significance (significant $\alpha \leq 0.1$). These taxa are *Siphotrochammina lobata* ($r = 0.787$; $\alpha = 0.115$; Table 8) and *Trochammina macrescens*

(r= 0.786; α = 0.115; Table 8), which correlate to elevation; coarsely agglutinated planispiral forms (r= 0.646; α = 0.117; Table 9), which correlate to mean grain size; and *Arenoparrella mexicana* (r= -0.642; α = 0.120; Table 7), which correlates to total carbon. Unfortunately, several species common in the biofacies did not correlate significantly with any measured physical variable. A larger sample size might have improved correlations with the environmental variables. Overall, the analysis suggests in a quantitative and repeatable way that several of the common species co-vary and may be controlled by several environmental factors, and some of these correlations can be related to the species that are most characteristic of the biofacies.

Salinity

In this study, juveniles of *Trochammina inflata* have a significant positive relationship to salinity, whereas juveniles of *Haplophragmoides wilberti* have a marginal negative correlation and were more abundant with lower salinities (22–30 psu). This result is consistent with biofacies relationships from other regions. Previous works have not considered juvenile forms, however, correlations have been observed between the adult forms and salinity in northern Europe and the United Kingdom (Horton et al., 1999).

Elevation

Statistical correlations between elevation and the intertidal foraminifera *Ammotium crassus*, *Ammonia parkinsoniana* and *Haplophragmoides wilberti* are new findings that have not been documented in previous investigations of the Mississippi

delta region. Previously mentioned researchers in this region suggested trends mainly with salinity rather than elevation.

Statistical analyses show a significant negative correlation between elevation and *Ammotium crassus* , which is most common at the marsh edge and mudflat sites. The correlation of *A. crassus* with elevation has not been specifically noted in previous intertidal marsh studies of the Mississippi delta or from other regions of the world, although a qualitative relationship was noted in the low-marsh biofacies North Carolina (Culver and Horton, 2005).

There is a significant negative correlation between elevation and *Ammonia parkinsoniana* (Table 7), a calcareous species found in the marsh edge locations. *Ammonia parkinsoniana*-elevation relationships are observed as a qualitative relationship in the low marsh and tidal flats in the Old Currituck inlet on the border of Virginia and North Carolina (Robinson and McBride, 2003). Calcareous species such as *Ammonia beccarii*, *Elphidium excavatum* and *Quinqueloculina seminulum* have been noted in the low intertidal marshes of the Mississippi delta region, Texas and the eastern coast of the U.S. (Scott et al., 1991; Williams, 1994; de Rijk, 1995 and Robinson and McBride, 2003). Calcareous species, such as *Haynesina germanica*, *Elphidium williamsoni* and *Quinqueloculina* spp., characterized the low marsh and intertidal flat in the United Kingdom (Horton et al., 1999).

Statistical analyses show a marginal negative correlation for *Ammoastuta salsa* and juveniles of *Haplophragmoides wilberti* to elevation. *Ammoastuta salsa* has not been mentioned in previous studies done using correlation analysis. In addition, these more recent investigations noted that salinity variations could be a function of elevation (de

Rijk and Troelstra, 1999; Horton et al., 1999; Culver and Horton, 2005). Herein elevation and salinity covary (Appendix B), so it remains unclear which, if not both, controls the distribution of affected species.

Sediment texture

Three taxa have significant positive correlates with mean grain size expressed as phi: *Polysaccammina ipohalina*, juveniles of an unknown textularid and *Miliammina fusca*. Each of these taxa has higher frequencies in the clayey-silt grain size fraction. These statistical correlations are new results in that these trends have not been reported in previous studies.

Organic Matter

Correlation analysis reveals that only two species had a significant positive correlation to total carbon: *Miliammina fusca* and the juveniles and adult forms of the unknown textularid. These three counting groups are the most common in the interior marsh. Previous investigations in the Mississippi delta hypothesized that foraminifera may trend with organic matter, however no statistical correlations were done (Lankford, 1959 and Plitnik, 1985). Several studies in Norway, the United Kingdom, southern California and Nova Scotia qualitatively connect *Miliammina fusca* to organic matter, measured as TOC (Scott and Medioli, 1978; Horton et al., 1999; and Murray and Alve, 1999).

Additionally, statistical analysis in this study demonstrates a covariance relationship between total carbon and sediment texture (Appendix B). The covariance complicates interpretation of the correlation between the foraminifers and the variables.

Do the foraminifers respond to just one variable, both, or neither, in which case the correlation is by chance? This difficulty can be resolved in future work by (1) increasing the number of samples in this dataset and (2) replicating the fossil counts so that a more powerful statistical method, like ANOVA, can be used to test the significance of the relationship between species and environmental variables.

Conclusions

1) This investigation in a transgressive coastal environment provides an improved understanding of marsh foraminifera by utilizing updated preparation methods and techniques that ensure a greater recovery of agglutinated taxa than was possible with previously used methods. Additionally, the use of modern taxonomy enables enhanced identification of foraminifera and a potential for greater diversity. Sampling to 10 cm depth ensured that deep-dwelling species were recovered.

2) There are six dominant or most abundant foraminiferal species noted by specimen density and frequency throughout the study area. The species (Table 5) are *Arenoparrella mexicana*, *Miliammina fusca*, *Haplophragmoides wilberti* (adult and juvenile) and *Trochammina inflata* (adult and juvenile). An additional 12 foraminiferal taxa are common throughout the sample sites (Fig. 10) and include *Ammonia parkinsoniana,* coarsely agglutinated planispiral forms, an unknown textularid (adults and juveniles), *Siphotrochammina lobata, Ammotium crassus, Trochammina macrescens, Elphidium matagordanum, Ammoastuta salsa,* organic linings of *Ammonia parkinsoniana*, *Trochamminita irregularis* and *Trochamminita salsa.*

3) Qualitatively, trends in relative frequency of eighteen taxa indicate relationships with subenvironments of the marsh and tidal creek (Figs. 11-14).

