AN APPLIED PALEOECOLOGY CASE STUDY: BAHIA GRANDE, TEXAS PRIOR TO CONSTRUCTION OF THE BROWNSVILLE SHIP CHANNEL

A Thesis

by

STEPHEN ALVAH LICHLYTER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Geology

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Approved by:

Chair of Committee, Thomas D. Olszewski
Committee Members, Thomas E. Yancey
Stephen E. Davis
Elizabeth A. Heise
Head of Department, Richard L. Carlson

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ABSTRACT

An Applied Paleoecology Case Study: Bahia Grande, Texas Prior to Construction of the Brownsville Ship Channel. (May 2006)

Stephen Alvah Lichlyter, B.S., University of British Columbia

Chair of Advisory Committee: Dr. Thomas D. Olszewski

Bahia Grande is a large lagoon located within Laguna Atascosa National Wildlife Refuge in Cameron County, Texas. When the Brownsville Ship Channel was built along the southern end of the lagoon in 1936, Bahia Grande was cut off from the marine water of Laguna Madre. Since that time, Bahia Grande has been primarily dry with only ephemeral fresh water coming from heavy rainfall events, resulting in a severe decline in biological productivity. A restoration project led by the U.S. Fish and Wildlife Service has proposed to cut new channels between Bahia Grande and the Ship Channel to restore the connection with Laguna Madre. This is a large-scale project with major implications for the water quality, surrounding ecology, and associated biota in the region. Unfortunately, because very little is known about Bahia Grande prior to isolation, it is difficult to predict whether the results of the restoration will be comparable to the pre-Ship Channel environment.

Paleoecological data provide the best opportunity to understand what Bahia Grande was like in the past. This study uses statistical analyses of the molluscan death assemblages from Bahia Grande to gain a better understanding of the environmental conditions in the lagoon before it was isolated. The first question addressed is how does

Bahia Grande relate to other water bodies on the Texas coast? This may provide a modern analog to the past conditions in Bahia Grande. The second question inquires whether there are any local patterns or variations within Bahia Grande and several smaller surrounding lagoons. These results provide an important baseline for comparison with the restored lagoon.

The results of this investigation show that, in a regional context, Bahia Grande was most similar to Alazan Bay and Baffin Bay, which are mostly enclosed shallow bays with high salinities due to the arid climate and limited freshwater inflow. Within Bahia Grande, there are several distinct molluscan assemblages. Salinity and water coverage are the most likely environmental factors responsible for the differences within Bahia Grande. Additionally, data from surrounding lagoons strongly indicate that some connections with Bahia Grande existed in the past.

ACKNOWLEDGMENTS

I would like to express my gratitude to my advisor, Dr. Thomas Olszewski, whose expertise, understanding, and patience added considerably to my graduate experience. In particular, Dr. Olszewski was constantly available to provide assistance or comments and his quick responses allowed this project to be completed in a timely manner. I feel privileged to be his first graduating student.

I would like to thank Dr. Elizabeth Heise for introducing me to this project. I was delighted to find a thesis project that not only kept me interested, but also makes a beneficial contribution to a worthwhile restoration project. I also express my sincere appreciation to Dr. Heise for her invaluable assistance in the field. Without her support and hospitality, this project would not have been possible. I must also acknowledge my other committee members, Dr. Thomas Yancey and Dr. Stephen Davis, for their insightful input and assistance with this thesis. Special thanks go to Dr. Beth Mullenbach, for allowing me to use her lab for sediment analysis and to Amy DeGeest, for graciously taking the time to assist me in the lab.

To all of my family and friends and to everyone else who helped me along the way, thank you for your support!

In conclusion, I recognize that this research would not have been possible without the financial assistance from the Texas Water Resources Institute, Dominion Exploration & Production, Anadarko Petroleum, and Texas A&M University. I am also grateful to the U.S. Fish & Wildlife Service for permitting me to do this project within Laguna Atascosa National Wildlife Refuge.

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INTRODUCTION

Paleoecology is the study of the ecology of past communities. It is often the best tool available for understanding what past environments were like. If it is possible to determine what sort of community lived in a given area in the past, then environmental conditions can be inferred based on knowledge of the species composition. Such data are important for understanding changes not only on a geologic time scale, but also for recognizing recent changes in modern systems.

This investigation attempts to answer the question of what Bahia Grande was like in the past, before it was hydrologically isolated by construction of the Brownsville Ship Channel. This is an important study for numerous reasons. Namely, this will provide baseline data that can be used to compare past conditions in Bahia Grande to the future state of the lagoon once it undergoes restoration. Coastal ecosystems are very susceptible to changes and are often the first visible indicators of alterations to the environment. Examples of such changes could be man-made hydrologic modifications, such as in Bahia Grande, or naturally occurring changes such as sea level changes or climate change. It is important, therefore, to understand the full effects of the modifications that caused Bahia Grande to become isolated. This study will provide significant data to aid in the understanding of the effect and the consequences of coastal changes not only for this case study in Bahia Grande, but for similar endeavors elsewhere. Additionally, the use of paleoecological data is a novel approach to examining the restoration of a lagoon

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This thesis follows the style of Paleobiology.

and successful application of the methods used here will hopefully lead to further use of paleoecology in a restoration setting.

To understand what Bahia Grande was like in the past requires an examination of two aspects of the lagoon. First, how does Bahia Grande compare to other bodies of water in the Texas coastal region? And, secondly, is there any local variation within Bahia Grande? In order to answer these questions, this investigation sampled the dead molluscan shell material from 51 locations in Bahia Grande and several surrounding smaller lagoons.

To answer the regional question about how Bahia Grande compares to other bodies of water along the Texas coast, the data obtained from Bahia Grande are directly compared with two other studies using multivariate statistics. The first study was a comprehensive examination of the entire Texas coastline done by the Texas Bureau of Economic Geology (White et al. 1983, 1986, 1989). The purpose of this comparison is to show, on a large scale, how Bahia Grande fits in with the other coastal water bodies in Texas. Is there another lagoon along the Texas coast that has a similar faunal death assemblage to Bahia Grande in the past and, if so, what are the primary factors controlling the environmental conditions in that lagoon? This could provide a modern analog to what Bahia Grande was like in the past and perhaps serve as a target for the restoration. The second study used for comparison was an investigation into the paleoecology of southern Laguna Madre by Smith (1985). She investigated 14 locations in southern Laguna Madre; this comparison addresses more specifically how individual locations in Bahia Grande relate to water bodies in the south Texas coastal region. On the regional scales considered here, climate and salinity are hypothesized to be likely causes for variation in faunal assemblages.

To answer the question of whether or not local variations exist within Bahia Grande, the data from Bahia Grande and several surrounding lagoons are analyzed using multivariate statistical methods. On a local scale, environmental characteristics such as salinity and frequency of water inundation are likely factors that may cause variations in the death assemblage distribution. The hypothesis is that a pattern of distinct habitats or an ecological gradient will be evident amongst the sampling locations indicating spatial variations in environmental conditions within Bahia Grande in the past.

BACKGROUND

Restoration

Bahia Grande is a 6,500 acre lagoon located in Cameron County, Texas west of Port Isabel (Figure 1) (26°02′30″ N 97°17′30″ W). Nearly all of Bahia Grande is located within Laguna Atascosa National Wildlife Refuge except for a small portion in the northwest corner that is privately owned (Figure 2). A satellite photo of the region (Appendix A) provides further details about Bahia Grande and the surrounding area.

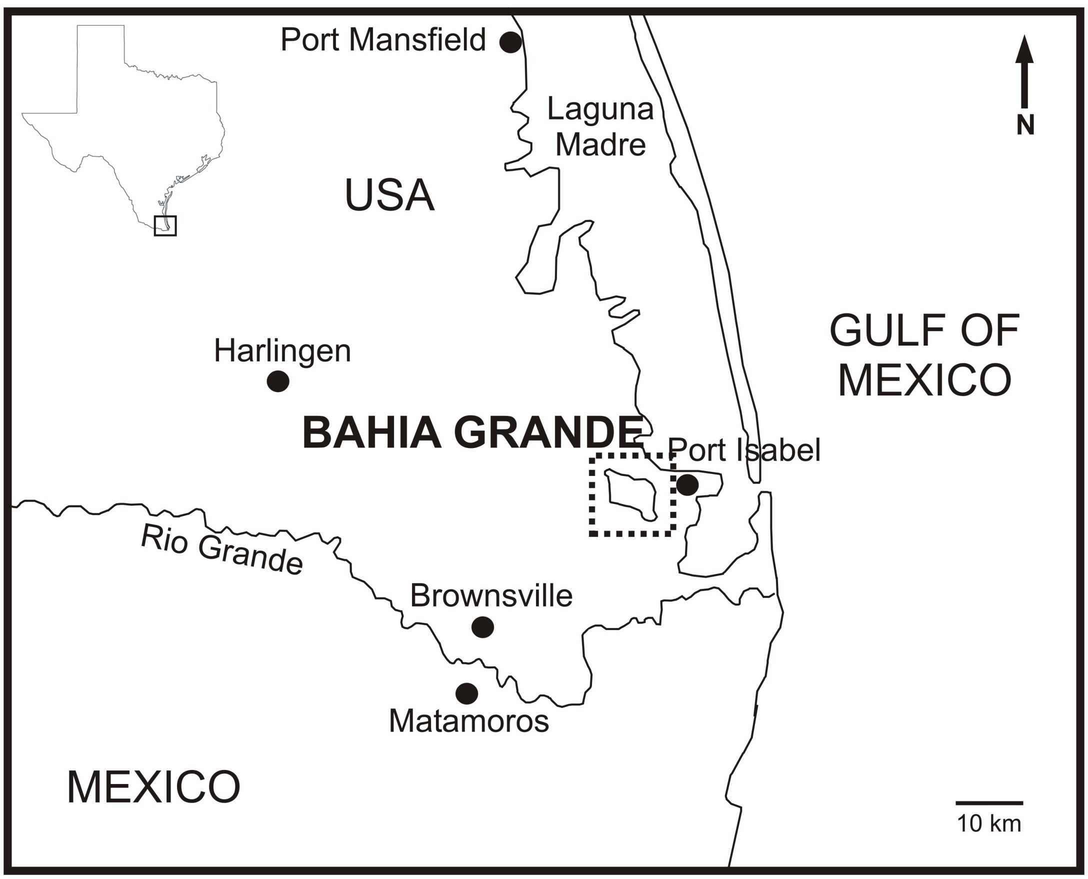

Figure 1. Regional map of South Texas. Bahia Grande is highlighted by the dashed box.

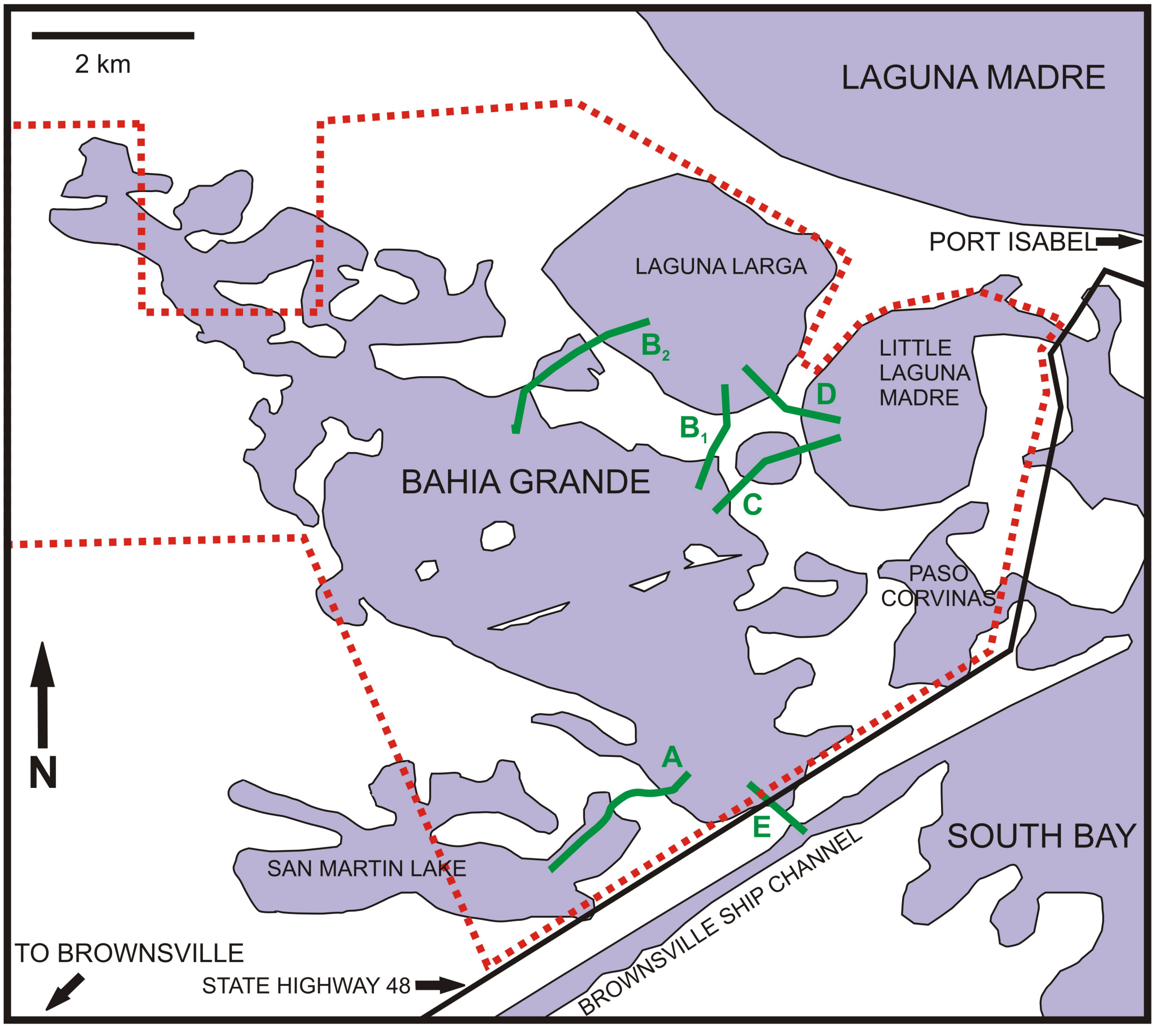

Figure 2. Map of Bahia Grande. The red dashed line indicates the Laguna Atascosa National Wildlife Refuge boundary. The solid green lines indicate proposed channel locations for restoration. Map based on USFWS (2004).

Prior to construction of the Brownsville Ship Channel between 1934 and 1936 there was free exchange of marine water and associated fauna between Bahia Grande and Laguna Madre. Additional blockage occurred in the 1940s when State Highway 48 was constructed across the southernmost portion of Bahia Grande. As a result of the blockages, for the past 70 years, only ephemeral water from heavy rain events covered the lagoon. This is in contrast to the high salinity water normally found in South Texas bays (e.g. Parker 1955, Breuer 1957, White et al. 1986). Due to the loss of water exchange with Laguna Madre, Bahia Grande suffered a significant decline in biological productivity (USFWS 2004).

