Sedimentation and barnacle recruitment and growth in a shallow coastal lagoon of south Texas

John Jack Gray
The University of Texas Rio Grande Valley

Follow this and additional works at: https://scholarworks.utrgv.edu/leg_etd

Part of the Animal Sciences Commons, Environmental Sciences Commons, and the Marine Biology Commons

Recommended Citation
https://scholarworks.utrgv.edu/leg_etd/13
SEDIMENTATION AND BARNACLE RECRUITMENT AND GROWTH IN A SHALLOW COASTAL LAGOON OF SOUTH TEXAS

BY

JOHN J. GRAY

A RESEARCH THESIS PRESENTED TO THE GRADUATE FACULTY OF THE UNIVERSITY OF TEXAS AT BROWNSVILLE COLLEGE OF SCIENCE, MATHEMATICS, AND TECHNOLOGY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF SCIENCE IN BIOLOGY

APPROVED BY:

Dr. Alejandro Fierro-Cabo, Biological Sciences, Thesis Director

Dr. Heather Alexander, Biological Sciences

Dr. Carlos Cintra-Buenrostro, Chemistry and Environmental Sciences

Dr. Kenneth Pruitt, Biological Sciences

Dr. Charles Lackey, Dean of Graduate Studies
Sedimentation and barnacle recruitment and growth in a shallow coastal lagoon of south Texas

A Thesis Presented to the Graduate Faculty of the College of Science, Mathematics, and Technology

The University of Texas at Brownsville

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Biology

by

John Jack Gray

January 2014
Acknowledgements

I would like to thank my thesis advisor and committee director, Dr. Alejandro Fierro-Cabo. Paramount to this study is your knowledge of ecosystem processes and the desire to increase the understanding of them. I thank you for the opportunity to have worked with you. I would like to thank the committee members: Dr. Alexander, Dr. Cintra-Buenrostro, and Dr. Pruitt, you each have incredible understanding and ability in your respective disciplines and I have benefitted greatly from each of you. I would also like to thank the University of Texas at Brownsville Biological Sciences department chair, Dr. David Hicks and administrative staff, Raquel Vasquez, for their seemingly limitless support, faculty, Dr. Richard Kline for always being willing to lend a hand, his mind, or tools, and fellow students Gustavo Boeta, Josh Bradford, M. Sc., Monica Delgado, Cinthya Fuentes-Tapia, Victor Garza, Mario Marquez, M. Sc., Crystal Martinez, Joe Molina, Isidro Montemayor, Jacob Rodriquez, Jonross Rodriquez, and Claudia Tamez, all of whom helped make this study possible. Thank you all for your efforts!

Funding for this study was provided by NOAA’s Office of Education, Educational Partnership Program’s Environmental Cooperative Science Center. Permitting for the study was through the Texas General Land Office.
Abstract

According to the United States Environmental Protection Agency, one of this nation’s greatest concerns to the receiving waters of an aquatic system is the impairment of water quality due to sediment transport. Thus, an aquatic system whose receiving waters are subject to unrestrained sediment transport from a spoil bank, which is an un-stabilized depository for sediment acquired during a dredge, should be a concern. In this study an attempt was made to assess sedimentation and its effect on the life cycle of sessile aquatic life over a year. South Bay was chosen for the study site because it is adjacent to an active spoil bank and close to Mexiquito Flats, a site not associated with an active spoil bank. Barnacles were chosen to be studied as an indicator of sedimentation because barnacles are a sessile aquatic filter feeding animal that have been shown to be affected by sediment transport, a precursor to sedimentation. *Balanus eburneus* Gould, 1841 was studied for recruitment and growth and a second barnacle, *B. amphitrite* Darwin 1854, was studied for recruitment only. Forty stations in South Bay were each installed with clay pads and cylinders from which sedimentation and barnacle recruitment and growth data were collected, respectively, and eight stations in Mexiquito Flats Measurement of sedimentation was collected at four and six month intervals and barnacle recruitment and growth collected as close to a per monthly basis as possible. Sedimentation appears to be occurring in both sites but differences between sites was not significant. Sedimentation in South Bay did not exhibit a decreasing trend with increasing distance from the spoil bank shore or exhibit any relation with barnacle recruitment or growth. Recruitment and growth followed seasonal patterns with
increasing recruitment of *B. eburneus* in May and September and of *B. Amphitrite* in May only. Growth of *B. eburneus* increased during the warmer months.
Table of Contents

I. Introduction ........................................................................................................... 1

II. Material and Methods
    - Site Description .................................................................................................. 6
    - Experimental Layout ......................................................................................... 6
    - Sedimentation ..................................................................................................... 9
    - Barnacle Recruitment ......................................................................................... 13
    - Barnacle Growth .................................................................................................. 14
    - Water-Column Parameters .................................................................................. 14

III. Data Analyses
    - Bio-volume and Relative Growth Rate .............................................................. 15
    - Statistical Analyses ............................................................................................ 15

IV. Results
    - Sedimentation: South Bay and Mexiquito Flats ............................................. 17
    - Sedimentation Gradient ..................................................................................... 19
    - Effect of Sedimentation on Barnacle Recruitment and Growth ................... 20
    - Seasonality ......................................................................................................... 23

V. Discussion ............................................................................................................ 28

VI. Conclusion .......................................................................................................... 32
    - Literature Cited ................................................................................................... 34

Data for Growth, Recruitment, Water Parameters, and Sedimentation is available.
List of Figures

Figure 1: South Bay, spoil bank, Mexiquito Flats, and white lines 1-4 correspond to approximate position of transects in South bay and white line 5–6 correspond to approximate positions of transects in Mexiquito flats.................................................................8