4) Q-mode cluster analysis grouped the samples into two clusters, one cluster contained two subclusters, based on similarity of taxon frequencies. Inspection of the geographic distribution of the clusters linked assemblages of foraminiferal species to subenvironments, which can be considered as biofacies. These biofacies are defined as (1) marsh, which includes two sub-biofacies, marsh edge and marsh levee, and (2) interior marsh (Table 6).

5) A relationship between foraminifer species and four physical variables was inferred based on correlation analysis. Of the 21 foraminiferal taxa analyzed, seven had significant correlations ($\alpha \leq 0.05$ level) and three had marginal correlations ($0.5 \leq \alpha \leq 0.1$ level) with one or more of the four environmental variables examined in this study (Table 6, a, b; Appendix B). A summary of the taxa and their significant and marginal correlations to each environmental variable are listed below. The significant positive correlations are listed first under the sub-notation i, the significant negative correlations are listed second under the sub-notation ii, and the marginal correlations are listed third under iii.

a. **Elevation**

i. No significant positive correlations with elevation.

ii. *Ammotium crassus* (r=-0.966; $\alpha = 0.008$; Table 6) and *Ammonia parkinsoniana* (r=-0.940; $\alpha = 0.018$; Table 6).

iii. Two marginal negative correlations with elevation are: *Ammoastuta salsa* (r=-0.863; $\alpha = 0.060$) and juveniles of *Haplophragmoides wilberti* (r=-0.794; $\alpha = 0.108$; Table 6a).

b. **Salinity**

i. Juveniles of *Trochammina inflata* (r = 0.957; $\alpha = 0.011$; Table 6b).

ii. No significant negative correlations with pore water salinity.

iii. Two taxa have marginal correlations:

1. The positive marginal correlation is to the organic test linings of *Ammonia parkinsoniana* (r=-0.828; $\alpha = 0.083$; Table 6b).
2. The other a negative marginal correlation is with juveniles of *Haplophragmoides wilberti* (r=-0.848; $\alpha = 0.070$; Table 6a).

c. **Mean Grain Size**

i. *Polysaccammina ipohalina* (r=0.866; $\alpha = 0.012$; Table 6a), juveniles of an unknown textularid (r=0.826; $\alpha = 0.022$; Table 6b) and *Miliammina fusca* (r=0.790; $\alpha = 0.035$; Table 6a).

ii. No negative correlations with mean grain size.

d. **Total Carbon**

i. *Miliammina fusca* (r=0.925; $\alpha = 0.003$; Table 6a), the juveniles of an unknown textularid (r=0.835; $\alpha = 0.019$; Table 6b), and adult forms of the unknown textularid (r=0.791; $\alpha = 0.034$; Table 6b).

ii. No negative correlations with total carbon.

6) The most exciting correlations of this study provide new results for the delta region. Older works demonstrated a relationship between foraminiferal assemblages and salinity. This work further suggests correlations between foraminiferal taxa and elevation, mean grain size and total carbon. Juvenile forms were considered separately, and responded to salinity, elevation, mean grain size and total carbon.

7) Future investigation should consider larger data sets and numerous other environmental factors (i.e., nutrient levels, organic and inorganic carbon, pore water oxygen, etc.) and combinations of these factors to explain significant and marginal correlations, patterns of species distribution, abundance and control of each of the parameters on species of the intertidal marshes.

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Appendix A

Taxonomic Notes

Order FORAMINIFERIDA Eichwald

Suborder TEXTULARIINA Delage and Hérouard

Superfamily ASTRORHIZACEA Brady

Family SACCAMMINIDAE Brady

Subfamily THURAMMININAE A. D. Miklukho-Maklay

Genus *Pseudothurammina* Scott, Medioli, and M.A. Williamson

Pseudothurammina limnetis (Scott and Medioli)

Armorella sphaerica Heron-Allen and Earland, 1932, ser.3, vol. 52, pt. 3, art. 10, p. 257; pl. 2, figs. 4-11.

Family POLYSACCAMINIDAE Loeblich and Tappan

Genus *Polysaccammina* Scott

Polysaccammina ipohalina Scott

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

Superfamily AMMODISCACEA Reuss

Family AMMODISCIDAE Reuss

Subfamily AMMODISCINAE Reuss

Genus *Ammodiscus* Reuss

Ammodiscus minutissimus Cushman and McCulloch

Ammodiscus minutissimus Cushman and McCulloch, 1939, vol. 6, p. 70; pl. 5, figs. 3-4.

Superfamily RZEHAKINACEA Cushman

Family RZEHAKINIDAE Cushman

Genus *Miliammina* Heron-Allen and Earland

Miliammina fusca (Brady)

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

Superfamily LITUOLACEA de Blainville

Family HAPLOPHRAGMOIDIDAE Maync

Genus *Haplophragmoides* Cushman

Haplophragmoides manilaensis Andersen

Haplophragmoides manilaensis Andersen, 1953, vol. 4, pt.1, p. 22; pl. 4, fig. 8.

Haplophragmoides wilberti Andersen

Haplophragmoides wilberti Andersen, 1953, vol. 4, pt. 1, p. 21; pl. 4, fig. 7.

Genus *Trochamminita* Cushman and Brönnimann

Trochamminita irregularis Cushman and Brönnimann, emend. Saunders

Trochamminita irregularis Cushman and Brönnimann, emend. Saunders, 1957, vol. 134, no. 5, p. 4; pl. 2, figs. 2-8.