A further consequence of the hydrologic isolation and ensuing drying of Bahia Grande has been the frequent dust storms caused by wind blowing the sediment from the former lagoon. The dust storms are a concern to the city of Port Isabel because they have detrimental effects on the respiratory health of citizens and cause substantial damage to ventilation systems (USFWS 2004).

Recent plans are now underway to restore marine water to Bahia Grande. The proposed plan is to cut several channels that will connect Bahia Grande to existing water bodies and re-flood the lagoon (USFWS 2004). In July 2005, a pilot channel (channel E in Fig. 2) was cut between Bahia Grande and the Brownsville Ship Channel to re-establish a water pathway. Further improvements to the pilot channel and additional channels that will connect surrounding lagoons are planned for the future. Besides thwarting the dust storms that affect Port Isabel, restoration of the lagoon will provide a habitat for marine invertebrates, fish, and waterfowl. A restored aquatic system in Bahia Grande is expected to have a positive influence on the terrestrial surroundings as well; mangrove plants fringe the bodies of salt water and ocelots and jaguarundi cats, both endangered species, reside in the surrounding brush (USFWS 2004). The objectives listed in the final draft of the restoration proposal (USFWS 2004) are: 1) to provide nursery areas and habitat for aquatic organisms such as shrimp, crabs, and fish, 2) to provide habitat for resident and migratory wildlife such as water birds, 3) to reduce Bahia Grande as a source of windblown dust, and 4) to provide increased public recreational areas.

It must be noted that the USFWS proposal for restoration of the lagoon does not state that the purpose of restoration is to exactly recreate the undisturbed environment prior to 1936. Numerous studies of wetland restorations (e.g. Choi 2004, Zedler 2001, Ehrenfeld 2000) have shown that this is an unrealistic and, often, impossible goal. Exact hydrologic patterns and complex trophic hierarchies are difficult to recreate and, therefore, wetland restorations are forever a work in progress with constantly changing expectations (Zedler 2001). Nevertheless, it is of interest to compare this tidal wetland restoration with the past environment for several reasons. First, although the intent may not be to reestablish the past conditions in Bahia Grande exactly, a comparison between the original lagoon and the degree of difference or lack of difference found in the restored lagoon is vital to determine the ultimate effects of the modifications caused by the Brownsville Ship Channel. Secondly, if we assume that the past fauna in Bahia Grande was a relatively mature assemblage and the environment was reasonably stable, it will be interesting to see if a community in the restored lagoon approaches a similar assemblage and, if so, how long it will take to reach maturity.

In order to evaluate how the restoration of Bahia Grande compares with the pre-Ship Channel environment, a better knowledge of the conditions in the lagoon prior to construction of the Brownsville Ship Channel is needed. Unfortunately, there is no written record of the conditions of Bahia Grande prior to isolation. However, the molluscan death assemblage in Bahia Grande is a source of information that may reveal what it was like in the past. The direct application of paleoecology is a novel approach towards evaluating the results of a shallow water coastal restoration. Promising results from this study of Bahia Grande could lead to increased use of paleoecology as a tool for understanding the history of shallow aquatic environments prior to restoration.

Geologic Context

Bahia Grande is located on a former lobe of the Rio Grande delta. The area has been mapped as Holocene wind-tidal deposits containing muddy sand and sandy mud (Price 1958). The delta lobes to the north of the Rio Grande, including the sediments composing Bahia Grande, were abandoned at least 4000 years B.P. (Rusnak 1960, Lohse 1962). Since the time of abandonment, aeolian action has been the primary physical process on the shores of Laguna Madre (Rusnak 1960). Sedimentation rates in southern Laguna Madre are relatively low compared with the northern portions of the Texas coast and because sea level rise recorded in Laguna Madre is greater than the sedimentation rate, the south Texas coastline is being slowly submerged (Morton et al. 2000).

Prior to isolation, Bahia Grande was a shallow lagoon with the primary source of water coming from Laguna Madre. Levees deposited by former distributaries of the Rio Grande when this part of the delta was active constrained the lagoon and formed numerous ridges that extended into it. The southern portion of the lagoon, for the most part, is open, with a few enclosed bays on the fringes (Figure 2). A disintegrated railroad trestle that was abandoned in the 1930s runs across the middle of the lagoon. The northern portion of the lagoon contains several large islands and a larger number of protected bays. Because the effect of lunar tides is minimal in the Gulf of Mexico (mean annual tide 1.2 feet), wind tides are of greater importance in Bahia Grande (Copeland 1968). Wind tides are a result of wind piling up water and occur irregularly based on wind strength and direction; they are a common phenomenon on the Gulf Coast. The dominant wind direction in the Bahia Grande region is southeasterly. Because this wind blows towards the northwest, the water in Bahia Grande is frequently pushed to the northwest side of the lagoon, leaving the shallowest areas of southwestern Bahia Grande more frequently exposed.

Old maps of Bahia Grande and the surrounding area give insight to the former connection with Laguna Madre. A surveyor's map from 1884 (Figure 3) clearly depicts a continuous water flow from Laguna Madre through to Bahia Grande. The surveyor has indicated several streams entering the west side of Bahia Grande, or what is likely San Martin Lake. This could indicate that a fresh water source was once present and flowing into Bahia Grande. There are also several streams shown in the southern portion of Bahia Grande flowing either to or from the Rio Grande. A considerable exchange of water between Bahia Grande and Laguna Madre is evident on the map. Such details may be important for interpreting water circulation or salinity changes in Bahia Grande. An additional map from 1929 is provided in Appendix B that shows more detail of the immediate Bahia Grande area just prior to construction of the Brownsville Ship Channel.

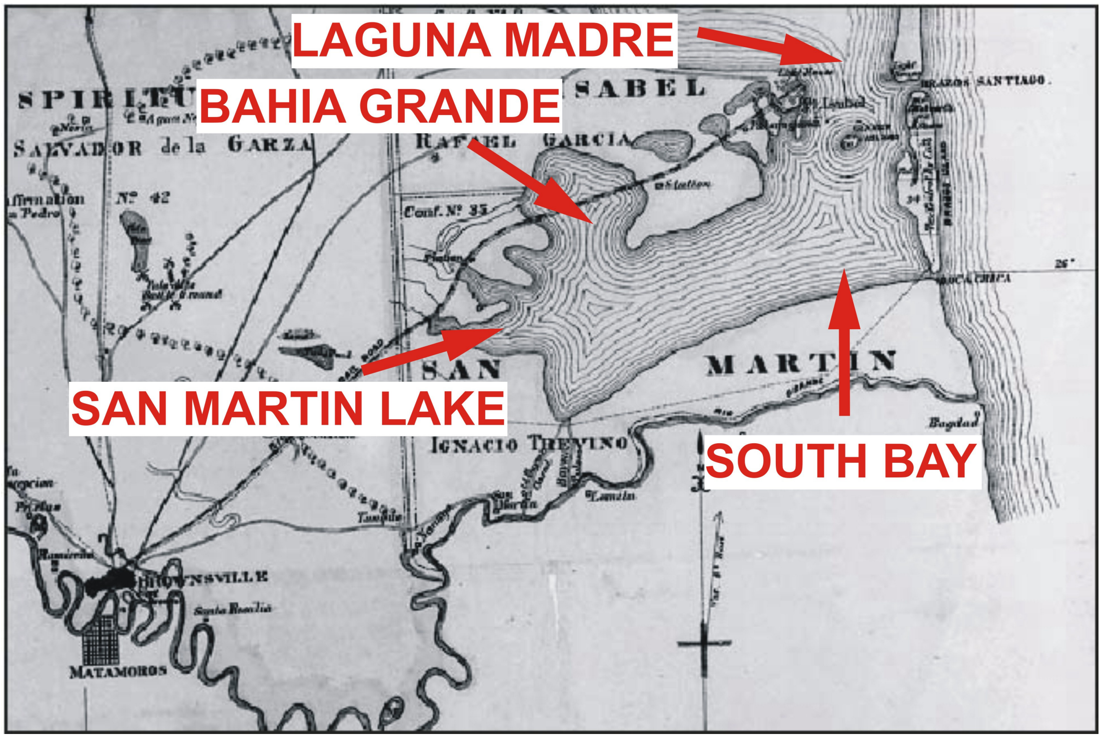

Figure 3. 1884 surveyor's map of Bahia Grande and surrounding region. From J.J.Cocke (county surveyor), Map of the County of Cameron, Texas, Oct 25, 1884.

Ecologic Context

Numerous benthic surveys have been done on the Texas coast (e.g. Stenzel 1940; Ladd 1951; Hedgpath 1953; Parker 1955, 1959, 1960; Breuer 1957, 1962; Tunnell and Chaney 1970; Harry 1976; Wilhite 1982; White et al. 1983, 1986, 1989; Smith 1985; Kalke and Montagna 1991; Powell et al. 1992; Montagna and Kalke 1995; Whaley and Minello 2002; Montagna 2003). It is difficult, however, to relate most of these surveys to what Bahia Grande was like in the past. Those done in the northern portions of the Texas coast, such as Harry (1976) and Whaley and Minello (2002), incorporate a much different fauna due to the much lower salinity and wetter climate in those regions. Other studies have sampled areas of South Texas close to Bahia Grade but are of a more regional nature and only have limited data from the areas immediately adjacent to Bahia Grande (e.g., White et al 1986; Montagna 2003). Some of the older studies only a list of species that were present without abundance data, limiting their comparability (e.g. Stenzel 1940; Breuer 1957, 1962; Parker 1959, Tunnell and Chaney 1970). Studies that collected live specimens (e.g. White et al. 1983, 1986, 1989; Montagna and Kalke 1995, Montagna 2003) present problems because molluscan death assemblages are usually time averaged and more diverse than their live counterparts (e.g. Peterson 1977; Staff et al. 1986; Staff and Powell 1988; Kidwell and Bosence 1991; Kowalewski et al 1998; Kidwell 2001). Time averaging can be a problem in death assemblages if there has been significant postmortem transportation of exotic species into the sampling area or if there are taphonomic biases on shell preservation. Additionally, significant time averaging can generate false patterns by making separate events appear to be synchronous (Kowalewski 1996). However, Kidwell (2002) showed that with large data sets, such as Bahia Grande, the live-dead comparison becomes much more consistent and Kowalewski (1996) noted that time averaging can also erase short term fluctuations and enhance persistent signals.

Other recent biological studies in the Bahia Grande area (Judd and Lonard 2002, 2004) examined the species richness and diversity of plant material in Laguna Atascosa National Wildlife Refuge. They found that the distribution of plants was related to environmental controls. Although this indicates the importance of environmental factors, it does not provide any information about the historical conditions of Bahia Grande.

Using the molluscan death assemblage from Bahia Grande is the best means available for understanding what the area was like in the past. The death assemblage studied here can be compared with other recent studies to determine how Bahia Grande relates to other bodies of water on the Texas coast and can also be used to establish if there were any local variations within Bahia Grande in the past. Since there is no other remaining evidence of the past in Bahia Grande, the fossil evidence provides the most insightful glimpse into what the environmental conditions were like.

FIELD METHODS

Sampling for this study was done using a systematic triangle-grid pattern. The triangle pattern was chosen rather than a square pattern because it maintains equal distances between all immediately adjacent points. Since there was no expectation of a strong patchy distribution of species, a systematic grid provides the simplest pattern for detecting biotic gradients (Davis 2002). However, additional sampling locations were incorporated to include several surrounding lagoons as well as inlets or points near potential water sources in Bahia Grande that could have different environmental features. The distance between locations is approximately 1 km, resulting in a total of 51 samples (Figure 4; Appendix C).

The samples were obtained using a shallow sediment coring device constructed from polyvinyl chloride (PVC) pipe. The coring device was designed to extract a core 15 cm in diameter and up to 30 cm deep (approximately 5300 cubic centimeters). At each location, the top few centimeters of sediment was scraped off prior to sampling to avoid potential contamination from recent deposition. Samples were processed as single homogenous units. Time averaging is a consideration in Bahia Grande. However, because of the relatively enclosed setting of Bahia Grande, transportation of exotic species from other water bodies into the lagoon is unlikely since there would be few sources. Also, shallow enclosed marine habitats, such as Bahia Grande, have been shown to preserve shells in better taphonomic condition than those in more open areas or tidal channels (Flessa et al. 1993). Time averaging in Bahia Grande may be a desirable characteristic given that it can erase short term fluctuations and enhance persistent signals (Kowalewski 1996).

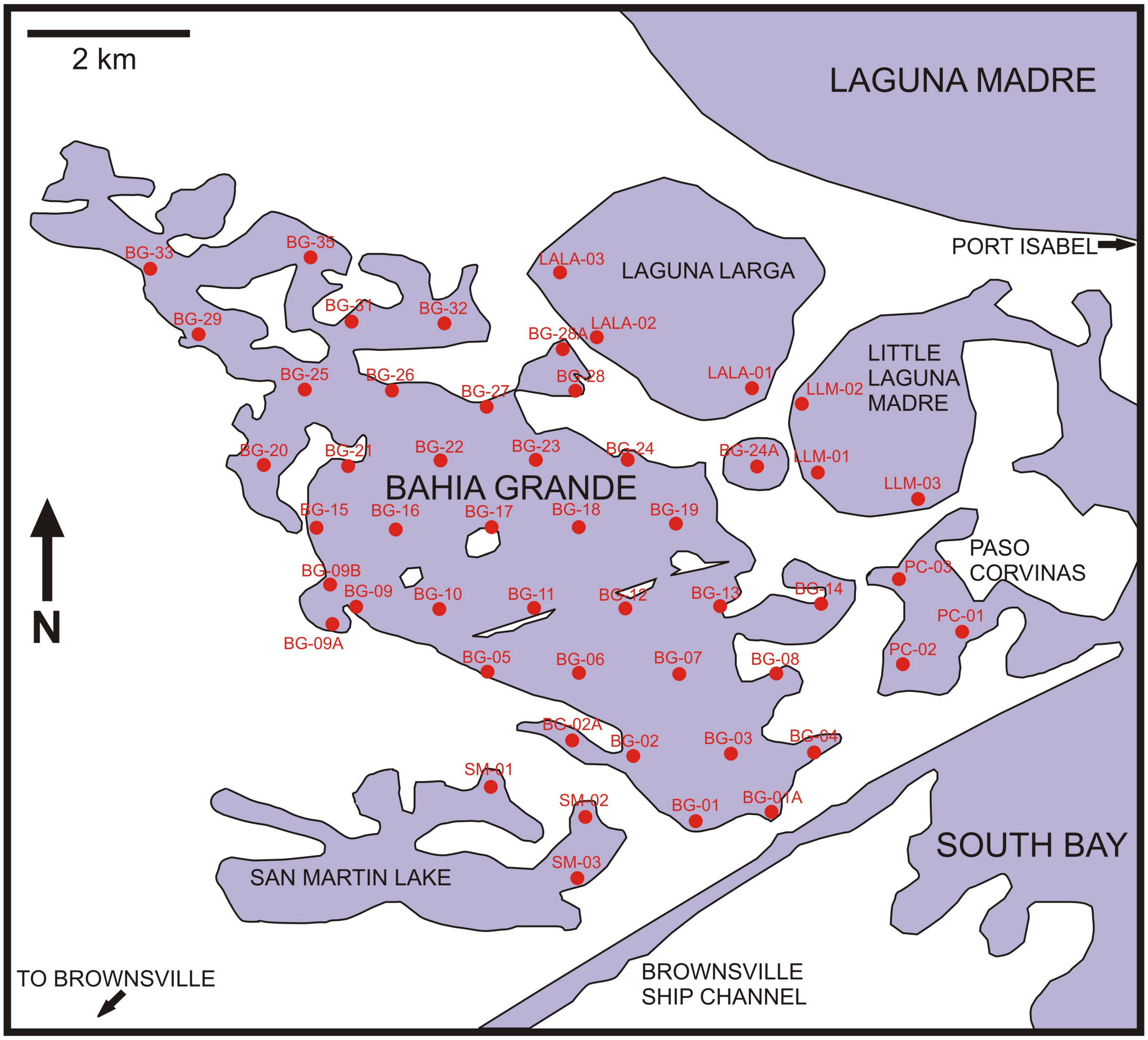

Figure 4. Map of Bahia Grande with labeled sampling locations.