Figure 2: Sampling station composed of a pole, a barnacle fixation cylinder located approximately eight cm above the clay pad.................................................................9

Figure 3: Clay pad installation showing clay settling to the bay bottom within the form (plastic trash container with bottom (0.5 m) removed) to create a marker horizon for sedimentation measurement and the marker pole which supports the barnacle attachment cylinder.................................................................11

Figure 4: Clay pad installed at base of marker and barnacle attachment cylinder holding pole........................................................................................................11

Figure 5: Close up of clear polyvinyl chloride tube including sample core and caps......12

Figure 6: Coring device with attached 5.0-cm coupling for quick install/release of clear PVC core collection tube.................................................................12

Figure 7: Barnacle fixation cylinder made of PVC pipe (10.2 cm diameter by 17.8 cm length) showing few organisms attached.................................................................13

Figure 8: Sedimentation in Mexiquito Flats (n = 2) and South Bay (n = 20) for the period July through November 2012. Error bars: 95% CI.................................................................18

Figure 9: Measured sedimentation (cm) in South Bay. Core samples exhibiting clay horizon are depicted at their respective distance from the shoreline for transects 1 (T1), 2 (T2), and 3 (T3) adjacent to the spoil bank. Samples taken in November 2012 four months after clay pad deployment.................................................................19

Figure 10: Measured sedimentation (cm) in South Bay. Core samples exhibiting clay horizon are depicted at their respective distance from the shoreline for transects 1 (T1), 2 (T2), and 3 (T3) adjacent to the spoil bank. Samples taken in May 2013 ten months after clay pad deployment.................................................................20

Figure 11: Cumulative (total) recruitment of Balanus eburneus from June through November, 2012 with the exception of July 2012, at stations (n = 20) where sedimentation was recorded in South Bay.................................................................21

Figure 12: Cumulative (total) recruitment of Balanus eburneus from December 2012 through May 2013 at stations (n = 14) where sedimentation was recovered in South Bay.................................................................21
Figure 13: Mean relative growth rate of *Balanus eburneus* for June through November 2012 at stations (n = 20) where sedimentation was recovered in South Bay.

Figure 14: Mean relative growth rate of *Balanus eburneus* for November 2012 through May 2013 at stations (n = 14) in South Bay where sedimentation was recorded.

Figure 15: Bars represent monthly means of water temperature (°C) of all stations (n = 40) in South Bay, with the exception of November 2012. Error bars: 95% CI.

Figure 16: Bars represent mean of monthly Secchi disc depth of all stations (n = 40) in South Bay, with the exception of June, July, and November 2012. Error bars: 95% CI.

Figure 17: Bars represent mean of monthly salinity (PPT) at all stations (n = 40) in South Bay, with the exception of November 2012 and April 2012. Error bars: 95% CI.

Figure 18: Bars represent mean of monthly recruitment for *Balanus eburneus* at all stations (n = 40) in South Bay, with the exception of July 2012. Error bars: 95% CI.

Figure 19: Bars represent mean of monthly recruitment of *Balanus Amphitrite* for all stations (n = 40) in South Bay, with the exception of July 2012. Error bars: 95% CI.

Figure 20: Bars represent mean of monthly relative growth rate for *Balanus eburneus* for all stations (n = 40) in South Bay, with the exception of June 2012. Error bars: 95% CI.
List of Tables

Table 1: Sediment accretion for South Bay (Transects 1-4, 10 stations each) and Mexiquito Flats (Transects 5-6, 4 stations each). Sedimentation (cm) above marker clay horizon from cores that exhibited a clay horizon marker thus if no data (ND) no marker was observed. Cores were taken in November 2012, five months after markers were installed and May 2013, eleven months after installation. Stations are 100 m apart from each other (see text for additional details). .................................................................18

Table 2: One-way ANOVA for Balanus eburneus recruitment by month, from June 2012 through May 2013, with the exception of July 2012.................................................................26

Table 3: One-way ANOVA for Balanus amphitrite recruitment by month, from June 2012 through May 2013, with the exception of July 2012.................................................................26

Table 4: One-way ANOVA for relative growth rate of Balanus eburneus by month from July 2012 through May 2013.................................................................27
I. Introduction

In the United States of America approximately 40% of assessed river miles during 1998 were shown to be adversely affected by excessive sediment which results in sediment stress (U.S.EPA, 2000). Sediment stress affects sediment flux, which is a natural and vital process within the receiving waters of an aquatic system, and thus higher levels of sediment load resulting from a variety of processes including erosion from wind, water, and gravity can compromise the ecological integrity of an aquatic environment because of increased turbidity (Nietch & Borst, 2001). Increased turbidity results in lower light levels for primary production which translates into lower food availability to zooplankton, insects, and fish (Henley et al., 2000). Additionally, high turbidity and any associated sedimentation result in the sub-lethal and lethal effects of lowering food abundance when it causes reduced light penetration into the water column and the smothering of coral colonies, respectively (Rogers, 1990). However turbidity is not all bad according to Loya (1976), because some species of corals such as *Siderastrea radians* (Pallas, 1766), *S. siderea* (Ellis & Solander, 1786), *Diploria strigosa* (Dana, 1846), and *Meandrina meandrites* (Linnaeus, 1758) are equipped to endure high sediment, which is possibly due to associated concentration of nutrients. And turbidity can provide cover for prey when it decreases the contrast between prey and its background (Utne-Palm, 2010).