Trochamminita salsa (Cushman and Brönnimann), emend. Saunders

Trochamminita salsa (Cushman and Brönnimann), emend. Saunders, 1957, vol. 134, no. 5, p. 6; pl. 1, figs. 3-8.

Family LITUOLIDAE de Blainville
Subfamily AMMOMARGINULININAE Podobina
Genus *Ammobaculites* Cushman

Ammobaculites exiguus Cushman and Brönnimann

Ammobaculites exiguus Cushman and Brönnimann, 1948a, vol. 24, p. 38; pl. 7, figs. 7-8.

Genus *Ammotium* Loeblich and Tappan

Ammotium crassus Warren

Ammotium crassus Warren, 1957, vol. 8, pt. 1, p. 32; pl. 3, figs. 5-7.

Ammotium directum Cushman and Brönnimann

Ammobaculites directus Cushman and Brönnimann, 1948a, vol. 24, p. 38; pl. 7, figs.3-4.

Ammotium pseudocassis (Cushman and Brönnimann)

Ammobaculites pseudocassis Cushman and Brönnimann, 1948a, vol. 24, p. 39; pl. 7, fig. 12.

Ammotium salsum (Cushman and Brönnimann)

Ammobaculites salsus Cushman and Brönnimann, 1948b, vol. 24, p. 16; pl. 3, figs. 7-9.

Subfamily AMMOASTUTINAE Loeblich and Tappan

Genus *Ammoastuta* Cushman and Brönnimann

Ammoastuta salsa Cushman and Brönnimann

Ammoastuta salsa Cushman and Brönnimann, 1948b, vol. 24, p. 17; pl. 3, figs. 14-16.

Superfamily SPIROPLECTAMMINIACEA Cushman

Family SIROPLECTAMMINIDAE Cushman

Subfamily SPIROPLECTAMMININAE Cushman

Genus *Spiroplectammina* Cushman

Spiroplectammina earlandi (Parker)

Textularia earlandi Parker, 1952, new name, vol. 106, no. 10, p. 458; *Textularia tenuissima* Earland, 1933, vol. 7, p. 95, pl.3, figs. 21-30.

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.

Trochammina macrescens Brady

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

Genus *Siphotrochammin* Saunders

Siphotrochammina lobata Saunders

Siphotrochammina lobata Saunders, 1957, vol. 134, no. 5, p. 9; pl. 3, figs. 1-2.

Genus *Tiphotrocha* Saunders

Tiphotrocha comprimata (Cushman and Brönnimann), emend. Saunders

Trochammina comprimata Cushman and Bronnimann, 1948, emend. Saunders, 1957, vol. 134, no. 5, p. 11; pl. 4, figs. 1-4.

Subfamily ARENOPARRELLINAE Saidova

Genus *Arenoparrella* Andersen

Arenoparrella mexicana (Kornfeld), emend. Andersen

Arenoparrella mexicana (Kornfeld), emend. Andersen, 1951, vol. 2, pt. 3, p. 96; pl. 11, fig. 4.

Superfamily TEXTULARIACEA Ehrenberg

Family PSEUDOGAUDRYINIDAE Loeblich and Tappan

Subfamily PSEUDOGAUDRYININAE Loeblich and Tappan

Genus *Pseudoclavulina* Cushman

Pseudoclavulina gracilis Cushman and Brönnimann

Pseudoclavulina gracilis Cushman and Brönnimann, 1948a, vol. 24, p. 40; pl. 7, figs. 17-18.

Suborder ROTALIINA Delage and Hérouard
Superfamily DISCORBACEA Ehrenberg
Family HELENINIDAE Loeblich and Tappan
Genus *Helenina* Saunders

Helenina anderseni (Warren)

Pseudoeponides anderseni Warren, 1957, vol. 8, pt. 1, p. 39; pl. 4, figs. 12-15.

Superfamily ROTALIACEA Ehrenberg
Family ROTALIIDAE Ehrenberg
Genus *Ammonia* Brünnich

Ammonia parkinsoniana (d'Orbigny)

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

Ammonia tepida (Cushman)

Rotalia beccarii (Linnaeus) var. *tepida* Cushman, 1926, p. 79; pl. 1.

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.

Elphidium gunteri Cole

Elphidium gunteri Cole, 1931, no. 6, p. 34; pl. 4, figs. 9-10.

Elphidium mexicanum Kornfeld

Elphidium incertum (Williamson) var. *mexicanum* Kornfeld, 1931, vol. 1, p. 89; pl. 16, figs. 1-2.

Elphidium matagordanum (Kornfeld)

Nonion depressula (Walker and Jacob) var. *matagordana* Kornfeld, 1931, vol. 1, p. 87; pl. 13, fig. 2.