Following collection, the samples were sieved to mesh sizes 2 mm, 1 mm, and 0.5 mm. Meta-analysis of similar molluscan studies by Kidwell (2002) found mesh size is an important control on paleoecological data. She suggested that a mesh size of ≥ 1.5 mm for marine death assemblages will yield the most significant agreement with the living community because sieves ≤ 1.5 mm are likely to be dominated by ephemeral larval and juvenile specimens (Kidwell 2001). Kowalewski and Hoffmeister (2003) argue that although mesh sizes clearly affect the perception of data, the most important factor is to be consistent with the same size. Using a consistent mesh size allows data to be compared on an equal basis and, since the perception of the data is the same, the results should be consistent. In this study, the use of smaller mesh sizes allows for inclusion of small adult species, such as *Odostomia* sp. and *Teinostoma parvicallum*. Using a variety of mesh sizes also provides the ability to take subsamples of the data to investigate how the different mesh sizes influence the computational patterns and makes this study more versatile for comparison with other studies, whether they use a fine (0.5 mm) or coarse (2 mm) mesh size. Finally, 1 mm mesh size is important for a direct comparison with samples obtained by the Bureau of Economic Geology study (White et al. 1983, 1986, 1989). The data matrices for each mesh size are shown in Appendices D, E, and F.

Abbott (1974) and Andrews (1971) were used to identify the shell material. Gastropods were counted if the species was identifiable and the apex was present. Bivalves were counted if the species was identifiable and the entire hinge was present. Both left and right valves were counted and the total of all valves was used for the data matrix. Gilinsky and Bennington (1994) showed that when the sample size is small compared to the number of samples in the collection area, counting each valve as a unique individual is often appropriate. Conversely, if the sample size is large compared to the collection area, in other words exhaustive, counting each valve as an individual is not appropriate. In Bahia Grande, the core samples are small compared to the overall collecting area (the entire lagoon) so it is appropriate to consider each valve as an individual.

REGIONAL COMPARISON (BEG SURVEY)

The first step in understanding the past environmental conditions in Bahia Grande is to identify how death assemblages in the lagoon relate to other bodies of water along the Texas coast. The Texas Bureau of Economic Geology (BEG) carried out a comprehensive survey of the entire Texas coastline in the 1970s and 1980s including an examination of sedimentology, geochemistry, bathymetry, and both live and dead benthic invertebrates (White et al. 1983, 1986, 1989). Although Bahia Grande was not sampled because it was dry or only contained ephemeral water at the time, samples were taken from nearby water bodies such as Laguna Madre and South Bay

The death assemblages collected by the BEG study are combined with those collected from Bahia Grande for this study to identify how Bahia Grande relates to other major water bodies on the Texas coast. This is important because it will show whether other water bodies could be used as a modern analog for what Bahia Grande was like in the past and what the restoration could look like in the future. For example, the species composition of Bahia Grande could be most similar to a water body that is typically hypersaline, such as Baffin Bay, with little freshwater inflow and high rates of evaporation. If this is the case, then it might be expected that the species composition of the restored lagoon will approximate the species found in Baffin Bay by White et al. (1989).

Data and Methods

The benthic data recorded by White et al. (1983, 1986, 1989) are presented as twelve sampling locations (Figure 5). Each location, however, is actually a conglomeration of numerous smaller samples. For example, all 10 of the sampling locations in South Bay are incorporated as a single location in the BEG publication (White et al. 1986). This leads to spatial averaging of the data so that differences among individual sampling sites are hidden in the larger grouping. Additionally, the dead specimens were simply recorded as present or absent for each species so there are no abundance data available.

A data matrix was formed using the death assemblages from the 12 locations sampled by the BEG combined with the death assemblage data collected from Bahia Grande. For the purpose of comparison with the BEG study, the data from Bahia Grande were also grouped into large clusters. All samples from within Bahia Grande were grouped into one location (BG) and the samples from each of San Martin Lake (SM), Laguna Larga (LL), Little Laguna Madre (LLM), and Paso Corvinas (PC) were also combined into separate groups. For equal comparison with the BEG study, only the 1 mm and larger sieve size counts from the Bahia Grande study were used and these data were transformed to presence/absence.

A non-metric multidimensional scaling (NMDS) ordination was performed on the combined Bahia Grande and BEG data sets. Ordination methods produce a plot of samples in two or three dimensions in which the distance between samples on the ordination plot represent their degree of dissimilarity.

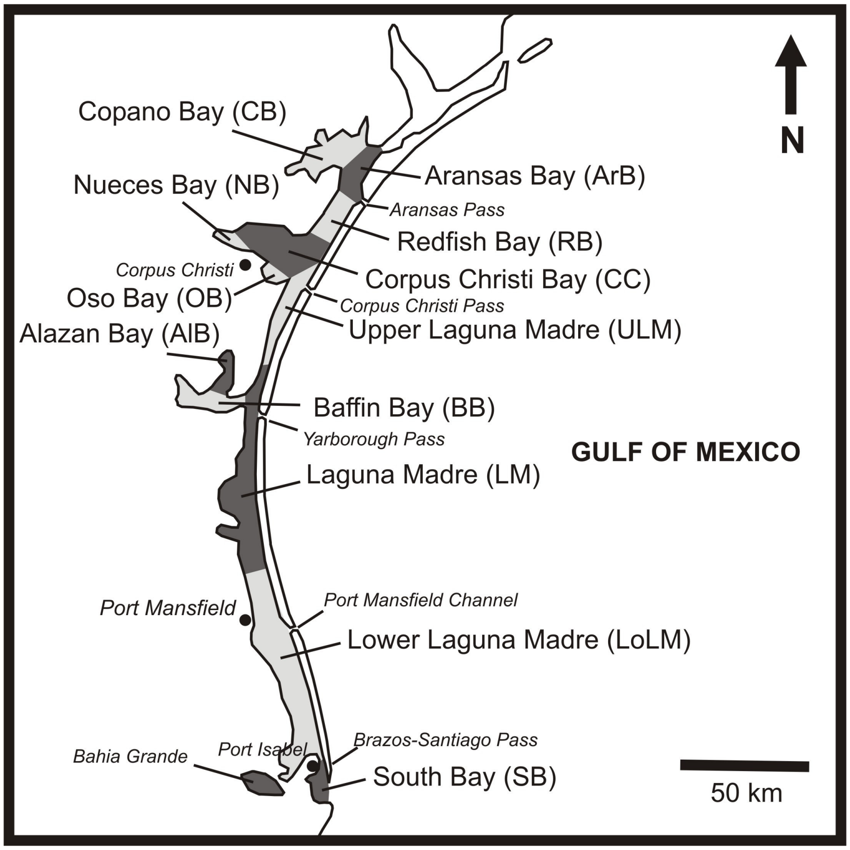

Figure 5. Map of the BEG sampling locations.

Results

The NMDS ordination (Figure 6) suggests a trend from the northern water bodies to the bays in south Texas, including Bahia Grande. The sites from the northern areas above Corpus Christi are primarily located on the lower half of Axis 2. Most of the southern locations, including Baffin Bay, Alazan Bay, and Lower Laguna Madre, plot above the northern locations on Axis 2. The sites from Bahia Grande and surrounding lagoons are located at the top of Axis 2. Oso Bay, which is a smaller water body and has a relatively limited sampling size, also plots on the top half of Axis 2 close to the Bahia Grande sites. This is probably a result of the sampling size of Oso Bay which is a smaller bay that contained only common species. Because the Euclidean distance measure used in this ordination is often affected by mutual absences (McCune and Grace 2002), the presence of only common species could cause Oso Bay to be an outlier. Trial ordinations were done using other distance measure methods, such as Sorensen or Jaccard, and resulted in very similar ordinations with Baffin Bay and Alazan Bay plotting closest to the Bahia Grande sites.

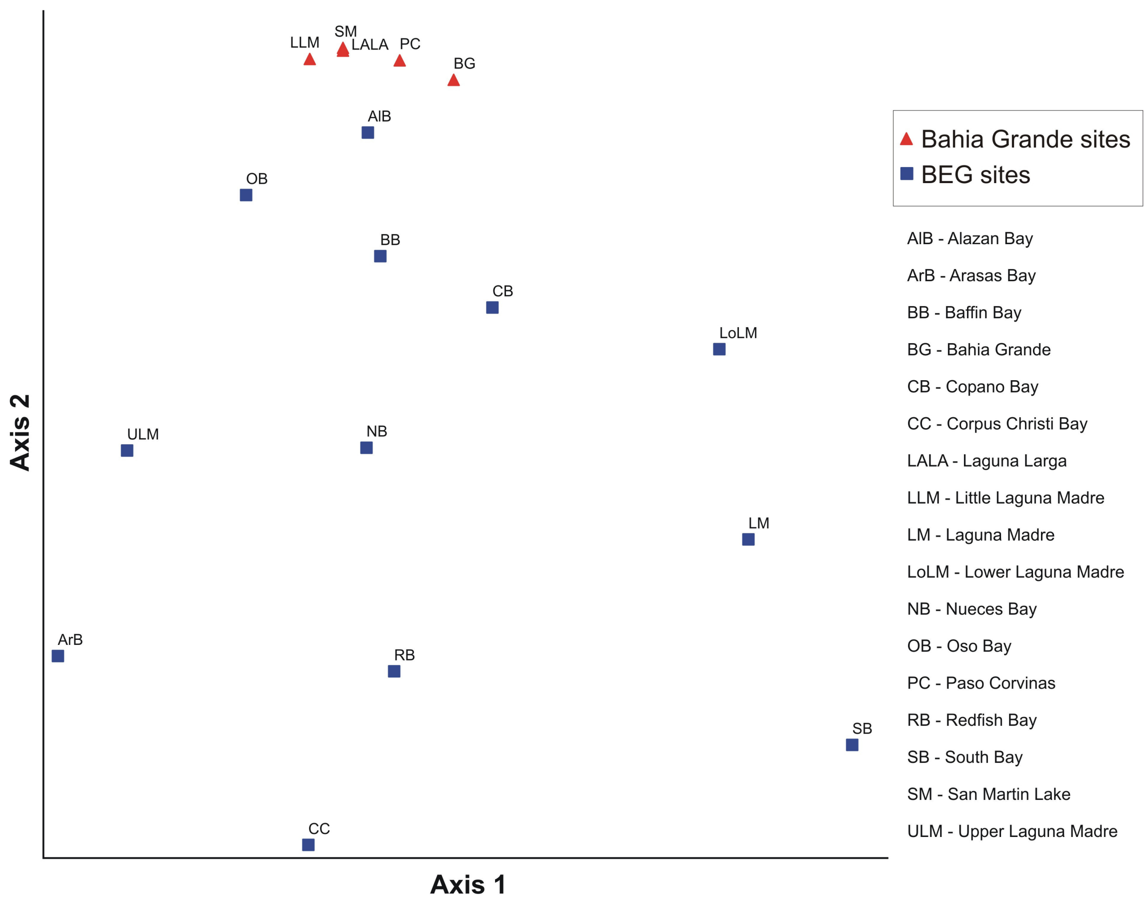

Figure 6. NMDS ordination of BEG sites along with Bahia Grande sites. Presence/absence data was used for this ordination. The distance measure used was relative Euclidean. Stress is 5.02%.

These results are expected since the sites north of Corpus Christi Bay typically have a greater inflow from rivers and the climate has more rain and less evaporation (Parker 1959; White et al. 1983). The sites south of Corpus Christi Bay have a much more arid climate and have very limited amounts of freshwater inflow (Parker 1959; White et al. 1986). The result is that salinities are much higher in south Texas and this is probably the determining factor in Bahia Grande, where many of the species, for example *Mulinia lateralis* and *Anomalocardia auberiana*, are tolerant at high salinities. In contrast, species that are tolerant to brackish or low salinity water, such as *Nuculana acuta*, *Rangia cuneata*, and *Macoma mitchelli*, are found primarily in the northern areas (Parker 1959). Interestingly, South Bay, which is geographically closest to Bahia Grande, is located on the bottom of Axis 2 along with the northern, lower salinity locations. This may be because South Bay is influenced by exchange with the Gulf of Mexico through Brazos Santiago Pass and also may be affected by fresh water entering from the Rio Grande, resulting in lower salinity. It is worth noting that the environment in South Bay was also affected by construction of the Brownsville Ship Channel.

Another important factor in the relationship between Bahia Grande and other water bodies may be the enclosed nature of the lagoon. Baffin Bay and Alazan Bay have a limited passage for water exchange with Laguna Madre resulting in sluggish water circulation and a longer residence time (Montagna and Li 1996). The limited amount of freshwater flowing into the bays also increases residence time. The long residence time of water is important because it reduces the extent of flushing for important biogeochemical cycles such as nitrogen and carbon (Mitsch and Gosselink 2000). The fauna has also been shown to be affected by water residence times (Montagna and Li

1996). An estimate for residence time of water in Baffin Bay is approximately one year compared with typical residence times three to six months for the bays north of Corpus Christi (Montagna and Li 1996). The bays to the north of Corpus Christi generally have more freshwater flowing into them and larger passages for water exchange, which reduces the water residence time. Since Bahia Grande is also a relatively enclosed lagoon, even prior to construction of the Brownsville Ship Channel, it is likely that residence times in Bahia Grande may have been similar to those found in Baffin Bay and Alazan Bay.