Sediment transport begins when hydric or aeolian forces, or cavitation cause soil or sediment to be dislodged and transported. When sediment enters the receiving water’s water column, either sediment transport continues or accretion (sedimentation)
begins. Sedimentation occurs when there is insufficient velocity in the current to keep the sediment suspended and sediment descends to the aquatic system’s floor and remains in place. Sedimentation cannot occur without sediment transport so thus sedimentation will function as an abiotic indicator of sediment transport. Sediment transport has also been shown to affect sessile aquatic life when the concentration of sediment exceeds the concentration of food particles in the water column.

The focus of this study is South Bay, located at the southernmost terminus of lower Laguna Madre, Texas. The Laguna Madre is a body of water situated between the south Texas mainland and Padre Island, a Gulf of Mexico coastal sand bar island (Tunnel & Judd, 2002). In Texas it is designated as the upper Laguna Madre north of the Saltillo Flats land bridge, and as the lower Laguna Madre, south of the flats. In the lower Laguna Madre, Boca Chica was the southernmost connection with the Gulf of Mexico, north of the confluence of the Rio Grande River with the Gulf of Mexico (Hook, 1991). As a reduction of depth in lower Laguna Madre occurred, the velocity of the current moving through Boca Chica was not sufficient to prevent sedimentation from closing the exchange and South Bay was born (Breuer, 1959; Hook, 1991).

The Brownsville Ship Channel (BSC) (see Figure 5), completed in 1936, was dredged from Brazos Santiago Pass (BSP) in a southwest direction ending 3.2 km southeast of the city of Brownsville, Texas with a total length of 27 km (Port of Brownsville, 2012). Dredge spoil, the removed sediment which is not typically stabilized against aeolian and hydric forces, was placed along the banks of BSC. As sediments from eroded dredge spoil were deposited, South Bay with its current shape was formed.
with its mouth opening into BSC. As maintenance dredging continues in BSC, the spoil bank will remain active and thus erosion of spoil material is likely to continue. The spoil bank is on the south bank of the Brownsville Ship Channel and west of the north facing mouth of South Bay. In addition to heavy hydric erosion of the spoil bank, the prevailing North and Northwest winds during the winter months are a significant factor in sediment transport into South Bay. Sand that has not been disturbed for more than ten years exhibits a friction threshold velocity of 16 cm s$^{-1}$ (Belnap & Gillette, 1997) which is considerably lower than the wind velocities reported for the Brownsville, TX area that range from 3.6 to 8.2 m s$^{-1}$. The prevailing directions are from 150º and 330º True, 20% and 8% of time, respectively (TCEQ, 2012). Thus as stated above, when originating from the Northwest, these wind velocities could easily displace unstabilized spoil into South Bay and testing for a sedimentation gradient adjacent to the spoil bank could point to the spoil bank as the source of sediment transport into South Bay.

There are currently no data available on the sedimentation rates in South Bay. At least one study (Hook, 1991) however does suggest that South Bay is being affected by the adjacent spoil bank. And according to another study assessing available data, there is a lack of resources on soil erosion and resuspension of sediment by waves and currents on the concentration and duration of suspended sediment in estuaries (Wilber & Clarke, 2001). And thus with no data currently available on the magnitude of the erosion processes taking place in the spoil bank or sedimentation rates in South Bay, and with the lack of data on estuary sedimentation rates in general, there is a need for determining
whether South Bay is being affected by sedimentation. In previous studies elsewhere, sedimentation rates have shown an effect on sessile aquatic life.

Two locally abundant forms of sessile aquatic life (Mook, 1976) are the barnacles, *Balanus eburneus* Gould, 1841 and *Balanus amphitrite* Darwin, 1854 and both will be used to study the effect of sedimentation on the life cycle of sessile aquatic life. *Balanus eburneus* has a range that includes the Gulf of Mexico (Orensanz et al., 2002) and *B. amphitrite* has been shown to be established in the Gulf of Mexico and the Caribbean (Zullo, 1966). *Balanus amphitrite* is easily distinguished, due to it having fine gray to purple colored vertical stripes from *B. eburneus* which is characterized by an ivory color (Boudreaux et al., 2009). Barnacles have been shown to be both active and passive filter feeders (Trager et al., 1990) and sediment transport within the water column from which they feed could affect their life cycle. Thus, barnacle recruitment and growth will be documented for relating to sedimentation.

It is clear that additional specific manipulative studies of individual taxa are required to obtain greater knowledge of the mechanisms affecting patterns of life cycle (Anderson et al., 2004). To assume that a correlation exists between barnacle growth and the concentration of phytoplankton, does not take into account that barnacle life cycle has been shown to be both correlated and not correlated to suspended sediment and phytoplankton abundance when variations in growth also occur with changes in both spatial and temporal patterns (Sanford & Menge, 2001). In addition, suspended sediment is shown to be both negatively and positively correlated to chlorophyll ‘a’ (Tyler et al., 2006) or the presence of phytoplankton which barnacles feed upon. Suspended sediment
has been shown not to affect recruitment of *B. amphitrite* in Mosquito Lagoon, an estuary on the east coast of Florida, USA (Boudreaux et al., 2009). Also it has been shown that barnacle recruitment is higher on sandy bottom as opposed to muddy sand bottom where recruitment is lower (Silina, 2002). Thus documenting seasonal variations in barnacle growth and recruitment will help validate whether sedimentation or seasonal variation is affecting barnacle life cycles.

This study has the purpose of improving the understanding of how sedimentation is occurring in South Bay and whether sedimentation affects barnacle life cycle. I hypothesize that the presence of active and un-stabilized spoil banks increases the sedimentation rates in adjacent estuaries and alters barnacle life cycle. Based on this hypothesis I predict that South Bay receives more sedimentation due to its proximity to a large active spoil bank than Mexiquito Flats, and that barnacle recruitment and growth in South Bay are being affected by sedimentation.