List of Species

Number	Taxonomic Name and Authority	Plate Number (this work)
1	*Ammoastuta salsa*(Cushman and Brönnimann), 1948	(Plate V, 18a-c)
2	*Ammotium crassus* Warren, 1957	(Plate V, 18a-c)
3	*Ammotium crassus* Warren, 1957 –just trochospiral	(Plate IV, 14a-b)
4	*Ammotium crassus* cf. *A. crassus*	
5	*Ammobaculites exiguus* Cushman and Brönnimann, 1948	(Plate III, 12a-b)
6	*Ammobaculites exiguus* Cushman and Brönnimann, 1948 -juvenile	
7	*Ammodiscus minutissimus* Cushman and McCulloch, 1939	(Plate I, 3a-c)
8	*Ammonia parkinsoniana* (d'Orbigny), 1839	(Plate VII, 27a-c)
9	*Ammonia parkinsoniana* (d'Orbigny), 1839 – organic test lining	
10	*Ammonia tepida* (Cushman), 1926	
11	*Ammonia* spp. juvenile	
12	*Ammotium directum* (Cushman and Brönnimann), 1948	(Plate IV, 15a-c)
13	*Ammotium pseudocassis* (Cushman and Brönnimann), 1948	(Plate IV, 16a-b)

Number	Taxonomic Name and Authority	Plate Number (this work)
14	*Ammotium* sp. A	
15	*Ammotium salsum* (Cushman and Brönnimann), 1948	(Plate IV, 17a-c)
16	*Arenoparrella mexicana* (Kornfled), 1951	(Plate VI, 23a-c)
17	*Buccella* sp. A	
18	*Elphidium excavatum* (Terquem), 1875	(Plate VII, 28a-c)
19	*Elphidium gunteri* Cole, 1931	
20	*Elphidium mexicanum* (Kornfeld), 1931	(Plate VIII, 29a-c)
21	*Elphidium* spp.,	
22	*Elphidium matagordanum* (Kornfeld), 1931	(Plate VIII, 30a-c)
23	*Haplophragmoides manilaensis* Andersen, 1953	(Plate I, 5a-b)
24	*Haplophragmoides manilaensis* Andersen, 1953 - juvenile	
25	*Haplophragmoides manilaensis* cf. *H. manilaensis* Andersen, 1953	
26	*Haplophragmoides wilberti* Andersen, 1953	(Plate II, 6a-c)
27	*Haplophragmoides wilberti* Andersen, 1953 – juvenile	(Plate II, 7a-b)
28	*Haplophragmoides wilberti* cf. *H. wilberti* Andersen, 1953	
29	*Helenina anderseni* (Warren), 1957	(Plate VI, 26a-c)

Number	Taxonomic Name and Authority	Plate Number (this work)
30	*Miliammina fusca* (Brady), 1870	(Plate I, 4a-c)
31	*Polysaccammina ipohalina* Scott, 1976	(Plate I 2a-c)
32	*Pseudoclavulina gracilis* Cushman and Brönnimann, 1948	(Plate VI 25a-c)
33	*Pseudothurammina limnetis* (Scott and Medioli), 1980	(Plate I, 1)
34	*Siphotrochammina lobata* Saunders, 1957	(Plate V, 21a-c)
35	*Siphotrochammina lobata* Saunders, 1957 – juvenile	
36	*Siphotrochammina lobata* cf. *S. lobata* Saunders, 1957	
37	*Spiroplectammina earlandi* (Parker), 1952	(Plate VI, 24a-c)
38	*Tiphotrocha comprimata* (Cushman and Brönnimann), 1948	(Plate VI, 22a-c)
39	*Trochammina inflata* (Montagu), 1808	(Plate V, 19a-c)
40	*Trochammina inflata* (Montagu), 1808 - juvenile	
41	*Trochamminita irregularis* Cushman and Brönnimann, 1957	(Plate II, 8a-c)
42	*Trochamminita irregularis* Cushman and Brönnimann, 1957 - juvenile	(Plate II, 9a-b)
43	*Trochammina macrescens* (Brady), 1870	(Plate V, 20a-c)
44	*Trochammina macrescens* (Brady), 1870 – juvenile	

Number	Taxonomic Name and Authority	Plate Number (this work)
45	*Trochamminita salsa* (Cushman and Brönnimann), 1957	(Plate III, 10a-c)
46	*Trochamminita salsa* (Cushman and Brönnimann), 1957 – juvenile	(Plate III, 11a-c)
47	Unknown textularid	
48	Unknown textularid juvenile	
49	Rotalid	
50	Coarsely agglutinated planispiral	(Plate VIII, 31a-c)

Plate I

Figure 1. *Pseudothurammina limnetis* (Scott and Medioli), 1980, X 100. 1, side view.

Figures 2a, 2b, 2c. *Polysaccammina ipohalina* Scott, 1976, X 100. 2a and 2c, views of opposite sides; 2b, apertural view.

Figures 3a, 3b, 3c. *Ammodiscus minutissimus* Cushman and McCulloch, 1939, X 100. 3a and 3c, views of opposite sides; 3b, edge view, aperture at lower left end.

Figures 4a, 4b, 4c. *Miliammina fusca* (Brady), 1870, X 100. 4a and 4c, views of opposite sides; 4b, edge view, aperture at top.

Figures 5a, 5b. *Haplophragmoides manilaensis* Andersen, 1953, X 100. 5a, apertural view; 5b, side view.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

Plate I

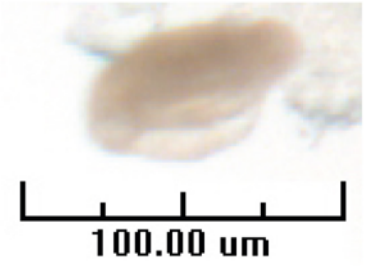
1

2a

2b

2c

3a



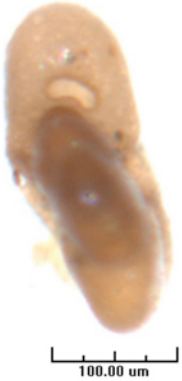
3b

3c

4a

4b

4c



5a

5b

Plate II

Figures 6a, 6b, 6c. *Haplophragmoides wilberti* Andersen, 1953, X 100. 6a and 6c, views of opposite sides; 6b, apertural view.

Figures 7a, 7b. *Haplophragmoides wilberti* Andersen, 1953, juvenile, X 100. 7a, side view; 7b, apertural view.