Discussion

Not surprisingly, the data from Bahia Grande and the surrounding lagoons plot closest to other locations in south Texas when compared with a large regional data set. Even though Alazan Bay and Baffin Bay are not as geographically close as South Bay, they are shallow, mostly enclosed bays similar to Bahia Grande where the climate is also similarly arid. Alazan Bay and Baffin Bay do not have much freshwater inflow and due to the climate, evaporation rates are generally high, resulting in higher salinities. The degree of flushing, as determined by residence time, in mostly enclosed lagoons such as Baffin Bay and Alazan Bay may also be important factors in their similarity to Bahia Grande. One should expect, therefore, that the restoration of Bahia Grande will most closely approximate Baffin Bay and Alazan Bay. However, because the fauna that previously inhabited Bahia Grande does not occur as commonly in the immediately adjacent areas, it may be difficult for some species to migrate back into the lagoon from areas further away on the coast.

REGIONAL COMPARISON (SMITH SURVEY)

A second study is presented for direct comparison with Bahia Grande to identify how it relates on a smaller regional scale. This data set is taken from a Master's thesis by Elizabeth J. Smith (1985) at Stephen F. Austin State University. Unlike the BEG study, Smith collected abundance data for both dead and live shell material using short cores very similar to the ones used in the present Bahia Grande study. The Smith study contains locations ranging from Baffin Bay to Port Isabel (Figure 7) and is used here to examine how individual locations from Bahia Grande relate to other proximal water bodies in the southern Laguna Madre region. This comparison will identify whether particular locations in Bahia Grande are similar to other areas in southern Laguna Madre that have been identified by Smith as containing several distinctive communities.

Data and Methods

Smith took samples from 14 locations along the South Texas coast from Laguna Madre near Port Isabel north to Baffin Bay (Figure 7). In this study, she took 20 cm cores at each location and counted both live and dead species. However, her "live" species are a count of everything, live or dead, from the top 5 cm of the core and the "dead" species are a count of everything from the lower 15 cm. Her purpose in doing this was to examine the living (or recently dead) population at the surface and compare with the death assemblage lower in the core that has a greater preservation potential for the fossil record.

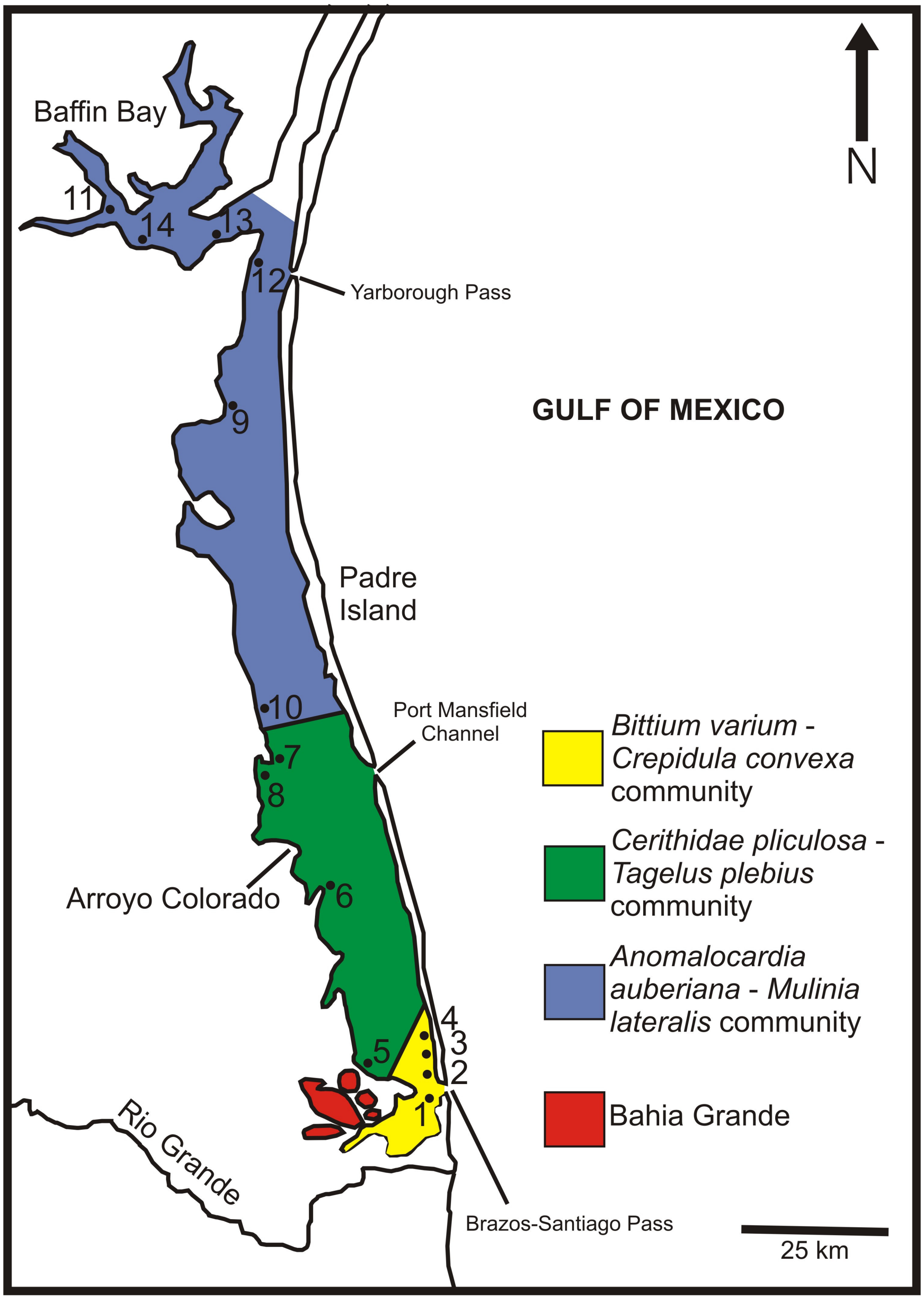

Figure 7. Map of Smith's sampling locations. The three identified death communities are labeled as well as Bahia Grande.

Smith observed three distinct communities of molluscan fauna from the death assemblage (everything below 5 cm) in the southern Laguna Madre region. In the South Bay and southernmost Laguna Madre area, a *Bittium varium-Crepidula convexa* community was identified. Smith proposed that this community was related to Brazos-Santiago Pass, which connects Laguna Madre to the Gulf of Mexico and allows an influx of water from the Gulf that is lower in salinity and temperature than is typically observed in south Texas lagoons. She also described this community as dominated by detritus feeders. In the more open water of southern Laguna Madre, Smith identified a community defined by *Cerithidae pliculosa-Tagelus plebius*. She proposed that this community is found in lower salinity water due the inflow of fresh water from Arroyo Colorado and is dominated by suspension feeders. And, finally, in Baffin Bay and the northern portions of Laguna Madre, *Anomalocardia auberiana-Mulinia lateralis* are the dominant species in the community. Smith identified this community as being tolerant to hypersaline conditions and inhabited primarily by infaunal suspension feeders.

For comparison, only the “dead” matrix was compared with the matrix from Bahia Grande. The data were vetted to exclude *Odostomia* sp. because it is a ubiquitous and ectoparasitic species that does not reflect specific environmental conditions. Species and locations with fewer than 10 occurrences were also excluded from analysis because the number of specimens is not sufficient to characterize species composition accurately.

Results

The NMDS ordination (Figure 8) shows a very clear trend of lower salinity sites on the bottom half of Axis 2 and higher salinity sites on the upper half of Axis 2. The

Bittium varium-Crepidula convexa community which Smith associated with relatively low salinity water influenced by exchange with the Gulf of Mexico is found at the bottom

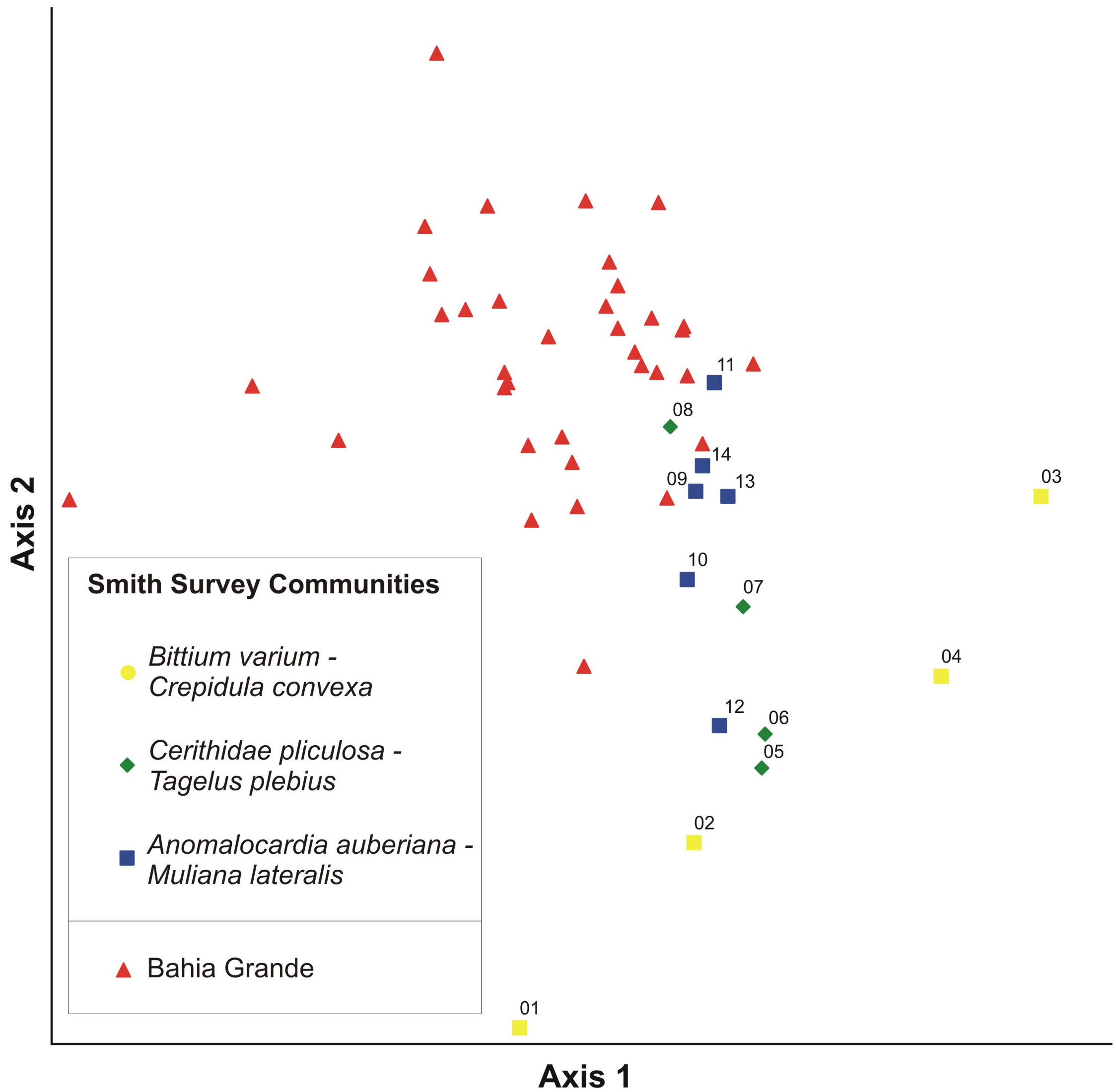

Figure 8. NMDS ordination of sites from Smith (1985) and Bahia Grande. Data was logarithmically transformed prior to analysis. Relative Euclidean distance measure was used for ordination. Stress is 11.2%. The labeled points represent the sampling locations from Smith (Fig. 7).

of Axis 2. The *Cerithidae pliculosa-Tagelus plebius* locations are higher on Axis 2 than the *Bittium varium-Crepidula convexa* community indicating that their fauna prefers a slightly higher salinity. The *Anomalocardia auberiana-Mulinia lateralis* community, which is found in Baffin Bay and northern portions of Laguna Madre is mostly found higher in Axis 2 than the other two communities and overlaps with some of the Bahia Grande data. In particular, locations 11, 13, and 14, which are located within Baffin Bay, plot amongst the Bahia Grande samples. Baffin Bay is known to be high in salinity with limited fresh water inflow, indicating that Bahia Grande in the past was probably very similar. Not surprisingly, the dominant species in Baffin Bay, *M. lateralis* and *A. auberiana*, are also the two most abundant bivalves in Bahia Grande.

It is also important to recognize that, although the communities classified by Smith are mostly identifiable as distinct groups in the ordination with the Bahia Grande data, there are some differences. For example, Smith's location 08 is located in Laguna Madre and plots amongst the *Anomalocardia auberiana-Mulinia lateralis* community and close to the Bahia Grande locations, even though Smith considered location 08 to be part of the *Cerithidae pliculosa-Tagelus plebius* community. Additionally, Smith's locations 06 and 12, which are from the *Cerithidae pliculosa-Tagelus plebius* and *Anomalocardia auberiana-Mulinia lateralis* communities, respectively, appear on the ordination to be most similar to the *Bittium varium-Crepidula convexa* community. It is possible that location 12 is affected by influx of water through Yarborough Pass, which connects Laguna Madre with the Gulf of Mexico.

Discussion

Comparison of Bahia Grande data with the Smith survey indicates that the highest salinity sites in the Smith survey are the most similar to Bahia Grande. The species that are tolerant to highly saline conditions, *M. lateralis* and *A. auberiana*, are the most dominant in Bahia Grande. Additionally, these species are infaunal suspension feeders which are typical of shallow lagoons with little freshwater inflow (Smith 1985). Many of the species that occur in higher abundance elsewhere in the Smith survey, such as the herbivorous gastropod *Bittium varium*, would not have ideal feeding conditions in a shallow lagoon with limited amounts of sea grass.

These results correspond nicely with the results from comparison between Bahia Grande and the BEG survey. Baffin Bay and Alazan Bay appear to be very closely related to the molluscan death assemblage in Bahia Grande in both comparisons. Despite the fact that these bays are not the closest geographically, the shallow, mostly enclosed lagoons bear the most similarity to Bahia Grande. The high salinity and relatively long water residence time in Baffin Bay are important environmental characteristics that may have been present in the past in Bahia Grande. In both comparisons, southern Laguna Madre and South Bay sampling locations are not very closely related to the Bahia Grande sites even though they are geographically close.

LOCAL TRENDS WITHIN BAHIA GRANDE

Besides knowing how Bahia Grande fits into a regional context, it is also valuable to understand differences within the lagoon. Previous studies (e.g. Warme 1969, 1971; Wiedemann 1972; Staff et al. 1986; Powell et al. 1992; Springer and Flessa 1996) comparing dead shell content versus live shell content have shown that preserved shell records are analogous to past ecological communities. For example, Warme (1969, 1971) found that live faunas from Mugu Lagoon in southern California reflected the death assemblages whether comparing individual species or whole communities. He also found that postmortem transport of shells was insignificant for most paleontological purposes.