Specific objectives are 1) determine if there is a difference in sedimentation between South Bay and Mexiquito Flats; 2) determine if the sedimentation in South Bay exhibits a gradient away from the spoil bank; 3) determine whether sedimentation has an effect on recruitment of *B. eburneus* and *B. amphitrite* and growth of *B. eburneus* in South Bay; and 4) document the seasonality over one year of barnacle recruitment and growth in South Bay.
II. Materials & Methods

Site Description

South Bay is a 1416 hectares shallow estuarine lagoon, with a mean depth of 0.5 m (TPWD, 2012). Its borders are the riparian edge of the Rio Grande River to the south, the BSC and associated spoil bank to the north, tidal flats to the west, and Brazos Island to the east. There is a diversity of aquatic flora dominated by the seagrasses *Halodule wrightii* (Ascherson, 1868) and *Thalassia testudinum* (Banks ex König, 1805) that supports 41 species of finfish and 9 species of shellfish, that are important to commercial and recreational fishing (TPWD, 2012). Black mangrove (*Avicennia germinans* (L., 1759)) stands fringe the south, west, and northern shores. Mexiquito Flats is not directly influenced by a spoil bank and has a maximum bottom depth of approximately 1-1.5 m with a community of seagrasses that is dominated by *Halodule wrightii* (Ascherson, 1868) and *Thalassia testudinum* (Banks ex König, 1805) over loosely packed sediments (personal observation) and therefore will be used as a reference site for sedimentation. Mexiquito Flats is approximately 3 km north to south and about 0.5 km east to west (personal observation) with black mangrove stands to the west, the BSC to the south, the original Queen Isabella causeway to the north, and LLM to the east.

Experimental Layout

Forty sampling stations were established in South Bay within four transects, and eight stations in Mexiquito Flats within two transects (Fig. 1). To estimate
sedimentation rates, acquire barnacle measurements, and assess any gradient in South Bay, three transects (1 - 3) were set adjacent to the spoil bank in a NW to SE direction. These transects are perpendicular to the shoreline, and extend approximately 1000 m into the bay with approximately 1000 m of separation between each. There was approximately 100 m between the shoreline and the first station and thereafter between successive stations. Another transect (4) was established north to south along the eastern shore of the South Bay entrance channel (Fig. 1). Transect 4 begins approximately 200 m south of the BSC, with each station approximately 100 m from the shoreline and each of ten stations with approximately 100 m of separation. Transect 4’s purpose was to collect data on sediment transport into South Bay. Two transects (5 and 6) were established in Mexiquito Flats in a W to E direction, with transect 5 being the southernmost of the two. The transects have approximately 1000 m of parallel separation, are approximately perpendicular to the shoreline, extend out approximately 400 m from the shoreline into the bay, and the stations on each transect have approximately 100 m of separation between each with the first being approximately 100 m from the shoreline (Fig. 1); thus, resulting in less stations at this reference site. A sampling station was composed of a clay pad with a PVC pole in the center of the pad with one attached cylinder (dimensions specified below) for barnacle recruitment and growth measurements (Fig. 2). To prevent disturbing the clay pad when collecting the barnacle attachment cylinder or the core samples for sedimentation at the station, work was done from the boat or not approaching by foot any closer than 0.5 meter and always from up-current to prevent foot movement re-suspended disturbed sediment from affecting sedimentation above clay horizon.
Figure 1: South Bay, spoil bank, Mexiquito Flats, and white lines 1-4 correspond to approximate position of transects in South bay and white line 5 – 6 correspond to approximate positions of transects in Mexiquito flats (modified from USGS Earth Explorer, Google Maps, and Click2Map, 2011)
Figure 2: Sampling station composed of a pole, a barnacle fixation cylinder located approximately eight cm above the clay pad.

**Sedimentation**

Sedimentation was measured using the feldspar clay pad technique. This technique consists of setting a marker horizon, on top of which new sedimentation will deposit (Cahoon & Turner, 1989; Conner & Day, 1991) (Fig. 1 & 2). Feldspar clay (G-200 from Imerys Ceramics) pads were put in place at the base of the barnacle attachment cylinder suspension pole at each of the 40 stations in South Bay and the eight stations in Mexiquito Flats. South Bay has minimal boat traffic outside of the channels within the bay and the end of transect one, two, and three did not reach the channel. Transect four was located along the entrance channel into South Bay. Transect five and six in Mexiquito Flats which is adjacent to a boating channel that prevented transects from
having more than four stations. The pads are a 0.5-m diameter circle, 2-3 cm thick, requiring about 2 kg of clay per pad that were installed with the use of a plastic trash container with the bottom removed. The container was used as a form to allow settling of the clay to the bottom in a circle (Fig. 3). An installed clay pad can be seen in Figure 4. Core samples were taken at the end of two consecutive periods, the first from July through November 2012 and the second from December 2012 through May 2013, three cores (5.0-cm diameter x 10.0-cm long) of sediment were collected at each station to obtain an average (Schenk & Hupp, 2009). The sedimentation cores were collected with a 5.08-cm diameter x 16.24-cm long clear polyvinyl chloride (PVC) tube (Fig. 5). The clear tube, which allows for inspection of sample and associated water column collection, was inserted down through the sediment, the clay pad, and sedimentation below. The body of the custom made coring device (Fig. 6) is a 5.08-cm diameter PVC pipe fitted with a 5.08-cm diameter check valve fitted with a butyl coupling. The coupling allows installation and replacement of the clear PVC tube. Core samples were retrieved either from the boat or from outside the perimeter of the clay pad without disturbing the clay pad. Following extraction, the tube was capped top and bottom, marked for station, stabilized vertically, transported, and then frozen until dissection. Frozen cores were split lengthwise and dissected for measurement of any sedimentation above clay horizon.
Figure 3: Clay pad installation showing clay settling to the bay bottom within the form (plastic trash container with bottom (0.5 m) removed) to create a marker horizon for sedimentation measurement and the marker pole which supports the barnacle attachment cylinder.