Figures 8a, 8b, 8c. *Trochamminita irregularis* Cushman and Brönnimann, 1957, X 100. 8a and 8c, views of opposite sides; 8b, apertural view.

Figures 9a, 9b. *Trochamminita irregularis* Cushman and Brönnimann 1957, juvenile, X 100. 7a and 7b, view of opposite sides.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

Plate II

6a

6b

6c

7a

7b

8a

8b

8c

9a

9b

Plate III

Figures 10a, 10b, 10c. *Trochamminita salsa* (Cushman and Brönnimann), 1957, X 100. 10a and 10c, views of opposite sides; 10b, apertural view.

Figures 11a, 11b, 11c. *Trochamminita* salsa (Cushman and Brönnimann), 1957, juvenile, X 100. 11a and 11c, views of opposite sides; 11b, apertural view.

Figures 12a, 12b. *Ammobaculites exiguus* Cushman and Brönnimann, 1948, X 100. 12a side view; 12b, edge view.

Figures 13a, 13b. *Ammotium crassus* Warren, 1957, X 100. 13a and 13b, views of opposite sides.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

Plate III

10a

10b

10c

11a

11b

11c

12a

12b

13a

13b

Plate IV

Figures 14a, 14b. *Ammobaculites crassus* Cushman and Brönnimann, 1948, X 100. The trochospiral portion of the test is shown; the uniserial portion is severed. 14a, side view; 14b, peripheral view.

Figures 15a, 15b, 15c. *Ammotium directum* (Cushman and Brönnimann),1948, X 100. 15a and 15c, views of opposite sides; 15b, peripheral view.

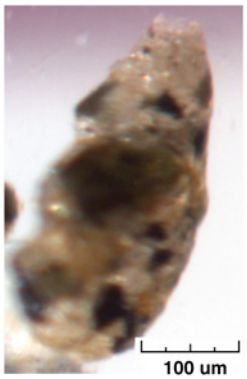
Figures 16a, 16b. *Ammotium pseudocassis* (Cushman and Brönnimann), 1948, X 100. 16a, side view; 16b, peripheral view.

Figures 17a, 17b. *Ammotium salsum* (Cushman and Brönnimann), 1948, X 100. 17a and 17c, views of opposite sides; 17b, peripheral view.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

Plate IV

14a



14b

15a

15b

15c

16a

16b

17a

17b

17c

Plate V

Figures 18a, 18b, 18c. *Ammoastuta salsa* (Cushman and Brönnimann), 1948, X 100. 18a and 18c, views of opposite sides; 18b, peripheral view.

Figures 19a, 19b, 19c. *Trochammina inflata* (Montagu), 1808, X 100. 19a, dorsal view; 19b, apertural view; 19c, ventral view.

Figures 20a, 20b, 20c. *Trochammina macrescens* (Brady), 1870, X 100. 20a, dorsal view; 20b, peripheral view; 20c, ventral view.

Figures 21a, 21b, 21c. *Siphotrochammina lobata* Saunders, 1957, X 100. 21a, dorsal view; 21b, peripheral view; 21c, ventral view.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

Plate V

18a

18b

18c

19a

19b

19c

20a

20b

20c

21a

21b

21c

Plate VI

Figures 22a, 22b. *Tiphotrocha comprimata* (Cushman and Brönnimann), 1948, X 100. 22a, dorsal view; 22b, ventral view.

Figures 23a, 23b, 23c. *Arenoparrella mexicana* (Kornfled), 1951, X 100. 23a, dorsal view; 23b, peripheral view; 23c, ventral view.

Figures 24a, 24b, 24c. *Spiroplectammina earlandi* (Parker), 1952, X 100. 24a and 24c, views of opposite sides; 24b, near-peripheral view.

Figures 25a, 25b, 25c. *Pseudoclavulina gracilis* Cushman and Brönnimann, 1948, X 100. 25a and 25c, views of opposite sides; 25b, apertural view.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

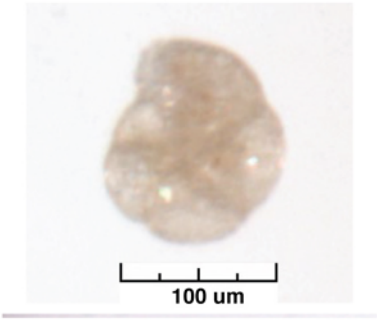
Plate VI

22a

22b

23a

23b



23c

24a

24b

24c

25a

25b

25c

Plate VII

Figures 26a, 26b, 26c. *Helenina anderseni* (Warren), 1957, X 100. 26a, dorsal view; 26b, peripheral view; 26c, ventral view.

Figures 27a, 27b, 27c. *Ammonia parkinsoniana* (d'Orbigny), 1839, X 100. 27a, dorsal view; 27b, apertural view; 27c, ventral view.

Figures 28a, 28b, 28c. *Elphidium excavatum* (Terquem), 1875, X 100. 28a and 28c, views of opposite sides; 28b, peripheral view.

Figures 29a, 29b, 29c. *Elphidium mexicanum* (Kornfeld), 1931, X 100. 29a and 29c, views of opposite sides; 29b, apertural view.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

Plate VII

26a

26b

26c

27a

27b

27c

28a

28b

28c

29a

29b

29c

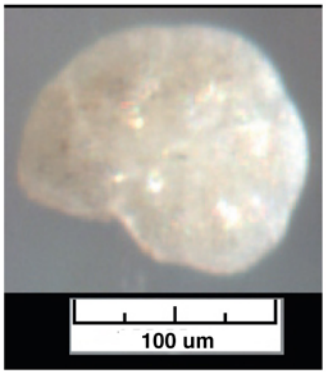
Plate VIII

Figures 30a, 30b, 30c. *Elphidium matagordanum* (Kornfeld), 1931, X 100. 30a and 30c, views of opposite sides; 30b, peripheral view.