Furthermore, the relationship between species and environmental conditions has been recognized in previous studies (e.g. Parker 1955; Johnson 1971; Stanton 1976; Kalke and Montagna 1991; Montagna and Kalke 1995; Bernasconi and Stanley 1997; Mannino and Montagna 1997; Judd and Lonard 2002; Whaley and Minello 2002; de Arruda and Amaral 2003). These patterns are significant and could be created by a number of factors. Parker (1955) and Kalke and Montagna (1991) found that salinity was a primary control on the distribution of mollusks in Texas bays. Mannino and Montagna (1997) found salinity to be the dominant environmental factor on benthic communities in Nueces Bay while sediment was a contributing secondary factor. Judd and Lonard (2002, 2004) found that elevation, salinity, and substrate were all major controls of plant species in coastal south Texas. Johnson (1971) documented substrate as an important influence on animal distribution. Whaley and Minello (2002) identified distance from the marsh edge as a control in the distribution of benthic infauna. Stanton (1976) found strong correlations between the shelled fossil community and the physical environment, such as geographic location, depth, and substrate, but found poor correlation in trophic structure and the fossil community. Recognizing a pattern in the distribution of preserved molluscan species from Bahia Grande is the first step in reconstructing the past environment. The next step is to infer what may have caused the pattern. With additional information about the environmental preferences of molluscan species in Texas (e.g. Parker 1959; Carpelan 1967; Stanley 1970; Abbott 1974), it is possible to suggest likely controls on the distribution of species.

Lack of evident pattern in species distribution would be an equally important result. This would imply that water circulation in the lagoon was thorough and there were no areas of substantially different environmental conditions. The wind-driven tides combined with effective open connections between Bahia Grande and adjacent bodies of water are probable mechanisms for creating a well-circulated lagoon.

Understanding trends within Bahia Grande is important for the restoration effort because it will help to understand possible water circulation patterns in the past. In particular, it is of interest to recognize whether connections were present between Bahia Grande and adjacent water bodies. The restoration effort has proposed to cut numerous channels connecting these water bodies (Fig. 2); these channels may greatly influence not only the exchange of water in Bahia Grande, but also the interchange of fauna between the lagoons.

Data and Methods

For statistical analysis, the data were vetted to exclude ubiquitous or extremely rare species as well as sites with limited specimens. All species with fewer than 10 total specimens or occurring in fewer than 3 sites were excluded. Sites with fewer than 10 total specimens were excluded from data analysis because the number of specimens is not sufficient to characterize species composition accurately. Additionally, the gastropod *Odostomia* sp., which occurs in nearly every location and is the dominant species in nearly all of those, was excluded from analysis because it is an ectoparasitic species that lives on a variety of hosts including bivalves and fish (Ward and Langdon 1986) and, therefore, is not likely to be directly sensitive to past benthic environments.

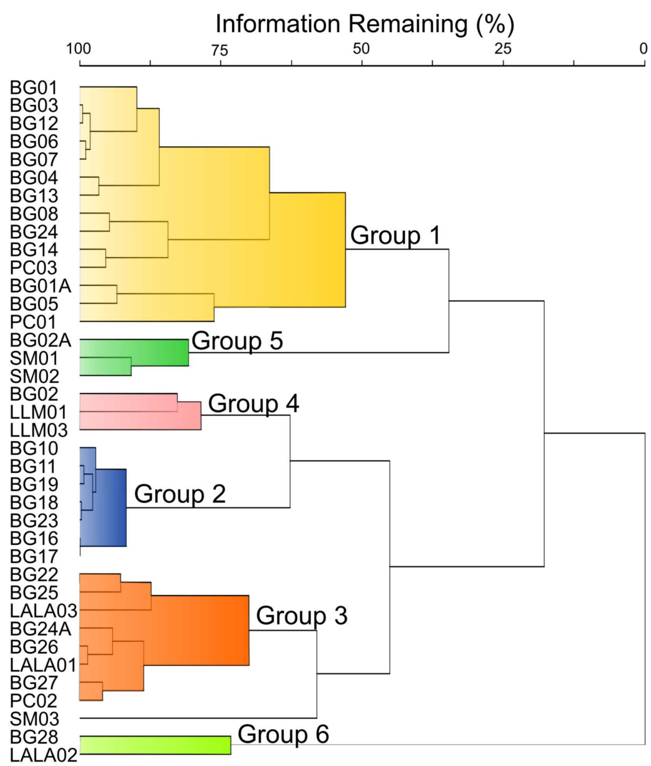

Figure 9. Cluster analysis of Bahia Grande. Raw abundance data were transformed logarithmically prior to analysis. Methods used were Ward's method of clustering and Relative Euclidean distance measure. Group colors correspond with Fig. 10.

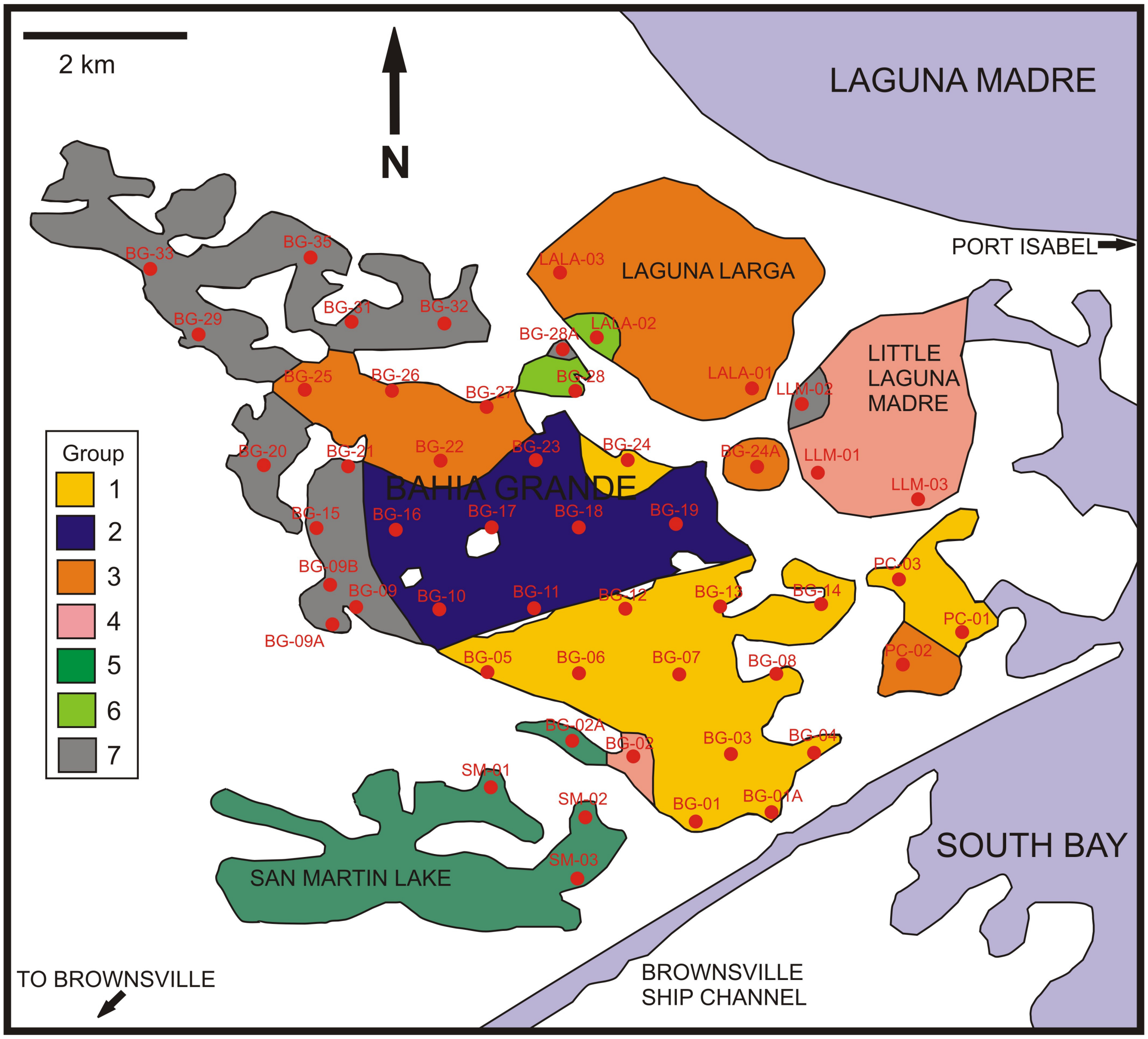

Figure 10. Geographic map of cluster analysis groups. Colors correspond with Fig. 9.

Cluster Analysis Results

Cluster analysis was used as a means of classifying sites into distinct associations based on their species compositions. The cluster dendrogram and corresponding map (Figures 9 & 10) show a number of distinct groups. The two most prominent groups (1 and 2) split the southern part of the lagoon into two halves. Sites in the northern part of Bahia Grande as well as Laguna Larga form another large group. San Martin Lake and Little Laguna Madre each have their own groupings as well. Finally, the gray shaded areas indicate sampling locations that were either completely barren or had fewer than 10 total specimens and were vetted from the statistical analysis.

Table 1. Cluster analysis group characteristics.

GROUP	PRIMARY LOCATION	TOTAL ABUNDANCE	DOMINANT SPECIES	INFERRED CONDITIONS
1	South – Central Bahia Grande	very high	*M. lateralis, M. tenta, T. plebius*	Frequent water coverage, moderate salinity
2	Central Bahia Grande	moderate to high	*M. lateralis, A. auberiana*	High salinity
3	North Bahia Grande and Laguna Larga	moderate	*M. lateralis, A. auberiana, B. varium*	Moderate to high salinity,
4	Little Laguna Madre	moderate	*A. auberiana*	Very high salinity
5	San Martin Lake	moderate to high	*A. aequalis, T. parvicallum*	Low to moderate salinity
6	Bahia Grande connection to Laguna Larga	low	*P. duplicatus*	Moderate salinity
7	Northern Bahia Grande	barren	n/a	High evaporation, infrequent water coverage

Table 2. Environmental preferences of key species. Sources: Parker 1959; Stanley 1970; Abbott 1974.

SPECIES	SALINITY	SUBSTRATE	FEEDING	ENVIRONMENT
Abra aequalis	Moderate (25-35 ‰)	Muddy sand	Suspension feeder	Coastal marine
Anomalocardia auberiana	Tolerant to salinity over 50‰	Mud and sand	Infaunal suspension feeder	Shallow hypersaline lagoons
Bittium varium	Moderate (25-35 ‰)	n/a	Epifaunal herbivore	Areas with abundant seagrass
Macoma tenta	Moderate to high (30-40 ‰)	Mud	Deposit feeder	Shallow water
Mulinia lateralis	Tolerant to a wide range of salinities	Mud	Suspension feeder	Found in a variety of environments
Polinices dupliucatus	Moderate (25-35 ‰)	Sand	Predatory gastropod	Tidal flats and sand bars
Tagelus plebius	Moderate (25-35 ‰)	Mud	Infaunal deposit feeder	Shallow, rarely found above mean tide
Teinostoma parvicallum	Moderate (25-35 ‰)	Sand	Epifaunal deposit feeder	Coastal marine

By identifying the dominant species in each group that was found using cluster analysis, it is possible to infer what the environmental conditions may have been like in each area. Table 1 lists the main characteristics of each group identified by the cluster analysis. The preferred environmental characteristics of the dominant species in Bahia Grande are listed in Table 2.

The most dominant groups are Group 1 and Group 2, located in the southern and central parts of Bahia Grande. The locations in each of these groups generally have higher abundance and richness than other areas of the lagoon. *Macoma tenta*, found predominantly in Group 1 is known to inhabit organic-rich, muddy bottoms and is generally restricted to subtidal settings (Stanley 1970). This indicates that this part of the lagoon may have been covered by water most of the time. The split between Group 1 and

Group 2 occurs as a straight line crossing the middle of Bahia Grande along the path of the disintegrated railroad trestle. The path of the railroad is also along a slight ridge, although it is impossible to say whether the ridge was naturally present before the railroad was built or if the ridge formed as a result of the railroad. Because this ridge is slightly higher than the basin of Bahia Grande, it is likely to have a significant effect on wind tides pushing water across the lagoon. During strong wind tides, the ridge is likely to pile up water on the windward side and create a barrier for water to be pushed away from the leeward side. Group 3 includes locations in the northern portion of the lagoon, as well as Laguna Larga and, although abundance varies among these sites, the dominant species indicate that water coverage was relatively frequent and salinity was moderate to high. *A. anomalocardia* is extremely dominant in Group 4 but *M. lateralis* is notably lacking. *A. anomalocardia* is one of the most tolerant species to hypersaline conditions indicating that Little Laguna Madre was likely hypersaline. BG-02 is also found in Group 4, but this site had low abundance and should be considered an outlier. Group 5 suggests that San Martin Lake was once connected with Bahia Grande since location BG-02A is very similar to the sites from San Martin Lake. *Abra aequalis* is not commonly found elsewhere in Bahia Grande or the surrounding lagoons. Group 6 is a pair of weakly related sites on the dendrogram and could possibly be considered as a couple of outliers. However, BG-28A and LALA-02 do lie adjacent to one another on the map and may indicate a previous connection between Laguna Larga and Bahia Grande. The gastropod *Polinices duplicatus* is found in these locations and only rarely elsewhere. Group 7 was not included in the analyses because the samples were either completely barren or very sparse. The majority of these locations are in the extreme northern portion of the lagoon. This barrenness may be an indication that the environment in this area was not very hospitable for mollusks. This could be due to lack of water coverage because the depth of Bahia Grande is much shallower in this region. Also, if water was only intermittently present, rate of evaporation is likely to be high and any water that was present may have been hypersaline or even briny.

The majority of the groups presented here were found regardless of the method used to calculate the cluster analysis. Relative Euclidean distance measure was used in Figure 9, however this method is prone to form groups associated by mutual absences (McCune and Grace 2002). Similar results obtained by using the quantitative Jaccard or Sorensen measures along with different linkage methods such as group averaging or flexible beta (McCune and Grace 2002) indicate that the results presented here are robust and not an artifact of the methods chosen. However, it is important to keep in mind that cluster analysis, regardless of methods used, can break a continuous gradient into distinct groups.

Site Ordination Results

The results of the NMDS indicate that the groups identified by cluster analysis (Figure 9) do not have well-defined boundaries but, rather, grade into one another. The plot of Axis 1 vs. Axis 2 (Figure 11) reveals the main locations identified by cluster analysis as Group 1 on the right side of Axis 1. The middle portion of Axis 1 is filled with the majority of locations from Group 2 and Group 3. The left side of Axis 1 contains Group 6 locations BG-28 and LALA-02 which were found to be a weakly clustered pair of outliers.

Axis 2 again shows most of the locations in the middle portion of the axis. SM-01, SM-02, and, to a lesser extent, BG-02A plot on the lower portion of Axis 2. These are the locations that comprise Group 5 in the cluster analysis and are dominated by the moderate salinity species *Teinostoma parvicallum* and *A. aequalis*.