Figure 4: Clay pad installed at base of marker and barnacle attachment cylinder holding pole.
Figure 5: Close up of clear polyvinyl chloride tube including sample core and caps.

Figure 6: Coring device with attached 5.0-cm coupling for quick install/release of clear PVC core collection tube.
**Barnacle Recruitment**

Barnacle recruitment was determined by counting new recruits at a nearly monthly basis, on a 10.2 cm diameter by 17.8 cm long PVC cylinder (Fig. 7) that was suspended in the water column at approximately eight cm from the bay’s bottom, attached to a PVC pole. When retrieved, pictures were taken for counting new recruits unless recruitment was minimal and thus documented in the field. The cylinder was then cleaned of new recruits and replaced into the water column. Recruitment data pictures for July 2012 were not recoverable from the secure digital memory card.

![Barnacle fixation cylinder made of PVC pipe (10.2 cm diameter by 17.8 cm length) showing few organisms attached.](image)

Figure 7: Barnacle fixation cylinder made of PVC pipe (10.2 cm diameter by 17.8 cm length) showing few organisms attached.
Barnacle Growth

Barnacle growth was determined for *B. eburneus* only. Measurements were obtained by numbering a maximum of 15 randomly picked new recruit barnacles. Each barnacle was measured for basal length (L), basal width (W), and height (H). If a barnacle died or went missing it was replaced with a new recruit, if available. Measurement was then notated as dead replacement (DR), dead no replacement (DNR), missing replacement (MR), or missing no replacement (MNR). The size of selected barnacles was determined by calculating the volume, hereafter named bio-volume, using the measurement of their L, W, and H using a digital caliper (mm) to the nearest 1/10 of a mm.

Water-Column Parameters

Water-column parameters, which were recorded *in situ* at each sampling station when recruitment and growth was measured, include Secchi disc depth (SDD) in cm, temperature in °C (T), and salinity (S) in parts per thousand (PPT). All parameters except Secchi disc depth were taken with a YSI Professional Plus handheld multi-parameter meter (temperature (±0.2°C), salinity (±1.0% of reading or 0.1 PPT, whichever is greater) (YSI, 2013) or with a Hach HQ30d (precision unavailable) portable multi-parameter meter with probes from either held submerged during readings at about 40 cm depth.
III. DATA ANALYSES

Bio-volume and Relative Growth Rate

Bio-volume of individual barnacles was calculated from the measurements of L, W, and H, considering the shape of a barnacle as an elliptical cone. The following formula was used:

\[ \text{Bio-volume} = \left(\pi \times \frac{L}{2} \times \frac{W}{2} \times H\right) \times \left(\frac{1}{3}\right). \]

The relative growth rate (RGR) expresses the barnacle size increase in a time interval in relation to the initial size. To calculate the RGR of an individual, the estimated bio-volume was used as a measure of barnacle size, and incorporated into the following formula (Gardner et al., 1985):

\[ \text{RGR} = \frac{\ln(\text{bio-volume 2}) - \ln(\text{bio-volume 1})}{t_2 - t_1} \]

Where \( \ln \) is the natural logarithm of the estimated bio-volume at times one and two, and \( t_2 - t_1 \) is the time interval in days between times one and two.

Statistical Analyses

For objective 1, to determine if South Bay had more sedimentation than Mexiquito Flats, sedimentation data were tested for statistical significance at a 95% confidence interval. For objective 2, to determine if a sedimentation gradient exists moving away from the spoil bank, sedimentation data from transects one, two, and three’s stations versus their distance (m) from the shoreline were viewed in scatter plots.
to determine if there was any trend between sedimentation and distance from spoil bank, for November 2012 (Fig. 9) and May 2013 (Fig. 10). For objective 3, to assess the effect of sedimentation on barnacle recruitment for both species and RGR for *B. eburneus* only, scatter plots for recruitment and RGR versus sedimentation for *B. eburneus* were produced to determine if there was any trend between sedimentation and recruitment or RGR. In the analysis of RGR, cylinders were treated as the experimental units where the growth rates (mm³/cm³ d) were averaged from all cohorts to obtain a mean growth rate for each cylinder over the time period between the current and previous dimensions measurements. For objective 4, to document the seasonality of recruitment and growth of *B. eburneus* and recruitment on *B. amphitrite*, one-way ANOVAs were run for *B. eburneus* recruitment by month, *B. amphitrite* recruitment by month, and *B. eburneus* RGR by month. These data along with water-column data were recorded for the period of June 2012 through May 2013, with the exception of recruitment data in July due to loss of data and water-column data in November due to equipment failure.
IV. RESULTS

Sedimentation: South Bay and Mexiquito Flats

Sedimentation during the period July 2012 to November 2012, in South Bay ranged from 0.1 to 8.0 cm and in Mexiquito Flats, which yielded only two measurements, was 0.1 and 2.1 cm (Table 1). For the period December 2012 to May 2013, the range of sedimentation for South Bay was from 1.8 to 9.0 cm and for Mexiquito Flats, no clay horizons were recovered in the cores, due to either re-suspension and loss or being covered with sedimentation deeper than the corer’s length. Average sedimentation for the period, July 2012 to November 2012, for South Bay was 2.7 ± 0.4 cm and for Mexiquito Flats the average was 1.1 ± 1.0 cm (Fig. 8). Due to only recovering sedimentation data for two stations in Mexiquito Flats, acceptance or rejection of the null hypothesis of no difference between sites was not attempted.