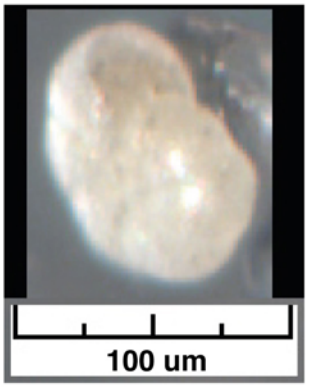
Figures 31a, 31b, 31c. Coarsely agglutinated planispiral, X 100. 31a and 31c, views of opposite sides; 31b, peripheral view.

- All images were photographed at the Micropaleontology Laboratory, Department of Marine Science, The University of Southern Mississippi, John C. Stennis Space Center, MS.

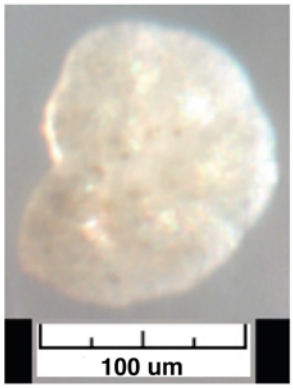
Plate VIII



30a



30b



30c

31a

31b

31c

Foraminiferal Census

		04BL01	04BL02	04BL03	04BL04	04BL05	04BL06	04BL07	
	Taxonomic Name:	Total in 10 cm^3/ml for 1/36 & 1/216	Total in 10 cm^3/ml for 1/36 & 1/216	Total in 10 cm^3/ml for 1/36	Total in 10 cm^3/ml for 1/36	Total in 10 cm^3/ml for 1/216	Total in 10 cm^3/ml for 1/36	Total in 10 cm^3/ml for 1/36	Total Species for all samples
1	*Ammoastuta salsa*	0	0	252	108	64.8	6	18	448.8
2	*Ammotium crassus*	0	0	432	351	0	3	3	789
3	*Ammotium crassus* just trochospiral	0	0	414	36	0	6	3	459
4	*Ammotium crassus* cf. *A. crassus*	0	0	18	0	0	0	0	18
5	*Ammobaculites exiguus* cf. *A. exiguus*	0	0	144	0	0	3	0	147
6	*Ammobaculites exiguus* cf. *A. exiguus* juvenile	0	0	18	0	0	0	0	18
7	*Ammodiscus minutissimus*	0	0	0	0	21.6	0	3	24.6
8	*Ammonia parkinsoniana*	36	0	666	522	0	15	36	1275
9	*Ammonia parkinsoniana* organic test lining	36	18	18	45	21.6	3	0	141.6
10	*Ammonia tepida*	0	0	0	0	64.8	0	9	73.8
11	*Ammonia* spp. juvenile	18	0	0	0	0	0	0	18
12	*Ammotium directum*	0	0	36	0	86.4	0	0	122.4
13	*Ammotium pseudocassis*	0	0	0	135	0	0	0	135
14	*Ammotium* sp. A	0	0	18	27	0	9	0	54

	Taxonomic Name:	04BL01	04BL02	04BL03	04BL04	04BL05	04BL06	04BL07	Total Species
15	*Ammotium salsum*	0	0	0	90	0	3	0	93
16	*Arenoparrella mexicana*	342	162	1026	585	1015.2	111	72	3313.2
17	*Buccella* sp. A	0	0	0	0	0	6	0	6
18	*Elphidium excavatum*	0	0	0	27	0	0	0	27
19	*Elphidium gunteri*	0	0	0	0	0	6	0	6
20	*Elphidium incertum*	0	0	0	18	0	0	0	18
21	*Elphidium* spp.	54	0	54	0	0	3	9	120
22	*Elphidium matagordanum*	0	0	72	405	21.6	3	45	546.6
23	*Haplophragmoides manilaensis* cf. *H. manilaensis* juvenile	0	0	18	0	0	0	0	18
24	*Haplophragmoides manilaensis*	0	0	72	0	64.8	3	0	139.8
25	*Haplophragmoides manilaensis* cf. *H. manilanensis*	0	0	18	0	0	0	0	18
26	*Haplophragmoides wilberti* -incomplete whorl	0	57.6	144	90	0	6	9	306.6
27	*Haplophragmoides wilberti*	396	115.2	954	306	129.6	102	45	2047.8
28	*Haplophragmoides wilberti* cf. *H. wilberti*	18	0	0	0	0	0	0	18
29	*Helenina anderseni*	0	0	0	36	0	0	0	36
30	*Miliammina fusca*	180	745.2	144	225	86.4	45	54	1479.6
31	*Polysaccammina ipohalina*	36	21.6	18	0	0	6	3	84.6