Axis 3, shown in a plot of Axis 3 vs. Axis 2 (Figure 12), helps to reveal additional groups found in the cluster analysis. Sites from Little Laguna Madre (Group 4), which are dominated by *A. auberiana* and most likely high salinity, plot near each other on the right side of Axis 3 indicating the robustness of this cluster pairing.

The results of ordination indicate that, while the groups identified by cluster analysis may be present, they do not have strongly defined boundaries. However, there are certainly differences from one end of the lagoon to the other and difference among the lagoons. The ordination supports the proposition that San Martin Lake and Bahia Grande were once connected. Sites from Paso Corvinas also appear closely related to Bahia Grande sites indicating that they may also have been connected in the past. The Laguna Larga connection with Bahia Grande also may have been a natural former connection. However, the evidence shown here does not indicate the presence of any former connections involving Little Laguna Madre.

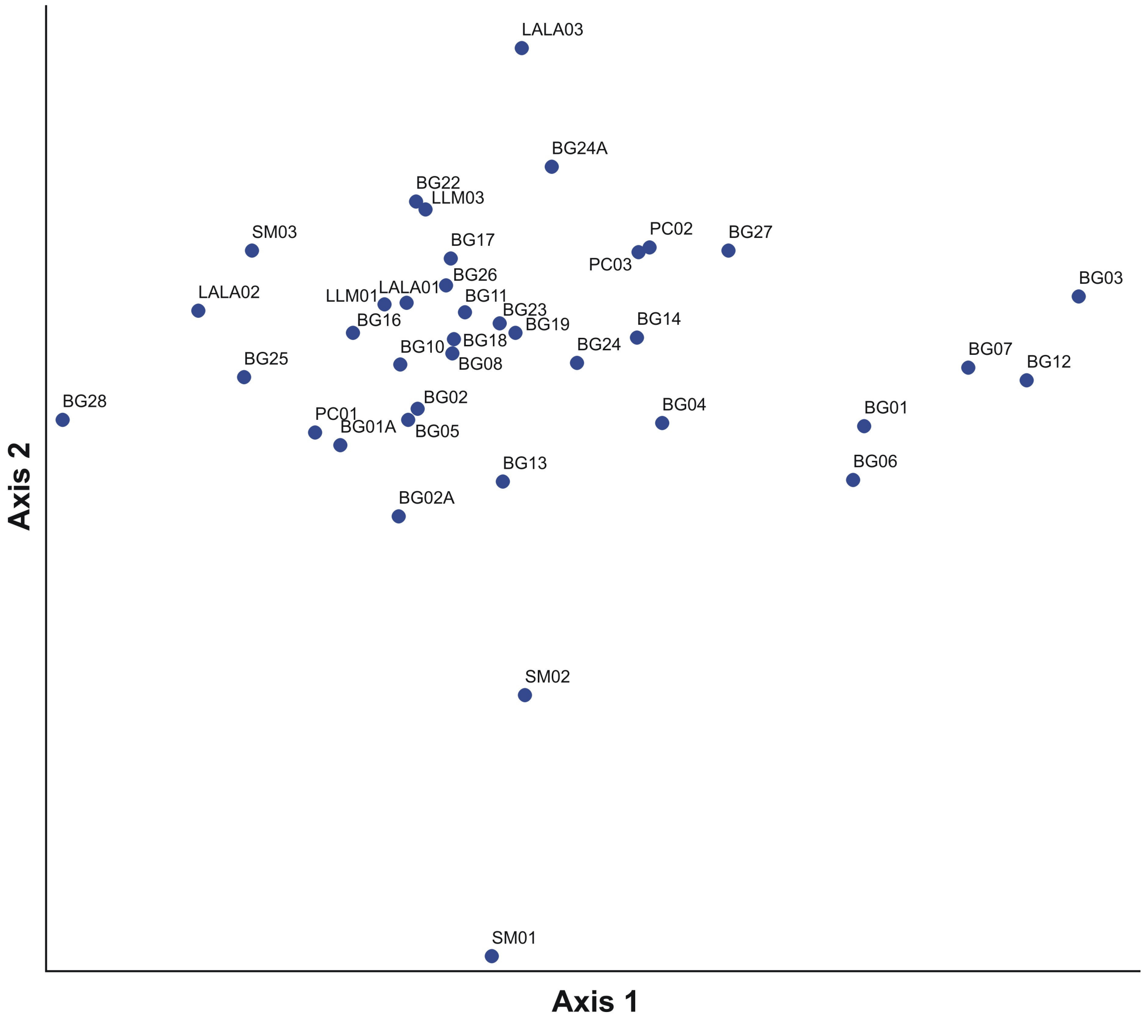

Figure 11. Bahia Grande site NMDS ordination Axis 1 vs. 2. Data were logarithmically transformed prior to analysis. Euclidean distance measure was used for the ordination. Stress is 8.7%

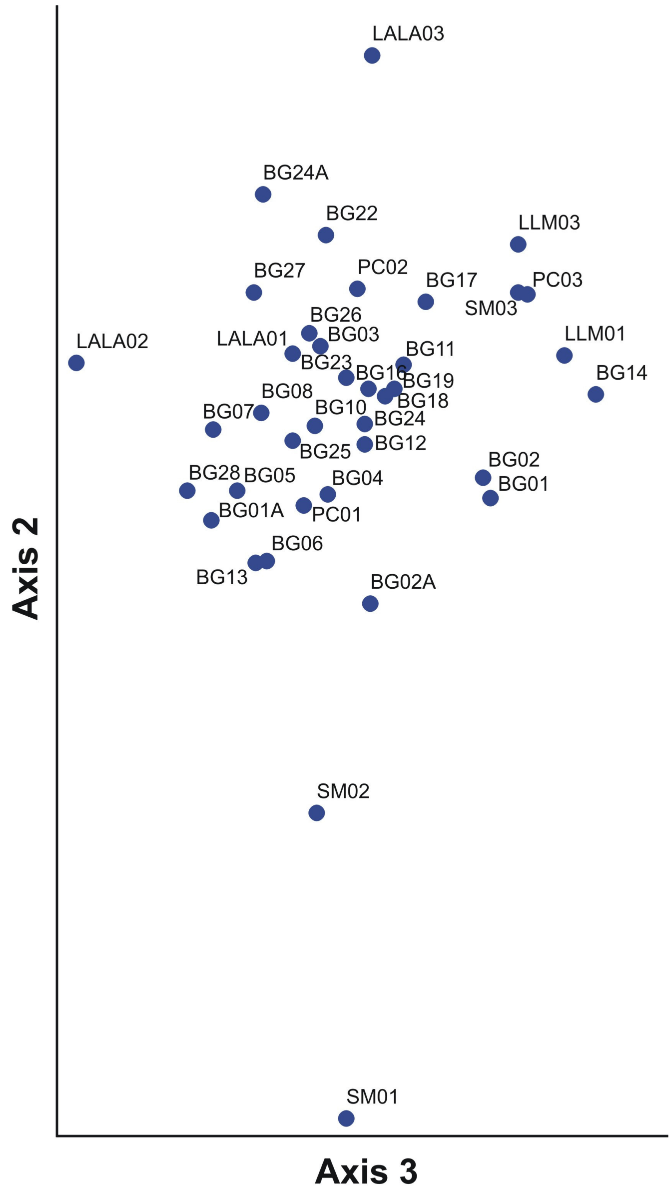

Figure 12. Bahia Grande site NMDS ordination Axis 3 vs. 2. Data were logarithmically transformed prior to analysis. Euclidean distance measure was used for the ordination. Stress is 8.7%

Species Ordination Results

A NMDS ordination of species (Figure 13) corresponds well with the results seen in the site ordination. Again, the data were vetted to exclude sites with 10 or fewer total specimens and species with 3 or fewer total occurrences. Although it was excluded from the sites analyses, *Odostomia* sp. was included in the species analyses in order to determine if it has effect on species associations.

The majority of species group in the upper left corner of the ordination plot. These mostly occur in low abundance and are from sampling locations with high richness, such as Group 1. Axis 1 pulls *M. lateralis* and *M. tenta* to the right side of the plot. *M. lateralis* is fairly ubiquitous but occurs in highest abundance in the southern portion of the lagoon (Group 1). *M. tenta* occurs less frequently overall but also has high abundance in the southern portion of the lagoon (Group 1). Axis 2 pulls *A. aequalis* and *T. parvicallum* to the bottom of the plot. These are the dominant species found in San Martin Lake (Group 1) and generally prefer moderately saline water. The large cluster of species falls in the upper portions of Axis 2 but *B. varium* and *A. auberiana* are pulled slightly above the rest. *A. auberiana*, in particular, is a euryhaline species known to exist in hypersaline lagoons. Axis 2, therefore, is interpreted to represent a gradient in salinity preference of species found in Bahia Grande with species that prefer moderate salinity closest to the bottom and species that can tolerate higher salinity near the top.

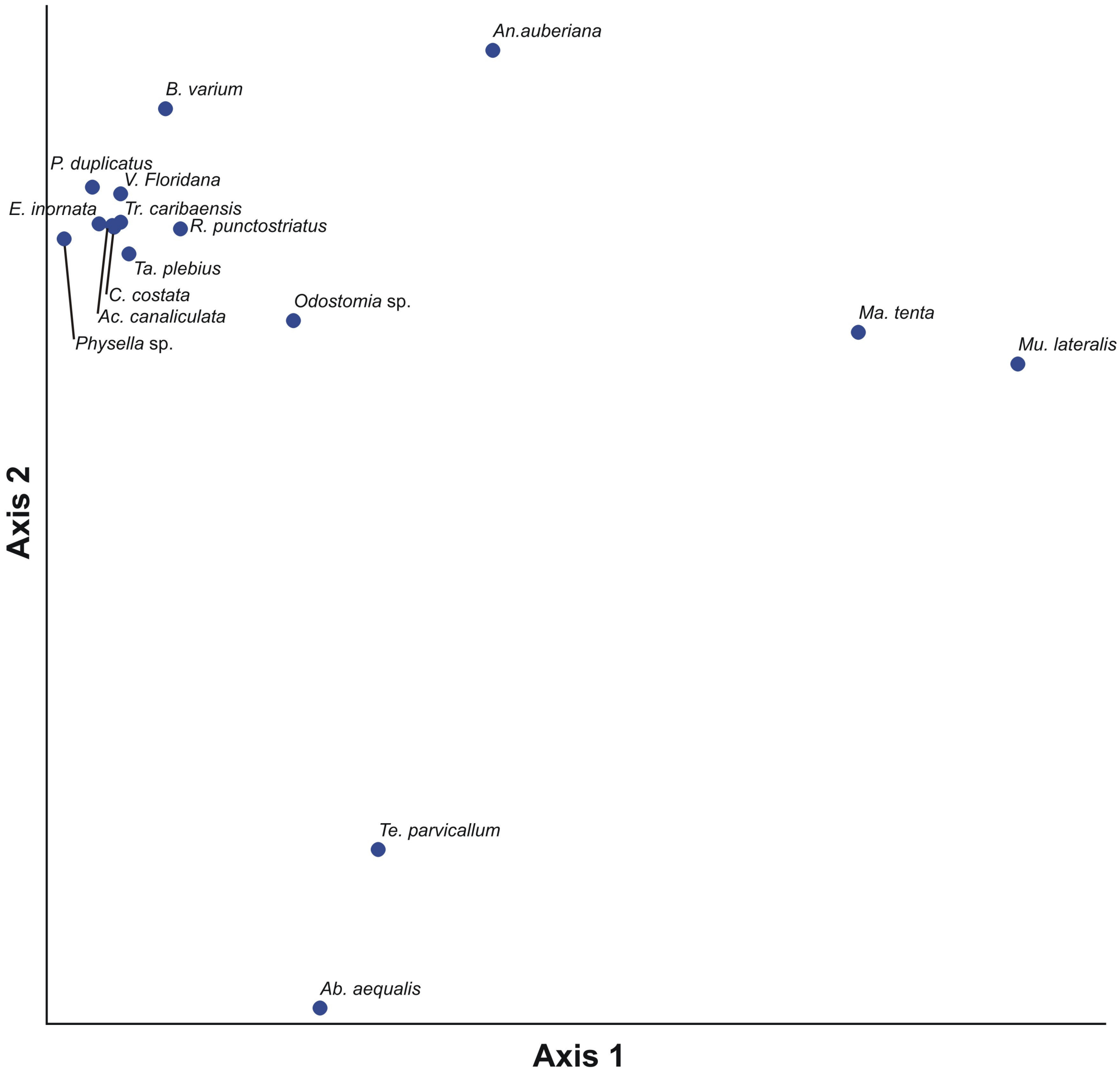

Figure 13. Bahia Grande species NMDS ordination. Axis 1 vs. Axis 2. Data were logarithmically transformed prior to analysis. Euclidean distance measure was used. Stress is 1.30%.

Sediment Analysis Results

In some studies, substrate has been found to have a primary effect on the benthic faunal distribution (e.g. Johnson 1971; Harry 1976; Stanton 1976). A sediment sample was collected at each sampling location in Bahia Grande and surrounding lagoons to evaluate substrate type. The sediment samples were taken at a depth of 15 cm below the sediment surface. Grain size distributions were determined using a Micrometrics®

Sedigraph 5120. Based on grain size, each sample was assigned to one of four categories (Appendix G). If the dominant grain size was <4 µm, the assigned category is “mud”. Samples where the dominant grain size is split between <4 µm and 4-60 µm are categorized as “silty mud”. Where grain size dominance is split between 4-60 µm and >60 µm samples are categorized as “sandy silt”. Finally, if the dominant grain size is >60 µm the assigned category is “sand”.

Sites in the NMDS ordination were categorized by grain size (Figure 14). The scattered pattern of grain sizes indicates that there is no strong relationship between sediment grain size and the distribution of mollusks in Bahia Grande. The lack of grain size relationship to the distribution of mollusks may be due to the fact that nearly all of the sediment in Bahia Grande is very fine grained with very little variation. Even in the locations categorized as “sand”, the sediment is relatively fine grained sand with no coarse grains.