For the period December 2012 to May 2013, the average sedimentation for South Bay was 4.6 ± 0.57 cm and there was no data recovered for Mexiquito Flats (transects 5 & 6) due to displacement of clay pads or sedimentation being greater than the depth of the coring device. Thus no comparison was made to South Bay for significance.
Table 1: Sediment accretion for South Bay (Transects 1-4, 10 stations each) and Mexiquito Flats (Transects 5-6, 4 stations each). Sedimentation (cm) above marker clay horizon from cores that exhibited a clay horizon marker thus if no data (ND) no marker was observed. Cores were taken in November 2012, five months after markers were installed and May 2013, eleven months after installation. Stations are 100 m apart from each other (see text for additional details).

<table>
<thead>
<tr>
<th>November</th>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transect 1</td>
<td>ND</td>
<td>ND</td>
<td>2.50</td>
<td>ND</td>
<td>ND</td>
<td>2.00</td>
<td>0.10</td>
<td>ND</td>
<td>1.90</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Transect 2</td>
<td>2.40</td>
<td>2.20</td>
<td>ND</td>
<td>1.20</td>
<td>1.20</td>
<td>2.42</td>
<td>8.00</td>
<td>4.90</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Transect 3</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>1.50</td>
<td>4.40</td>
<td>2.10</td>
<td>2.30</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>Transect 4</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>4.30</td>
<td>1.50</td>
<td>3.00</td>
<td>5.00</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Transect 5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transect 6</td>
<td>ND</td>
<td>ND</td>
<td>0.10</td>
<td>2.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>May</th>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transect 1</td>
<td>ND</td>
<td>ND</td>
<td>3.00</td>
<td>ND</td>
<td>ND</td>
<td>1.80</td>
<td>ND</td>
<td>ND</td>
<td>2.50</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Transect 2</td>
<td>6.25</td>
<td>3.50</td>
<td>ND</td>
<td>ND</td>
<td>7.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>8.00</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Transect 3</td>
<td>ND</td>
<td>5.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>3.00</td>
<td>ND</td>
<td>3.90</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Transect 4</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>9.00</td>
<td>ND</td>
<td>4.20</td>
<td>4.50</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Transect 5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transect 6</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8: Sedimentation in Mexiquito Flats (n = 2) and South Bay (n = 20) for the period July through November 2012. Error bars: 95% CI.
Sedimentation Gradient

There is no gradient exhibited for the period July 2012 through November 2012 (Fig. 9) along transects 1, 2, or 3 with regard to distance of the station from the shoreline adjacent to the spoil bank. Recorded sedimentation in South Bay during this period varied from 0.1 to 8.0 cm, with an average of $2.7 \pm 0.4$ cm, and no evident spatial pattern. For the period December 2012 through May 2013 (Fig. 10) transects 1, 2, or 3 did not exhibit any gradient in sedimentation with regard to distance of the station from the shoreline adjacent to the spoil bank. Recorded sedimentation in South Bay during this period varied from 1.8 to 9.0 cm, with an average of $4.6 \pm 0.57$ cm, and no evident spatial pattern.

Figure 9: Measured sedimentation (cm) in South Bay. Core samples exhibiting clay horizon are depicted at their respective distance from the shoreline for transects 1 (T1), 2 (T2), and 3 (T3) adjacent to the spoil bank. Samples taken in November 2012 four months after clay pad deployment.
Figure 10: Measured sedimentation (cm) in South Bay. Core samples exhibiting clay horizon are depicted at their respective distance from the shoreline for transects 1 (T1), 2 (T2), and 3 (T3) adjacent to the spoil bank. Samples taken in May 2013 ten months after clay pad deployment.

Effect of Sedimentation on Barnacle Recruitment and Growth

For the period June through November 2012, sedimentation data in South Bay did not show any relation to the recruitment data for *B. eburneus* (Fig. 11). For the period December 2012 through May 2013 sedimentation data did not show any relation to recruitment of *B. eburneus* (Fig. 12). For the period June through November 2012 sedimentation data did not show any relation with RGR for *B. eburneus* (Fig. 13). For the period December 2012 through May 2013 sedimentation data did not show any relation with RGR of *B. eburneus* (Fig. 14).
Figure 11: Cumulative (total) recruitment of *Balanus eburneus* from June through November, 2012 with the exception of July 2012, at stations (n = 20) where sedimentation was recorded in South Bay.

Figure 12: Cumulative (total) recruitment of *Balanus eburneus* from December 2012 through May 2013 at stations (n = 14) where sedimentation was recovered in South Bay.
Figure 13: Mean relative growth rate of *Balanus eburneus* for June through November 2012 at stations (n = 20) where sedimentation was recovered in South Bay.