	Taxonomic Name:	04BL01	04BL02	04BL03	04BL04	04BL05	04BL06	04BL07	Total Species
32	*Pseudoclavulina gracilis* cf. *P. gracilis*	36	0	18	45	0	0	0	99
33	*Pseudothurammina limnetis*	0	0	18	0	0	0	0	18
34	*Siphotrochammina lobata*	198	54	108	81	367.2	18	3	829.2
35	*Siphotrochammina lobata* juvenile	36	43.2	0	0	108	0	0	187.2
36	*Siphotrochammina lobata* cf. *S. lobata*	0	21.6	0	0	0	0	0	21.6
37	*Textularia earlandi*	0	0	18	0	43.2	0	0	61.2
38	*Tiphotrocha comprimata*	72	39.6	126	0	151.2	3	6	397.8
39	*Trochammina inflata*	432	0	54	531	216	18	3	1254
40	*Trochammina inflata* juvenile	396	0	54	27	259.2	0	0	736.2
41	*Trochamminita irregularis*	18	97.2	126	27	129.6	27	39	463.8
42	*Trochammina macrescens*	180	18	144	108	194.4	30	9	683.4
43	*Trochammina macrescens* juvenile	72	0	36	0	21.6	6	9	144.6
44	*Trochamminita salsa*	0	0	18	45	21.6	3	0	87.6
45	*Trochamminita salsa* juvenile	0	0	18	0	21.6	0	0	39.6
46	Unknown textularid	72	187.2	180	72	172.8	12	12	708
47	Unknown textularid juvenile	288	442.8	54	81	151.2	32	27	1076
48	Rotalid	18	0	0	27	0	0	0	45
49	Coarsely agglutinated planispiral	0	442.8	342	270	0	18	51	1123.8

Appendix B

Statistical Data Analysis

		As. salsa	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
As. salsa	Pearson Correlation	1	❖-0.863	-0.534	-0.612	-0.381
	Sig. (2- tailed)	.	0.06	0.354	0.144	0.398
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	❖-0.863	1	0.695	0.284	0.195
	Sig. (2- tailed)	0.06	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.534	0.695	1	-0.309	-0.195
	Sig. (2- tailed)	0.354	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.612	0.284	-0.309	1	❖ 0.674
	Sig. (2- tailed)	0.144	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.381	0.195	-0.195	❖0.674	1
	Sig. (2- tailed)	0.398	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		A. crassus	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
A. crassus	Pearson Correlation	1	❁ -0.966	-0.526	-0.324	-0.451
	Sig. (2- tailed)	.	0.008	0.363	0.478	0.31
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	❁ -0.966	1	0.695	0.284	0.195
	Sig. (2- tailed)	0.008	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.526	0.695	1	-0.309	-0.195
	Sig. (2- tailed)	0.363	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.324	0.284	-0.309	1	❖ 0.674
	Sig. (2- tailed)	0.478	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.451	0.195	-0.195	❖ 0.674	1
	Sig. (2- tailed)	0.31	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		A. parkinsoniana	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
A. parkinsoniana	Pearson Correlation	1	❁-0.940	-0.433	-0.488	-0.325
	Sig. (2-tailed)	.	0.018	0.466	0.267	0.477
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	❁-0.940	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.018	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.433	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.466	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.488	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.267	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.325	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.477	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		A. parkinsoniana - organic test lining	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
A. parkinsoniana - organic test lining	Pearson Correlation	1	0.553	❖ 0.828	0.179	-0.137
	Sig. (2-tailed)	.	0.334	0.083	0.702	0.769
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.553	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.334	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	❖ 0.828	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.083	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	0.179	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.702	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.137	0.195	-0.195	❖ 0.674	1
	Sig. (2-tailed)	0.769	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		A. mexicana	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
A. mexicana	Pearson Correlation	1	0.067	0.11	-0.642	-0.57
	Sig. (2-tailed)	.	0.915	0.86	0.12	0.182
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.067	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.915	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.11	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.86	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.642	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.12	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.57	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.182	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		Elphidium spp.	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
Elphidium spp.	Pearson Correlation	1	0.274	0.745	-0.291	0.172
	Sig. (2-tailed)	.	0.656	0.149	0.527	0.712
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.274	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.656	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.745	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.149	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.291	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.527	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	0.172	0.195	-0.195	❖ 0.674	1
	Sig. (2-tailed)	0.712	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		E. matagordanum	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
E. matagordanum	Pearson Correlation	1	-0.538	-0.228	-0.403	-0.252
	Sig. (2-tailed)	.	0.35	0.713	0.369	0.585
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	-0.538	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.35	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.228	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.713	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.403	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.369	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.252	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.585	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		H. wilberti juvenile	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
H. wilberti juvenile	Pearson Correlation	1	❖ -0.794	❖ -0.848	0.269	0.246
	Sig. (2-tailed)	.	0.108	0.07	0.56	0.595
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	❖ -0.794	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.108	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	❖ -0.848	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.07	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	0.269	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.56	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	0.246	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.595	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		H. wilberti	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
H. wilberti	Pearson Correlation	1	-0.39	0.206	-0.323	-0.266
	Sig. (2-tailed)	.	0.516	0.74	0.48	0.564
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	-0.39	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.516	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.206	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.74	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.323	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.48	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.266	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.564	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		M. fusca	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
M. fusca	Pearson Correlation	1	0.267	-0.328	❁0.925	❁0.790
	Sig. (2-tailed)	.	0.664	0.59	0.003	0.035
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.267	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.664	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.328	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.59	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	❁0.925	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.003	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	❁0.790	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.035	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		P. ipohalina	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
P. ipohalina	Pearson Correlation	1	0.443	0.313	0.373	❁0.866
	Sig. (2-tailed)	.	0.455	0.608	0.410	0.012
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.443	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.455	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.313	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.608	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	0.373	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.410	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	❁ 0.866	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.012	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		S. lobata	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
S. lobata	Pearson Correlation	1	0.787	0.754	-0.150	-0.433
	Sig. (2-tailed)	.	0.115	0.141	0.749	0.332
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.787	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.115	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.754	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.141	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.150	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.749	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.433	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.332	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		T. comprimata	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
T. comprimata	Pearson Correlation	1	0.565	0.370	-0.075	-0.381
	Sig. (2-tailed)	.	0.321	0.540	0.873	0.400
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.565	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.321	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.370	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.540	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.075	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.873	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.381	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.400	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		T. inflata	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
T. inflata	Pearson Correlation	1	0.244	0.747	-0.341	-0.553
	Sig. (2-tailed)	.	0.692	0.147	0.455	0.198
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.244	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.692	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.747	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.147	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.341	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.455	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.553	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.198	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		T. inflata juvenile	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
T. inflata juvenile	Pearson Correlation	1	0.723	❁ 0.957	-0.193	-0.387
	Sig. (2-tailed)	.	0.167	0.011	0.678	0.391
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.723	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.167	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	❁ 0.957	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.011	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.193	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.678	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.387	0.195	-0.195	❖ 0.674	1
	Sig. (2-tailed)	0.391	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		T. irregularis	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
T. irregularis	Pearson Correlation	1	0.323	-0.387	0	0.473
	Sig. (2-tailed)	.	0.596	0.520	0.999	0.283
	N	14	5	5	7	7
Elevation (m)	Pearson Correlation	0.323	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.596	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.387	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.520	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	0	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.999	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	0.473	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.283	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		T. macrescens	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
T. macrescens	Pearson Correlation	1	0.509	0.786	-0.500	-0.348
	Sig. (2-tailed)	.	0.381	0.115	0.253	0.444
	N	14	5	5	7	7
Elevation (m)	Pearson Correlation	0.509	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.381	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.786	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.115	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.500	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.253	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.348	0.195	-0.195	❖ 0.674	1
	Sig. (2-tailed)	0.444	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		T. salsa	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
T. salsa	Pearson Correlation	1	-0.434	-0.225	-0.431	-0.638
	Sig. (2-tailed)	.	0.465	0.717	0.335	0.123
	N	14	5	5	7	7
Elevation (m)	Pearson Correlation	-0.434	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.465	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.225	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.717	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	-0.431	0.284	-0.309	1	❖ 0.674
	Sig. (2-tailed)	0.335	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	-0.638	0.195	-0.195	❖ 0.674	1
	Sig. (2-tailed)	0.123	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		Coarsely agglutinated planispiral	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
Coarsely agglutinated planispiral	Pearson Correlation	1	-0.143	-0.667	0.57	0.646
	Sig. (2-tailed)	.	0.818	0.218	0.182	0.117
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	-0.143	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.818	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	-0.667	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.218	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	0.57	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.182	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	0.646	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.117	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		Textularid Juvenile unknown	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
Textularid Juvenile unknown	Pearson Correlation	1	0.593	0.028	❁0.835	❁0.826
	Sig. (2-tailed)	.	0.292	0.965	0.019	0.022
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.593	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.292	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.028	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.965	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	❁ 0.835	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.019	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	❁ 0.826	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.022	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