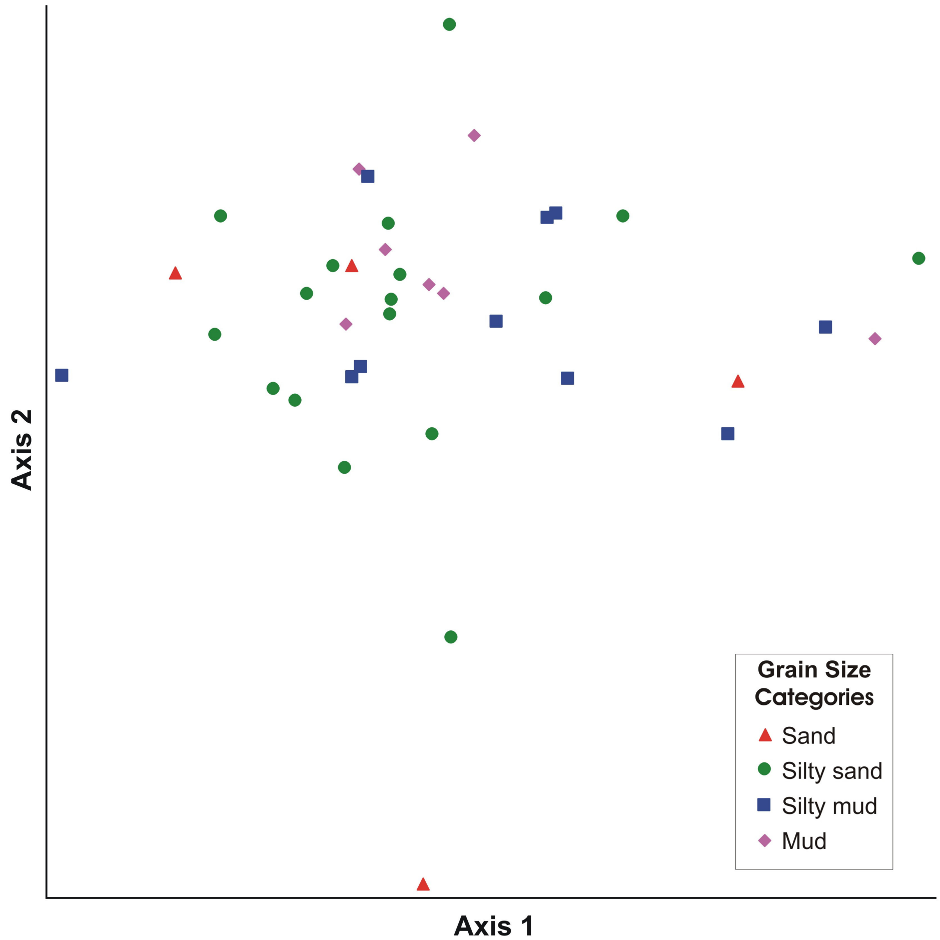

Figure 14. NMDS ordination of sites (same as Fig. 11) categorized by grain size. Data were logarithmically transformed. Euclidean distance metric was used for ordination. Stress is 8.7%

Discussion

Within Bahia Grande, cluster analysis identifies a number of distinct faunal assemblages, but ordination indicates that there is much more of a blurred gradient between areas in Bahia Grande. The groups identified indicate that the southern portion of Bahia Grande, which would have been more open and likely contained deeper water, was probably covered by water most of the time as indicated by the presence of *M. tenta*. This area also has the richest collections of species. In the northern portions of the lagoon, the dominant species present are *A. auberiana* and *M. lateralis* with very few other species. This suggests that the environment may have been more stressed due to high salinity since these species are known to tolerate a greater range of salinities.

San Martin Lake has a distinct fauna characterized by *T. parvicallum* and *A. aequalis*. In addition to San Martin, BG-02A also has a similar fauna so it is very possible that at one time, these bodies of water were connected.

Little Laguna Madre also has a distinctive fauna that is almost exclusively *A. anomalocardia* with very few other species occurring here. It is quite likely that Little Laguna Madre was a hypersaline environment that only a few specialized species could inhabit. Since none of the surrounding lagoons appear to have a similar fauna, it is questionable as to whether there were ever any natural connections between Little Laguna Madre and Bahia Grande or Laguna Larga. Interestingly, the USFWS proposal has proposed to cut channels here anyway.

The northern portion of Bahia Grande had very few specimens. Although these locations were left out of analyses for statistical reasons, it seems likely that, due to the shallow depth and the limited accessibility due to the islands and ridges in the northern area, combined with high rates of evaporation, this part of Bahia Grande frequently had very little water coverage. As a result, it was a very inhospitable environment for mollusks. It is unlikely that this result is a taphonomic bias. The few shells that were found in the northern, mostly barren sites in Bahia Grande were in similar taphonomic condition to the rest of the lagoon and the species composition included more fragile species such as the small gastropod *Odostomia* sp. that would be likely to be poorly preserved if taphonomic conditions were unfavorable.

DISCUSSION

The restoration of Bahia Grande is an effort to return a large area of wind-driven tidal lagoon to a biologically productive environment after nearly 70 years of hydrologic isolation from a continuous marine water supply. Numerous reasons to carry out this restoration include restored habitat for fauna and flora, reduction of dust blown into Port Isabel from the dry lagoon, and increased recreational use. Paleoecological analysis of Bahia Grande provides critical baseline information for understanding the environment in the lagoon prior to the disturbance caused by the Brownsville Ship Channel.

In a regional context, based on comparisons with two other studies, Bahia Grande relates most closely to the high salinity environments found in Baffin Bay and Alazan Bay. This outcome is corroborated by the high abundance of *A. auberiana* found in Bahia Grande, which is a euryhaline species frequently occurring in hypersaline lagoons. *M. lateralis* is known to occur in a variety of environments ranging from brackish to hypersaline, so is less diagnostic of particular conditions. Although the water bodies immediately adjacent to Bahia Grande (Lower Laguna Madre and South Bay) are also relatively high in salinity compared with the open ocean, these locations are more open with a greater influx of lower salinity water, either from the Rio Grande or through Brazos Santiago Pass connecting the Gulf of Mexico with Laguna Madre. Baffin Bay and Alazan Bay, on the other hand, have a very arid climate, have limited fresh water inflow, and have high rates of evaporation, which are favorable conditions for high salinity. In addition, the longer water residence time in mostly enclosed bays with limited freshwater inflow, such as Baffin Bay and Alazan Bay, may be an important characteristic that was also present in Bahia Grande in the past.

The local differences in Bahia Grande indicate that salinity and amount of water coverage are the dominant environmental factors on the molluscan distribution. The central part of the lagoon, which likely had the greatest amount of water coverage and moderate salinity, provided the most hospitable conditions and has the richest and most abundant sampling locations. Locations in the northern section of Bahia Grande were relatively barren and likely were exposed to high evaporation rates and infrequent water coverage, making them inhospitable. Data from surrounding lagoons suggest that in the past, connections were present between San Martin Lake and the southern portion of Bahia Grande. Connections between Laguna Larga and Bahia Grande and between Paso Corvinas and Bahia Grande were also likely present based on the data obtained in this study. The restoration of Bahia Grande has proposed to cut these channels as well as others that may not have been present in the past, such as Channel D between Little Laguna Madre and Laguna Larga (Figure 2; USFWS 2004). The choice of which channels are cut may have a pronounced affect on the water circulation patterns in Bahia Grande and the ability of fauna to move between the water bodies.

The results found in this study indicate that Bahia Grande was a dynamic ecosystem in the past with numerous environmental features affecting the faunal distribution. Since there is very little recorded information about the history of Bahia Grande, the paleoecological approach used here provides at least a partial understanding of past conditions so that there is something to compare the current and future state of the lagoon with. This knowledge is important in recognizing how Bahia Grande has changed as a result of construction of the Brownsville Ship Channel.

Coastal ecosystems, such as Bahia Grande, are fragile and very vulnerable to any sort of natural or anthropogenic change. They are often the first visible indicators that change is occurring. Because many types of fauna and flora are unique to specific coastal environments and also because of the importance of these areas as resources for humans, it is vital that we understand the histories of these systems and recognize how they change with time. Although the study presented here is a case study limited to one area, coastal ecosystems around the world are experiencing similar changes as humans continue to build and expand such things as ship channels or jetties or seawalls without always considering the impact on the ecosystem.

From a paleontological perspective, this study is unusual in being directly applied to a modern situation. It is not often that a paleontological model of the past can be so quickly compared to the present. It will be interesting to discover in the near future how the results of this study compare with the results of the restoration of Bahia Grande.

While the methods used in this study are not new to paleontology, they are a somewhat innovative approach to understanding restoration in a shallow aquatic environment. The successful application of these methods here will hopefully lead to future use of paleoecological data for understanding coastal wetland systems that are undergoing restoration or rehabilitation (e.g. Zedler 1996, 2001; Landres et al. 1999; Jackson 2001).

Although it was not possible during the course of this study, in similar future studies it would be useful to obtain age dates of the shell material being examined (e.g. Flessa et al. 1993; Flessa and Kowalewski 1994; Meldahl et al. 1997; Kowalewski 1998). This would provide a better model for understanding how time averaging has affected the data by providing an estimate of the range of ages of the shells in Bahia Grande. It may also be helpful to determine the micropaleontology of the area since foraminifera and other small benthic organisms can be used to determine environmental conditions. An examination of the palynology of Bahia Grande was done as part of this study, but results were inconclusive since pollen does not preserve well in the arid climate of south Texas and is easily degraded when exposed to frequent wetting and drying (Holloway 1989). Finally, to add to the data collected for this study, it would be interesting to obtain more recent data from the regional bays such as Baffin Bay, Laguna Madre, South Bay, and even in the Brownsville Ship Channel. Recent data from these areas would be useful not only for comparison with the past and future assemblages from Bahia Grande, but also with the past collections from the same areas to see how they have changed since the White et al. (1983, 1986, 1989) and Smith (1985) surveys were done.

CONCLUSIONS

Based on comparison with two other studies, on a regional scale, Bahia Grande compares most closely with the high to hypersaline conditions found in Baffin Bay and Alazan Bay. These bays are shallow lagoons with an arid climate and little freshwater inflow resulting in high salinity. The enclosed nature of these bays may also play an important role in lengthening water residence times and reducing the amount of flushing. The immediately adjacent water bodies, such as South Bay and Lower Laguna Madre contain a somewhat different fauna. This may have implications for the migration of species to Bahia Grande following the restoration.

The distribution of mollusks in Bahia Grande shows distinct groups based on cluster analysis. The dominant environmental factors associated with these groupings are salinity and frequency of water indundation. The groups do not have distinct boundaries but are graded into one another, as shown using NMDS ordination.

Substrate type, as determined by grain size, does not appear to have much effect on the distribution of mollusks in Bahia Grande. Although grain size is known to be a key factor in other water bodies, the sediment in Bahia Grande is limited to mostly very fine grain size without much variation. Other environmental factors, such as salinity, are more discriminating in Bahia Grande.

Based on the groups described by cluster analysis, not all of the proposed channels in the USFWS proposal may be “natural” former connections between Bahia Grande and the surrounding lagoons. Some connections, such as San Martin Lake-Bahia Grande, Laguna Larga-Bahia Grande and Paso Corvinas-Bahia Grande do seem to be indicated by the molluscan fauna. Other connections, such as Little Laguna Madre-Laguna Larga are not supported by the fossil evidence.

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APPENDIX A

SATELLITE IMAGE OF BAHIA GRANDE AND SURROUNDING REGION

Figure 15. Satellite image of Bahia Grande. This image shows Bahia Grande and the surrounding region. The Laguna Atascosa National Wildlife Refuge boundary is shown in purple. The proposed channel locations for restoration are yellow. It is possible to see the well defined boundary between the Brownsville Ship and Bahia Grande that prevents water from getting into Bahia Grande. Also visible in this image are the former channel patterns from when this part of the Rio Grande delta was active that surround Bahia Grande. From USFWS (2004).

APPENDIX B

1929 MAP OF BAHIA GRANDE

Figure 16. 1929 map of Bahia Grande.

APPENDIX C

UTM COORDINATES FOR SAMPLING LOCATIONS

SAMPLE	EASTING	NORTHING
BG-01	671893	2878048
BG-01A	673000	2878048
BG02	671333	2878917
BG-02A	670500	2879000
BG-03	672429	2878917
BG-04	673368	2878927
BG-05	669595	2879798
BG-06	670690	2879798
BG-07	671893	2879798
BG-08	673000	2879798
BG-09	667952	2880738
BG-09A	667429	2879000
BG-09B	667402	2880338
BG-10	669024	2880738
BG-11	670095	2880738
BG-12	671333	2880738
BG-13	672429	2880738
BG-14	673524	2880738
BG-15	667429	2881679
BG-16	668500	2881679
BG-17	669595	2881679
BG-18	670690	2881679
BG-19	671893	2881679
BG-20	666905	2882643
BG-21	668013	2882616
BG-22	669024	2882643

SAMPLE	EASTING	NORTHING
BG-23	670095	2882643
BG-24	671257	2882466
BG-24A	672961	2882448
BG-25	667429	2883548
BG-26	668628	2883307
BG-27	669682	2883183
BG-28	670501	2883536
BG-28A	670418	2884025
BG-29	665883	2884057
BG-31	667841	2884169
BG-32	669024	2884500
BG-33	664645	2885131
BG-35	667526	2885110
LALA-01	672813	2883609
LALA-02	670642	2884198
LALA-03	670351	2884789
LLM-01	673516	2882548
LLM-02	673594	2883162
LLM-03	674302	2881968
PC-01	674215	2881107
PC-02	674751	2880074
PC-03	675090	2880895
SM-01	669609	2878492
SM-02	670696	2878119
SM-03	670363	2877144

All UTM coordinates are from zone 14 using the 1927 North American Datum

APPENDIX D

BAHIA GRANDE DATA MATRIX - 2 mm

	BG 01	BG 01A	BG 02	BG 02A	BG 03	BG 04	BG 05	BG 06	BG 07	BG 08	BG 09	BG 09A	BG 09B	BG 10	BG 11	BG 12	BG 13	BG 14
Acteocina canaliculata	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bittium varium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Episcynia inornata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina lineolata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odostomia sp.	0	0	0	3	8	0	0	0	0	0	0	0	0	0	0	0	3	0
Physella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polinices duplicatus	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rictaxis punctostriatus	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	4
Teinostoma parvicallum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Truncatella caribaeensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vitrinella floridana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Abra aequalis	0	0	0	3	2	0	0	3	1	0	0	0	0	0	0	0	0	0
Anomalocardia auberalis	11	0	4	2	46	7	0	4	6	0	0	0	0	0	2	9	0	27
Brachidontes exustus	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Cyrtopleura costata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0
Macoma tenta	4	0	0	0	132	2	0	16	64	2	0	0	0	1	0	69	1	5
Mulinia lateralis	15	0	4	4	213	29	0	73	122	7	0	0	0	2	15	228	7	3
Ostrea equestris	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tagelus plebeius	9	0	0	0	2	0	0	0	0	0	0	0	0	0	0	4	0	2
Tellina texana	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**46**	**0**	**8**	**12**	**405**	**38**	**0**	**98**	**194**	**10**	**0**	**0**	**0**	**3**	**18**	**311**	**11**	**43**