Figure 14: Mean relative growth rate of *Balanus eburneus* for November 2012 through May 2013 at stations (n = 14) in South Bay where sedimentation was recorded.
**Seasonality**

As expected, water column temperature was higher in the summer months and lower in the winter months and ranged from 15.8 to 34.5 °C (Fig. 15). Secchi depth, with the exception of June, July, and November 2012, was recorded at each station and ranged from 4.6 to 79.0 cm over the whole study period (Fig. 16). Salinity in South Bay exhibited somewhat consistent levels ranging from 26 to 68 PPT. No data is reported for April due to equipment malfunction (Fig. 17). Recruitment in *B. eburneus* was significantly different between months (Table 2). Recruitment exhibits a peak in May and another in September (Fig. 18). This pattern of recruitment does not seem to be associated with water temperature, salinity, or turbidity. Recruitment in *B. amphitrite* was significantly different between months (Table 3). Recruitment exhibits a peak in May (Fig. 19). This pattern of recruitment does not seem to be associated with water temperature, salinity, or turbidity. Values are average RGR of *B. eburneus* at each of 40 stations where number of individuals (N) varied from 1 to 15. RGR was significantly different between months (Table 4). RGR in July was twice as fast as the observed rate in the cooler months, i.e. December, January, and March (Fig. 20).
Figure 15: Bars represent monthly means of water temperature (°C) of all stations (n = 40) in South Bay, with the exception of November 2012. Error bars: 95% CI.

Figure 16: Bars represent mean of monthly Secchi disc depth of all stations (n = 40) in South Bay, with the exception of June, July, and November 2012. Error bars: 95% CI.
Figure 17: Bars represent mean of monthly salinity (PPT) at all stations (n = 40) in South Bay, with the exception of November 2012 and April 2012. Error bars: 95% CI.

Figure 18: Bars represent mean of monthly recruitment for *Balanus eburneus* at all stations (n = 40) in South Bay, with the exception of July 2012. Error bars: 95% CI.
Table 2: One-way ANOVA for *Balanus eburneus* recruitment by month, from June 2012 through May 2013, with the exception of July 2012.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB R <em>B. eburneus</em></td>
<td>10</td>
<td>9877.58</td>
<td>6.74</td>
<td>0</td>
</tr>
<tr>
<td>Between Groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>429</td>
<td>1485.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>439</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 19: Bars represent mean of monthly recruitment of *Balanus Amphitrite* for all stations (n = 40) in South Bay, with the exception of July 2012. Error bars: 95% CI.

Table 3: One-way ANOVA for *Balanus amphitrite* recruitment by month, from June 2012 through May 2013, with the exception of July 2012.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB R <em>B. amphitrite</em></td>
<td>10</td>
<td>434.96</td>
<td>10.54</td>
<td>0</td>
</tr>
<tr>
<td>Between Groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>429</td>
<td>41.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>439</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 20: Bars represent mean of monthly relative growth rate for *Balanus eburneus* for all stations (n = 40) in South Bay, with the exception of June 2012. Error bars: 95% CI.

Table 4: One-way ANOVA for relative growth rate of *Balanus eburneus* by month from July 2012 through May 2013.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>df</th>
<th>Mean Squ F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB RGR <em>B. eburneus</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>10</td>
<td>1379335</td>
<td>8.069</td>
</tr>
<tr>
<td>Within Groups</td>
<td>1446</td>
<td>1709518</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1458</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
V. DISCUSSION

To my knowledge, there are no studies reporting sedimentation in the Lower Laguna Madre. This study has compared sedimentation in two sites, one adjacent to the BSC spoil bank, and the other not directly linked to an active spoil bank. The data collected for the period June through November 2012 shows that South Bay received a sedimentation average of $2.7 \pm 0.40$ cm and Mexiquito Flats received an average of $1.1 \pm 1.0$ cm. These averages however, are higher than the amount of sedimentation received by the majority of the lagoons in the United States (Nichols, 1989). Whether the formation of South Bay is the result of sediment transport of eroded material of the adjacent spoil, or whether the spoil material is being transported into South Bay via the BSC is inconclusive. However Vaughn & Kimber (1977) showed that when spoil banks are placed immediately adjacent to a canal (channel) there is accelerated erosion as a result of an increased slope near the bank and consequent bank cutting action by surface runoff.

The clay horizon technique has been successfully applied in many sedimentation studies (Cahoon & Turner, 1989; Connor & Day, 1991). In this study however, after the feldspar clay pads were installed, sea water was discovered to prevent consolidation of the clay and therefore the clay may have been susceptible to re-suspension and displacement. Possible displacement of clay horizons could be the reason for many missing data of sedimentation above the clay marker horizon. Future studies could benefit from using other techniques. For example, the dyed frozen core technique,
currently in development by Plante, (2013) may result in more reliable recovery of erosion or sedimentation data.

Based on the sedimentation data that could be collected, no gradient away from the spoil bank was evident. Even if the main source of sediments reaching South Bay could be the spoil bank, suspended sediment may be distributed in different patterns across the lagoon due to tidal or wind driven currents. For Laguna Madre it has been reported that typical median total suspended material concentrations in a water column depth of 1 m above seagrass beds at being 18 mg l\(^{-1}\) (Teeter et al., 2001) and for total suspended material in a 2.0-m water column above a bare bottom, the annual median value was found to be 150 mg l\(^{-1}\) (Brown & Kraus, 1997). A study comparing suspended material concentration values versus accretion observed in this study may show a correlation.

Barnacle recruitment and growth in South Bay does not appear to be directly and/or immediately affected by sedimentation. Sedimentation has been shown to have an effect on initial recruitment of a cyprid stage barnacle with the number of recruits being the greatest when substrate was sheltered from sediment deposition (Maughan, 2001). However, the effects of sedimentation on recruitment are possibly only one variable among several, because there can be both direct outcomes from seasonal effects and indirect outcomes that result with predation (Airoldi, 2003). Since recruitment rates for \textit{B. eburneus} was always higher than \textit{B. amphitrite} competition between the species and not sedimentation is a possibility as an effect for the lower recruitment rate of \textit{B. amphitrite}. 