		Unknown Textularid	Elevation (m)	Specific Conductivity	Ctotal Ave	Mean Grain Size
Unknown Textularid	Pearson Correlation	1	0.417	0.338	❁0.791	0.436
	Sig. (2-tailed)	.	0.485	0.579	0.034	0.328
	N	7	5	5	7	7
Elevation (m)	Pearson Correlation	0.417	1	0.695	0.284	0.195
	Sig. (2-tailed)	0.485	.	0.192	0.643	0.753
	N	5	5	5	5	5
Specific Conductivity	Pearson Correlation	0.338	0.695	1	-0.309	-0.195
	Sig. (2-tailed)	0.579	0.192	.	0.613	0.755
	N	5	5	5	5	5
Ctotal Ave	Pearson Correlation	❁ 0.791	0.284	-0.309	1	❖0.674
	Sig. (2-tailed)	0.034	0.643	0.613	.	0.097
	N	7	5	5	7	7
Mean Grain Size	Pearson Correlation	0.436	0.195	-0.195	❖0.674	1
	Sig. (2-tailed)	0.328	0.753	0.755	0.097	.
	N	7	5	5	7	7

❁ Correlation is very significant at the ≤ 0.05 level (2- tailed).

❖ Correlation is marginally significant at the ≤ 0.1 level (2- tailed).

Vita

Chandra A. Dreher was born in Denver, Colorado on November 8th, 1978. When her parents took her on a trip to Groton Long Point, Connecticut at a very young age, she discovered a love for the ocean, beaches and intertidal critters. Since that experience, Chandra has always had a desire to explore and learn about the ocean and coastal regions. Chandra graduated from Standley Lake High School in 1997. Following her passion for the ocean, she decided to attend Eckerd College in St. Petersburg, FL. While attending Eckerd College, Chandra took two outstanding courses that brought her to Australia's Ayers Rock and Great Barrier Reef as well as to Roatan, Honduras. During these courses her love for geology and coastal processes grew into a decision to combine both interests and study them in greater detail. After graduating from Eckerd with a major in Geology and a minor in Biology, Chandra received an internship that turned into a contract position with the United States Geological Survey (USGS) in St. Petersburg, FL. While at the USGS, Chandra was able to work with a wonderful team, Jack Kindinger and Jim Flocks, gaining valuable experience, skills and knowledge of stratigraphic framework projects along the South-Central Louisiana coast and in Tampa Bay, FL. Approximately two years later, Chandra decided it was time to take the next step in the road of education. She chose to attend the University of New Orleans when provided with the opportunity to do research with Dr. Mark Kulp on the South-Central Louisiana coast. In the summer of 2004, Chandra began a masters project that was different than the stratigraphic framework she had been previously pursuing. She decided to combine her geology and biology backgrounds by studying marsh foraminifera in Louisiana's intertidal marshes. This decision allowed her to team up and work with a

wonderful expert of foraminifera, Dr. Charlotte Brunner, while learning more about intertidal interactions. Chandra completed the requirements for her Master of Science from the University of New Orleans on September 1, 2006. This degree was awarded in December of 2006.