BAHIA GRANDE DATA MATRIX - 2 mm continued

	BG 15	BG 16	BG 17	BG 18	BG 19	BG 20	BG 21	BG 22	BG 23	BG 24	BG 24A	BG 25	BG 26	BG 27	BG 28	BG 28A	BG 29	BG 31
Acteocina canaliculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bittium varium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Episcynia inornata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina lineolata	0	0	0	0	0	0	0	0	0	0	1	0	0	0	11	0	0	0
Odostomia sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
Physella sp.	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Polinices duplicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
Rictaxis punctostriatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teinostoma parvicallum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Truncatella caribaeensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vitrinella floridana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abra aequalis	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Anomalocardia auberalis	0	1	5	0	1	0	0	0	0	2	1	0	1	4	0	0	0	0
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyrtopleura costata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Macoma tenta	0	0	0	0	0	0	0	0	1	1	2	0	0	6	0	0	0	0
Mulinia lateralis	0	3	30	22	57	0	0	13	20	10	149	0	4	22	0	0	0	2
Ostrea equestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tagelus plebeius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tellina texana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**0**	**4**	**35**	**22**	**58**	**1**	**0**	**13**	**22**	**13**	**156**	**0**	**5**	**35**	**16**	**0**	**0**	**2**

BAHIA GRANDE DATA MATRIX - 2 mm continued

	BG 32	BG 33	BG 35	LALA 01	LALA 02	LALA 03	LLM 01	LLM 02	LLM 03	PC 01	PC 02	PC 03	SM 01	SM 02	SM 03	**TOTAL**
Acteocina canaliculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Bittium varium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Episcynia inornata	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	**2**
Littorina lineolata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**12**
Odostomia sp.	0	0	0	0	0	11	0	0	0	0	0	0	0	7	2	**36**
Physella sp.	0	0	0	0	0	3	0	0	0	0	0	0	6	0	0	**12**
Polinices duplicatus	0	0	0	0	20	4	0	0	0	0	0	0	0	0	0	**30**
Rictaxis punctostriatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**7**
Teinostoma parvicallum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Truncatella caribaeensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Vitrinella floridana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Abra aequalis	0	0	0	0	0	0	0	0	0	0	0	0	12	10	0	**34**
Anomalocardia auberalis	0	0	0	0	0	13	88	3	17	0	2	12	1	0	0	**269**
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Cyrtopleura costata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**
Macoma tenta	0	0	0	2	0	0	0	0	0	0	14	4	0	0	0	**326**
Mulinia lateralis	0	0	0	5	0	68	3	3	19	0	15	2	0	2	1	**1172**
Ostrea equestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Tagelus plebeius	0	0	0	0	0	2	0	0	12	0	1	0	0	2	0	**34**
Tellina texana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
TOTAL	**0**	**0**	**0**	**7**	**20**	**102**	**91**	**6**	**48**	**0**	**32**	**18**	**19**	**21**	**5**	**1948**

APPENDIX E

BAHIA GRANDE DATA MATRIX – 1 mm

	BG 01	BG 01A	BG 02	BG 02A	BG 03	BG 04	BG 05	BG 06	BG 07	BG 08	BG 09	BG 09A	BG 09B	BG 10	BG 11	BG 12	BG 13	BG 14
Acteocina canaliculata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bittium varium	3	0	0	0	0	1	0	1	1	0	0	0	0	0	0	2	0	0
Episcynia inornata	0	0	0	0	0	1	0	1	2	0	0	0	0	0	0	0	0	0
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina lineolata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odostomia sp.	140	4	70	152	89	25	10	188	24	11	1	1	0	9	21	41	33	152
Physella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polinices duplicatus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Rictaxis punctostriatus	0	0	4	0	1	0	0	1	2	2	0	0	0	0	0	3	0	8
Teinostoma parvicallum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Truncatella caribaeensis	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	1	1	0
Vitrinella floridana	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abra aequalis	0	0	5	5	10	5	0	5	6	0	0	0	0	0	0	4	0	0
Anomalocardia auberalis	21	0	10	1	68	6	0	12	14	3	0	0	0	1	10	15	2	21
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyrtopleura costata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma tenta	6	0	0	0	25	0	1	2	22	0	0	0	0	0	0	36	0	2
Mulinia lateralis	69	5	1	1	320	35	6	91	223	8	0	0	0	8	7	287	8	10
Ostrea equestris	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tagelus plebeius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Tellina texana	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
TOTAL	**241**	**9**	**91**	**159**	**516**	**73**	**17**	**302**	**295**	**24**	**1**	**1**	**0**	**19**	**38**	**389**	**44**	**194**

BAHIA GRANDE DATA MATRIX – 1 mm continued

	BG 15	BG 16	BG 17	BG 18	BG 19	BG 20	BG 21	BG 22	BG 23	BG 24	BG 24A	BG 25	BG 26	BG 27	BG 28	BG 28A	BG 29	BG 31
Acteocina canaliculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bittium varium	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0
Episcynia inornata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina lineolata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odostomia sp.	0	4	6	49	10	2	0	14	83	71	714	6	16	176	65	151	1	0
Physella sp.	0	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	0
Polinices duplicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rictaxis punctostriatus	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0
Teinostoma parvicallum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Truncatella caribaeensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Vitrinella floridana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Abra aequalis	0	0	0	1	0	0	0	0	0	1	0	0	0	6	0	0	0	0
Anomalocardia auberalis	0	1	17	10	10	0	0	3	2	4	3	0	2	22	0	0	0	0
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyrtopleura costata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma tenta	0	0	0	0	0	0	0	0	0	1	0	0	3	5	0	0	0	0
Mulinia lateralis	0	5	14	6	15	1	1	8	28	18	12	2	10	67	0	0	0	2
Ostrea equestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tagelus plebeius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tellina texana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**0**	**10**	**37**	**66**	**36**	**3**	**1**	**26**	**113**	**97**	**733**	**8**	**31**	**277**	**68**	**151**	**1**	**2**

BAHIA GRANDE DATA MATRIX – 1 mm continued

	BG 32	BG 33	BG 35	LALA 01	LALA 02	LALA 03	LLM 01	LLM 02	LLM 03	PC 01	PC 02	PC 03	SM 01	SM 02	SM 03	**TOTAL**
Acteocina canaliculata	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**2**
Bittium varium	0	0	0	0	0	4	1	0	1	0	4	3	0	0	2	**26**
Episcynia inornata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	8	**9**
Littorina lineolata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Odostomia sp.	1	0	0	79	54	1168	0	0	4	5	56	15	762	181	28	**4692**
Physella sp.	0	0	0	0	0	0	0	0	0	0	0	0	13	1	0	**18**
Polinices duplicatus	0	0	0	1	2	4	0	0	0	0	0	0	0	0	0	**8**
Rictaxis punctostriatus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**25**
Teinostoma parvicallum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Truncatella caribaeensis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**7**
Vitrinella floridana	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**3**
Abra aequalis	0	0	0	0	0	0	0	0	0	0	1	0	70	24	0	**143**
Anomalocardia auberalis	0	0	0	0	0	4	7	0	8	0	5	27	1	2	9	**321**
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Cyrtopleura costata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Macoma tenta	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	**109**
Mulinia lateralis	0	0	0	7	5	44	1	0	1	3	17	12	0	0	1	**1359**
Ostrea equestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Tagelus plebeius	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**3**
Tellina texana	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**2**
TOTAL	**1**	**0**	**0**	**87**	**61**	**1224**	**10**	**0**	**18**	**9**	**89**	**59**	**846**	**208**	**48**	**6733**

APPENDIX F

BAHIA GRANDE DATA MATRIX – 0.5 mm

	BG 01	BG 01A	BG 02	BG 02A	BG 03	BG 04	BG 05	BG 06	BG 07	BG 08	BG 09	BG 09A	BG 09B	BG 10	BG 11	BG 12	BG 13	BG 14
Acteocina canaliculata	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Bittium varium	4	0	2	0	8	3	2	0	0	0	0	0	0	0	1	0	0	2
Episcynia inornata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina nebulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odostomia sp.	293	11	267	635	233	160	73	216	147	64	5	2	3	14	46	118	67	273
Physella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polinices duplicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rictaxis punctostriatus	0	0	0	0	1	0	0	1	0	2	0	0	0	0	0	3	0	0
Teinostoma parvicallum	56	8	0	1	10	15	10	59	13	2	3	0	0	2	2	40	17	6
Truncatella caribaeensis	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Vitrinella floridana	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
Abra aequalis	5	0	0	11	16	4	0	17	21	0	0	0	0	0	0	3	4	0
Anomalocardia auberalis	13	0	3	1	69	11	1	5	8	0	0	0	0	2	13	27	0	11
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyrtopleura costata	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma tenta	3	0	0	0	27	0	0	4	39	0	0	0	0	0	0	21	0	1
Mulinia lateralis	54	2	1	1	254	25	3	23	223	5	0	0	0	3	6	158	10	4
Ostrea equestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tagelus plebeius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tellina texana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**435**	**21**	**273**	**649**	**620**	**219**	**89**	**325**	**453**	**73**	**8**	**2**	**3**	**21**	**68**	**372**	**98**	**299**

BAHIA GRANDE DATA MATRIX – 0.5 mm continued

	BG 15	BG 16	BG 17	BG 18	BG 19	BG 20	BG 21	BG 22	BG 23	BG 24	BG 24A	BG 25	BG 26	BG 27	BG 28	BG 28A	BG 29	BG 31
Acteocina canaliculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bittium varium	0	0	0	0	0	0	0	16	0	1	3	1	2	5	0	0	0	0
Episcynia inornata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina nebulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odostomia sp.	2	5	18	173	52	1	8	28	91	193	1588	29	52	470	19	47	1	2
Physella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polinices duplicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rictaxis punctostriatus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Teinostoma parvicallum	0	0	0	1	4	0	1	0	1	4	0	0	0	0	0	0	0	0
Truncatella caribaeensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Vitrinella floridana	0	0	0	0	0	0	0	0	1	2	0	0	0	0	5	0	0	0
Abra aequalis	0	0	0	0	0	0	0	0	1	1	0	0	0	5	0	0	0	0
Anomalocardia auberalis	0	5	14	6	9	0	0	3	11	10	6	0	2	7	0	0	0	0
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyrtopleura costata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma tenta	0	0	0	0	0	0	0	0	0	1	1	0	0	6	0	0	0	0
Mulinia lateralis	0	0	3	4	6	0	0	7	12	18	16	0	12	61	0	0	0	1
Ostrea equestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tagelus plebeius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tellina texana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**2**	**10**	**35**	**184**	**71**	**1**	**9**	**54**	**117**	**231**	**1614**	**30**	**68**	**554**	**26**	**47**	**1**	**3**

BAHIA GRANDE DATA MATRIX – 0.5 mm continued

	BG 32	BG 33	BG 35	LALA 01	LALA 02	LALA 03	LLM 01	LLM 02	LLM 03	PC 01	PC 02	PC 03	SM 01	SM 02	SM 03	**TOTAL**
Acteocina canaliculata	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**3**
Bittium varium	0	0	0	1	0	16	0	0	0	0	6	14	4	1	4	**96**
Episcynia inornata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Epitonium sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	13	**14**
Littorina nebulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Odostomia sp.	3	0	0	265	268	2220	0	0	5	14	192	142	3100	565	131	**12311**
Physella sp.	0	0	0	0	0	0	0	0	0	0	1	0	2	0	1	**4**
Polinices duplicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Rictaxis punctostriatus	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	**11**
Teinostoma parvicallum	0	0	0	0	0	0	0	0	0	2	2	4	83	25	0	**371**
Truncatella caribaeensis	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	**10**
Vitrinella floridana	0	0	0	1	4	0	0	0	0	1	1	1	0	0	0	**22**
Abra aequalis	0	0	0	0	0	0	0	0	0	1	0	0	141	46	0	**276**
Anomalocardia auberalis	0	0	0	3	0	8	5	0	4	1	12	35	1	1	2	**309**
Brachidontes exustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Cyrtopleura costata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**
Macoma tenta	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	**105**
Mulinia lateralis	0	0	0	8	0	12	0	0	0	0	19	8	0	5	2	**966**
Ostrea equestris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Tagelus plebeius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Tellina texana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**3**	**0**	**0**	**278**	**277**	**2256**	**6**	**0**	**9**	**19**	**233**	**209**	**3331**	**643**	**153**	**14502**

APPENDIX G

SEDIMENT ANALYSIS GRAIN SIZE PERCENTAGES

SAMPLE	> 60 µm	4-60 µm	< 4 µm	CATEGORY
BG-01	22.844	41.653	35.503	Sand
BG-01A	11.529	27.492	60.979	Silty mud
BG02	5.941	37.543	56.516	Silty sand
BG-02A	2.105	34.448	63.446	Silty mud
BG-03	9.267	23.931	66.801	Silty mud
BG-04	9.091	35.679	55.230	Silty sand
BG-05	10.575	53.303	36.122	Silty sand
BG-06	11.111	32.339	56.550	Silty sand
BG-07	10.725	32.782	56.494	Silty sand
BG-08	2.821	26.839	70.341	Silty mud
BG-09	1.394	29.128	69.478	Silty mud
BG-09A	2.771	42.137	55.092	Silty sand
BG-09B	6.397	42.861	50.742	Silty sand
BG-10	4.167	20.471	75.362	Mud
BG-11	5.413	21.792	72.795	Silty mud
BG-12	6.763	15.429	77.807	Mud
BG-13	2.218	24.444	73.338	Silty mud
BG-14	3.133	33.539	63.328	Silty mud
BG-15	3.810	32.416	63.774	Silty mud
BG-16	16.794	18.095	65.111	Silty mud
BG-17	5.581	33.645	60.773	Silty mud
BG-18	5.974	25.440	68.586	Silty mud
BG-19	6.366	14.325	79.309	Mud
BG-20	12.195	1.547	86.257	Mud
BG-21	8.000	10.623	81.377	Mud
BG-22	8.009	6.733	85.258	Mud
BG-23	7.418	10.670	81.912	Mud
BG-24	8.947	33.559	57.494	Silty sand
BG-24A	0.779	2.365	96.856	Mud
BG-25	13.622	18.965	67.412	Silty mud
BG-26	15.534	3.885	80.581	Mud
BG-27	7.916	23.310	68.774	Silty mud
BG-28	12.284	37.335	50.381	Silty sand
BG-28A	9.202	50.491	40.306	Silty sand
BG-29	7.214	11.260	81.526	Mud
BG-31	15.349	3.936	80.715	Mud

BG-32	2.278	1.192	96.530	Mud
BG-33	16.582	4.284	79.134	Mud
BG-35	10.677	2.407	86.916	Mud
LALA-01	45.243	22.836	31.921	Sand
LALA-02	38.302	18.816	42.882	Sand
LALA-03	11.837	14.702	73.461	Silty mud
LLM-01	3.303	33.994	62.702	Silty mud
LLM-02	11.111	14.662	74.226	Silty sand
LLM-03	7.082	39.283	53.635	Silty sand
PC-01	2.639	29.704	67.658	Silty mud
PC-02	9.337	33.271	57.393	Silty sand
PC-03	14.417	30.045	55.538	Silty sand
SM-01	21.154	30.158	48.688	Sand
SM-02	8.902	30.760	60.338	Silty mud
SM-03	11.444	22.580	65.976	Silty mud

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