\textit{amphitrite}. 

29
More conclusive evidence on the effect of sedimentation on barnacle growth may be acquired by measuring growth and total suspended solids following episodic wind or rain events. The non-linear pattern of sedimentation and the absence of a gradient with distance from the spoil bank, may indicate the presence of currents and associated eddies within South Bay. Another study documenting growth, shows that barnacles directly exposed to current grew bigger and this rate of growth was double that of barnacles in an eddy (Crisp & Bourget, 1985) thus a future study could compare stations located in currents and eddies. Future studies might also consider the use of flow meters to determine current direction and velocity. Current direction and velocity data along with recruitment and growth data in a given area could support or determine a relation between plankton abundance and recruitment and growth. In addition, flow meters could help positioning stations for sediment deposition data in a more homogenous environment with respect to currents. To further study barnacle growth patterns and how they may be affected by environmental variables, a more accurate approach might be to measure growth in shorter time increments, for example after two, five, and ten days, to give a more precise representation of the growth pattern (Thiyagarajan et al., 2003). In addition, accuracy for barnacle numbering and individual identification was difficult due to placing a barnacle’s corresponding number on the inner side of the recruitment and growth cylinder. Future studies might consider placing numbers on the barnacle carapace.

Results obtained for barnacle recruitment showed a distinctive seasonal pattern. An important peak occurs in May for both *B. amphitrite* and *B. eburneus*. This
seasonal response is comparable to the recruitment observed for *B. eburneus* and *B. amphitrite* in the Indian River, Florida where maximum recruitment density of *Balanus* spp. was recorded in May at 1.83 barnacles/cm² (Mook, 1976). A study along the Louisiana coast (Brown & Swearingen, 1998) also shows recruitment occurring more significantly during the spring at 0.39 barnacles /cm². This study shows maximum recruitment density of 0.73 barnacles / cm² recorded in September.

In regard to barnacle growth, obtained results also show a seasonal pattern which appears to be related to water temperature. For example, there was significant difference in RGR between July and December. The highest RGR occurred in July when the highest water temperature was recorded (31.2 °C), however growth is seen to increase sequentially from December 2012 through May 2013 with the coldest water temperature being recorded in March 2013. Growth could also be associated with temporal variations in phytoplankton abundance. Prior studies show growth rates associated with the presence of phytoplankton abundance, but assert that short-term growth rates only partially matched spatial and temporal variations in phytoplankton where the steepest growth curves were associated with the warmest months (Sanford & Menge, 2001).

Initially the collection of erosion data and sedimentation was to be acquired from the berm bordering the south side of the spoil bank and tidal flat, respectively, at points adjacent to transects 1, 2, and 3. However, erosion and sedimentation data was not retrieved for logistical complications. In future sedimentation studies in South Bay, it is recommended to include a parallel assessment of erosion in the spoil bank, which may show a correlation with sedimentation rates in the bay.
VI. CONCLUSION

Past recorded observations and studies state that South Bay was formed due to sediment transport from the adjacent spoil bank. Therefore it is likely that additional sediment disposal in the bank from periodic dredging is being transported into South Bay by means of both hydric and wind erosion. As stated by the U. S. EPA, increased sediment load can cause sediment stress in the receiving waters of transported sediment and therefore South Bay could be subjected to sediment stress. Sediment load has been shown to affect sessile aquatic life in both recruitment settlement and growth thus with increased sediment load, sessile aquatic life could be threatened. Being that this is the only study documenting the seasonality of some aspects of the life cycle of barnacles in lower Laguna Madre, future studies could contrast documented seasonal variations in undisturbed sessile aquatic life cycle with the effect(s) of sediment stress.

In addition, but not studied here, water depth in South Bay due to sedimentation could be reduced to the point that seagrass beds which are currently only exposed during low tides, as witnessed by the author, could become exposed permanently reducing spawn habitat. Thus, if additional spoil is deposited and stabilization of the spoil is not facilitated, South Bay could become a tidal flat submerged only at high tide or be lost completely. Suspecting that the spoil bank adjacent to South bay is a significant source of sediment, I have explored sedimentation in South Bay and its effects on the life cycle of barnacles. However, due to the loss of clay pads and the abundance of missing sedimentation data, comparing my recruitment and growth findings with other studies on the effect of sedimentation on aquatic sessile life was not feasible.
Improved data collection techniques to improve accuracy and precision for sedimentation and recruitment and growth should be incorporated into future studies. Additionally, future studies might investigate an economical approach toward the stabilization of spoil bank deposits and documenting the effect of water current on plankton abundance and barnacle recruitment and growth.
Literature Cited


Breuer, J. P. (1959). An ecological survey of the South Bay area especially that was influenced while Boca Chica was open. Texas Game and Fish Division, Marine Fisheries Division Project Report: M-9 D-2, job G-1.


(2011).
Physiology of Crop Plants. Iowa State University Press.
Henley, W. F., Patteson, M. A., Neves, R. J., & Lemly, A. D. (2000). Effects of
sedimentation and turbidity on lotic food webs: A concise review for natural
resource managers. Reviews in Fisheries Science, 8(2), 125-139.
fishes in South Bay. Contributions in Marine Science, 32, 127-141
Loya, Y. (1976). Effects of water turbidity and sedimentation on the community
Maughan, B. C. (2001). The effects of sedimentation and light on recruitment and
development of a temperate, subtidal, epifaunal community. Journal of


U.S. EPA. *The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review*.


